Where Can I Get More Information?

1. Statewide Extension Housing and Energy Information

    Cooperative Extension Service (CES) - Richard Seifert
    University of Alaska Fairbanks
    308 Tanana Loop, Room 215 or P.O. Box 756180
    Fairbanks, AK 99775-6180
    Phone: 1-800-478 TECH (8324) or (907) 474-7201 Fax: (907) 474-5139
    Email: ffrds@uaf.edu
    *Information on technical questions about construction of energy-efficient homes
    *Information on indoor air quality and radon
    *To read the ABSN newsletter online visit:
    http://www.uaf.edu/ces/faculty/seifert
    or to receive it via email or as a hard copy contact us via email: ffrds@uaf.edu

2. Energy Efficient Education Workshops, AKWarm Sessions, Ventilation Workshops, and Weatherization Training

    Alaska Building Science Network (ABSN) www.absn.com
    P.O. Box 111097
    Anchorage, AK 99511
    Ph: 907-562-9927 or toll free #: 1-800-563-9927 Fax: 907-770-5412

3. National and international information on energy efficiency & renewable energy technology

    Energy Efficiency and Renewable Energy Clearinghouse
    www.eere.energy.gov/
    The U.S. D.O.E.'s website on all things energy efficient and renewable.
    No longer has an 800 number for calls, unfortunately.

4. AHFC Energy Library — http://www.ahfc.state.ak.us/energy/ric.cfm

    Alaska Housing Finance Corporation (AHFC)
    Cary Bolling
    Research Information Center (RIC)
    Email: cbolling@ahfc.state.ak.us
    Website: www.ahfc.state.ak.us (RIC Library)
    P.O. Box 101020
    Anchorage, AK 99510-1020
    4300 Boniface Parkway, Suite 120
    Anchorage, AK 99504
    Phone: 1-800-478-4636 (Alaska) 1-907-330-8164 (Anchorage & Outside Alaska)
    Fax: 1-907-338-1747

Emergency Preparedness for Alaskans

SAL-00007

Richard D. Seifert

Alaska is an area of natural beauty and magnificent landscapes. Natural forces loom large in our history and in our daily lives. Because of this, our lives are subject to a wide range of natural disasters. Floods, earthquakes, wildfires, severe storms, tidal waves (tsunamis), and volcanic eruptions are normal routines. Being prepared for these eventualities is just a matter of a little time and effort to pull together some supplies to help you adjust to emergencies without undue stress.

Stocking up now on emergency supplies can add to your safety and comfort during and after any natural disaster. Store enough supplies for at least 72 hours.

Emergency Supply Checklist

Survival

- ❑ Water 2 quarts to 1 gallon per person per day
- ❑ First aid kit freshly stocked
- ❑ First aid book
- ❑ Food (packaged, canned, no-cooked, baby food, and for special diets)
- ❑ Can opener (non electric)
- ❑ Blankets or sleeping bags
- ❑ Portable radio flashlight and spare batteries
- ❑ Essential medication and glasses
- ❑ Fire extinguisher A B C type
- ❑ Food and water for pets
- ❑ Money

Sanitation Supplies

- ❑ Large plastic trash bags for trash, waste, water protection
- ❑ Large trash cans
- ❑ Bar soap and liquid detergent
- ❑ Shampoo
- ❑ Toothpaste and toothbrushes
- ❑ Feminine and infant supplies
- ❑ Toilet paper
- ❑ Household bleach
- ❑ Newspaper to wrap garbage and waste

Safety and Comfort

- ❑ Sturdy shoes
- ❑ Heavy gloves for clearing debris
- ❑ Candles and matches
- ❑ Change of clothing
- ❑ Knife or razor blades
- ❑ Garden hose- for siphoning and fire fighting
- ❑ Tent

Cooking

- ❑ Camp stove, propane appliances
- ❑ Fuel for cooking (camp stove fuel, etc.)
- ❑ Plastic knives, forks, spoons
- ❑ Paper plates and cups
- ❑ Paper towels
- ❑ Heavy duty aluminum foil

Tools and Supplies

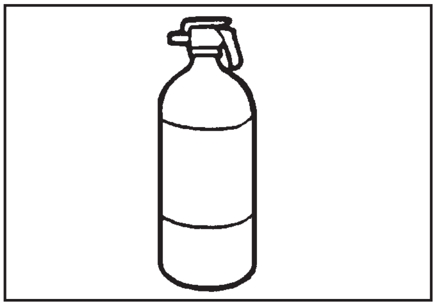
- ❑ Axe, shovel, broom, woodcutting saw
- ❑ Crescent wrench for turning off gas
- ❑ Screwdriver, pliers, hammers
- ❑ Coil of ½" rope
- ❑ Plastic tape and sheeting
- ❑ Toys for children

Visit the Cooperative Extension Service energy and housing home page at
www.uaf.edu/ces/faculty/seifert/

3/93/RDS/250 Reprint September 2006

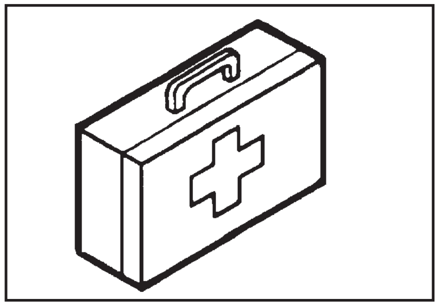
Emergency Supplies To Be Stored

After a major earthquake, electricity, water, and gas may be out of service. Emergency aid may not reach you for several days. Make sure you have the following items in your home, at your office, or in your car.



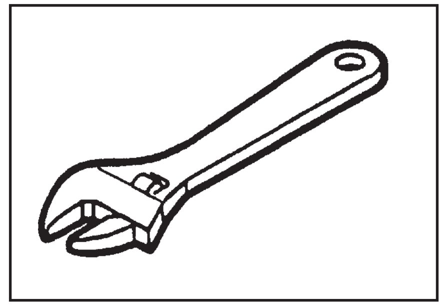
Fire extinguisher

Your fire extinguisher should be suitable for all types of fires and should be easily accessible.



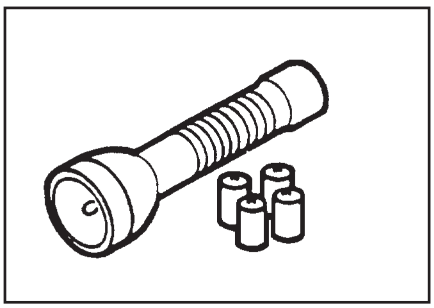
First aid kit

Your first aid kit should be in a central location and should include emergency instructions.



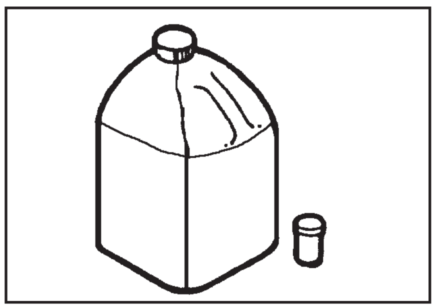
Wrench

Have crescent or pipe wrench to turn off gas and water valves if necessary.



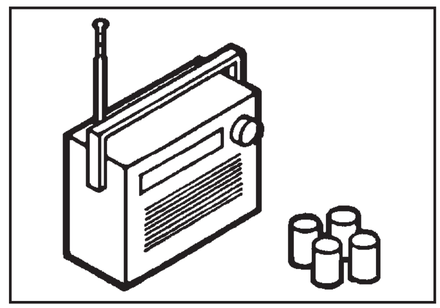
Flashlight and extra batteries

Keep flashlights in several locations in case of a power failure. Extra batteries last longer if you keep them in the refrigerator.



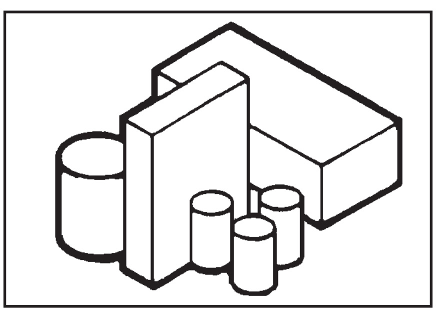
Water and disinfectant

Store several gallons of water for each person. Also keep a disinfectant such as iodine tablets or chlorine bleach to purify water if necessary.



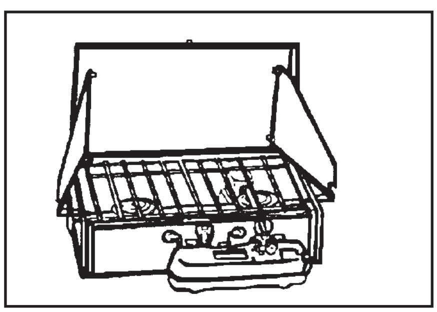
Radio and extra batteries

Transistor radios will be useful for receiving emergency broadcasts and current disaster information.



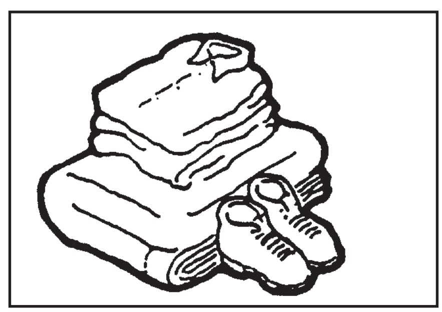
Dry or canned food

Store a one-week supply of food for each person. It is preferable to store food that does not require cooking.



Alternate cooking source

Store fuels and appliances and matches for cooking in case utilities are out of service.



Blankets, clothing and shoes

Extra blankets and clothing may be required to keep warm. Have shoes suitable for walking through debris.

ALASKA RESIDENTIAL BUILDING MANUAL

7TH EDITION

COOPERATIVE
EXTENSION
SERVICE
UNIVERSITY OF ALASKA FAIRBANKS

Alaska Residential Building Manual

HCM-00051

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COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF ALASKA FAIRBANKS

February 2008

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Acknowledgements for Contributors to the Manual

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Introduction

This new manual is the result of three years of development and assembles the latest information on building science and housing technologies. It is specifically designed for building in the most demanding arctic and subarctic climates in North America. Much of the rest of the country has been covered by manuals that are specific to their regions, but the arctic and subarctic regions with heating degree days greater than 12,000 have not been covered.

In addition, we have tried to include techniques that meet the needs of all Alaska climates. In southeast Alaska, anywhere from 80 to 200 inches of rain falls a year and the relative humidities are always high, but in some climates in the interior and northern Alaska the precipitation is only 5 to 10 inches a year and it is a veritable desert. Even there houses still have condensation problems because of the cold surfaces that are common in buildings.

We have tried to adapt this manual to as many various audiences as possible. There is an appendix, which gives information on applicable educational standards for high school and vocational teaching in the State of Alaska. The manual is also intended to meet vocational training needs in the building construction trades and as a manual for contractor licensure. It will be used in public education for homeowners and homebuyers by the Cooperative Extension Service.

An important aspect that has continued to evolve over time, and which is further developed in this manual, is the emphasis on sustainability in materials and housing and its concomitant environmental awareness, and the need for using materials that can be recycled and are "green." World oil production is peaking, and that means fuel prices will continue to rise and fuel will become more and more precious and expensive with time. This encourages a look at the zero net energy home concept; the idea that a building will supply as much of its own energy needs as possible onsite from natural sources. This is an extremely difficult problem in the far north, and it becomes more difficult the farther north you try to build. However, it is a goal toward which we should strive, and this manual has taken steps in that direction. More work needs to be done.

In addition, we now have a Cold Climate Housing Research Center, and it has great potential for improving our awareness and updating performance specifications for different building materials.

This manual has a considerable historical chapter, which is intended to give a new generation a better idea of how we came to develop the energy efficiency and superinsulated concepts that Alaska is known for. We also give due credit to the Native populations of Alaska and their adaptations to the north before contact with the first white explorers.

Throughout the manual we have tried to give the latest information on indoor air quality and ventilation. Ventilation improvements have been considerable over the past ten years since the major revision of the Alaska Housing Manual and other Alaska based manuals. We now have techniques that require less energy to move an equivalent amount of air, and the control systems are becoming better as we enter the new millennium.

This manual gives considerable attention to radon and soil gas control. This is an important issue in Alaska and continues to be a problem in many of the inhabited communities in the Railbelt. There are some rural com munities, one such is Nome where radon can be a problem because some of the houses are built with soil contact. Normally houses built in an area where there is permafrost have no soil contact and therefore will not have a radon problem.

Although not as comprehensive as we would have preferred, this manual also has a chapter on retrofit. As hous ing becomes more expensive and energy becomes more expensive, one of the major thrusts in all of North America will be upgrading and retrofitting hous ing to make it more energy efficient. This saves the materials that are now in vested in the housing stock, rather than abandoning or destroying old houses. This is a more sustainable way of deal ing with an old house.

While retrofit probably is worthy of having an entire manual devoted to it, an attempt was made here to give a good overview of assessing houses for retrofit and making judgments about whether a house is worth the expense of retrofit or whether it should be aban doned because it is in bad repair. It is always difficult to design a manual to meet the needs of widely diverse audi ences. We have attempted to do so in this manual, and its shortcomings if any, are due to the fact that we couldn't be as specific as we wanted, or as detailed, and still keep the manual affordable and comprehensible in the time frame that such courses are normally taught.

If history is any teacher in this re gard, this manual will be continuously upgraded and perfected with new edi tions and additions from the research done in the State of Alaska. As we have for the past 30 years, we continue to learn from the circumpolar nations, par ticularly Canada, Sweden, Norway, and Denmark.

As a further introduction and insight into the wide purposes of this manual, a discussion of sustainable housing and the concept of sustainability is in order.

This manual was developed with the intent of moving Alaska toward a stan dard of high quality, energy-efficient, sustainable housing. The following dis cussion elaborates on this concept and why it is so crucial to build affordable, sustainable housing for Alaska's citizens.

Sustainable Development

In 1987, the United Nations World Com mission on Environment and Develop ment defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Pursuing sustainability is an effort to maintain a high quality of life without exhausting the Earth's resources and without degrading our natural environment. Clean air and wa ter, open space and community spaces, and human health are essential to a high quality of life. Can we meet our material needs without reducing these aspects of our well being? Can we achieve de velopment that is not in conflict with environmental quality? These questions get right to the heart of sustainable development. In this manual, it is our intent to present options and direction for building sustainable buildings for our climate zone.

There is a growing recognition that we are beginning to encounter the limits of a finite planet. Our standard of living in the United States, as in all industrial nations, depends on vast amounts of raw materials and nonrenewable energy sources from around the world. Our life style impacts every corner of the Earth, contributing to global climate change and loss of biodiversity.

The materials and energy used in home building, along with all other industrial production and the waste of production, are called the throughput of the economy. This throughput has been growing faster than the human population as we have continued to increase our level of consumption. It is now estimated that if we wanted to provide the lifestyle of the average American to everyone on Earth, we would need at least three additional Earths to provide the energy and raw materials to do so. It appears that without significant changes, we will not even be able to extend the current American lifestyle to future generations of Americans.

It is well understood that the Earth's resources are finite, but we also face limits to waste and pollution. Just as we depend on the Earth to provide the raw materials for production, we also depend on the Earth's ecosystems to absorb and breakdown wastes. Our industrial processes, heating and powering our homes and buildings, and our transportation systems put carbon dioxide and hazardous pollutants into our biosphere. Oceans and forests can absorb large amounts of carbon, but our current carbon emissions are greater than what ecosystems can process, and so the amount of carbon dioxide in the atmosphere continues to rise.

Excessive levels of pollution can also disrupt ecosystems. We depend on these ecosystems to absorb our wastes, but we also depend on a variety of other natural services. Forests collect, filter, and store water; prevent soil erosion; and build soil fertility. Ecosystems provide habitat for animal and plant species. Vegetation produces oxygen. Ocean and air currents circulate water and air around the globe, moderating extremes of cold and heat. The ozone layer protects us from ultraviolet radiation.

Because the Earth is finite, it can only support a finite human population. Biologists use the term "carrying capacity" to refer to the population that a given area can support. We can think of our total impact as our level of consumption or individual throughput multiplied by the human population. As our throughput increases, the population that the Earth can support decreases. Conversely, the less resources and energy that are used and waste that is produced to meet each person's needs, the greater the population that can be supported. We already mentioned that if everyone lived the current American lifestyle, one Earth would not be enough. The United States has only 5 of the world's people. Most of the world's people are quite impoverished.

Unfortunately, biological examples and numerous failed civilizations from previous centuries indicate that populations can grow beyond the carrying capacity. This is called overshoot. When this happens, the ability to support life is diminished and eventually the population may crash. This happened on St Mathew Island in the Bering Sea when biologists transplanted 29 reindeer there in 1944. It was estimated that the island could support 1,600 to 2,300 reindeer. Without any predators or other natural controls, the island's reindeer population grew to over 6,000 by 1963. But the animals soon exhausted the food resources of the island and there were only 43 surviving reindeer by 1966. Archeology has turned up many human examples where civilizations that began in rich forest ecosystems ended in deserts of their own making.

Measuring the Earth's carrying capacity presents numerous challenges, but William Rees and Mathis Wackernagel have developed a tool to measure human impacts in a different way: ecological footprint estimates. Ecological footprints can be thought of as the inverse of carrying capacity. We will recall that carrying capacity is the population that can be supported by a given region. Ecological footprint measures the land area required to support a given popu lation. It should be clear, for example, that any modern city imports resources from elsewhere and exports its wastes. The urban areas depend on agricultural land for food production, forest lands to produce wood, and ecosystems to ab sorb and break down wastes. The total land area that a region depends on for all these services is called its ecological footprint. This is the tool that was used to determine that there are not suffi cient resources on Earth to extend the American lifestyle around the globe.

We will now turn to the connection between sustainable development and the building industry.

Sustainable Building

There is a strong focus within the build ing industry on achieving sustainability through better community and building design. These efforts are usually referred to as sustainable building or green build ing. In the United States, the U.S. Green Building Council has established LEED, Leadership in Energy and Environmen tal Design, a national rating system for green building. The home is one of our most basic and significant needs, and even small changes in home building and community design can create substantial and lasting benefits on a global scale.

Throughout most of history, building and construction relied on locally avail able materials in the hands of knowl edgeable craftsmen. It was only with the availability of inexpensive energy sourc es that these locally appropriate meth ods were displaced. In the northwestern United States, after the construction of large dams in the Columbia River basin, electricity was so cheap that most new construction had little or no insulation. These houses, however, have outlived cheap electricity and have had to be renovated. In the eastern United States 150 to 200 year old homes can be com monly found, while most new construc tion has a shorter lifespan. In the humid and hot southeast, homes traditionally had large front porches and high ceilings because these features promote passive cooling. The air conditioner has dis placed these architectural components, but some modern homes in this region can now get dangerously hot if the air conditioning fails.

Architects and builders have been addressing energy efficiency in build ings since the energy crises in the 1970s. Many of the early advances in this area have since become standard practice. Sustainable building goes far beyond en ergy efficiency, however. Consideration is given to a number of areas, includ ing the building's location, orientation to the sun, natural features of the site, the building materials, and the size and function of the space as well as its adaptability for future use. These cur rent advances promise to be tomorrow's building standards.

Sustainable building is about creating social and ecological benefits, not just minimizing negative impacts. It is about approaching and expanding the limits of what is possible through design and ap plying our best efforts towards building healthy, comfortable homes in healthy communities while maintaining a high quality natural environment. Accord ing to the Rocky Mountain Institute, a leading organization in the field, the "ultimate goal of sustainable building is to make possible offices, homes, even entire subdivisions, that are net produc ers of energy, food, clean water and air, beauty, and healthy human and biologi cal communities."

Designing for Sustainability

So how might a conscientious home builder attend to "meeting the needs of the present without compromising the ability of future generations in meeting their own needs" in the very real actions of designing and building a home?

Below is a useful set of questions to pose to yourself when building a home. It is a checklist for achieving a sustain able house .

- Is a particular site suitable for build ing? Are there public trail systems that need to be considered?
- Are there waterways that will be im pacted?
- Will it make us more or less depen dant on driving?
- Is there adequate access to the sun for passive solar heating?
- Will there be a garden for growing food or a woodlot for heating fuel?
- What materials will go into the building and will they off-gas toxins into the home?
- What materials are locally available?
- Has the wood been harvested sus tainably, or have sensitive habitats been compromised?

We can't expect to tackle every issue with every building, but there is room in every building for some improvement. The final project will involve a number of trade-offs. It will be a balance be tween what we'd like to build and what we are able to build given the location, budget, and other limitations.

The first rule of building science is considering the whole house as a sys tem. Sustainable building extends that system beyond the house to include the surrounding community and natural environment. Green features should not just be thrown into an existing de sign. Getting the most benefit requires an integrated approach. Some features can generate considerable cost savings up front and over the life of the home. Others, such as buying sustainably har vested wood, will add to the cost. Some homeowners prefer to use the cost sav ings of some choices to offset the higher cost of others.

Several principles can help guide the design process:

Make Appropriate Use of Land

Land that is for sale isn't automatically good to build on. If you build in a flood plain, expect floods. Homes face many environmental challenges in Alaska. Dis continuous or melting permafrost soils should be avoided if possible. North facing slopes will not receive valuable sunlight when it is most needed. Coastal areas face high winds and exposure to tsunamis. There are homes in southcen tral and southeast Alaska standing in avalanche paths. Some sites may have agricultural or cultural value that should be considered. In many areas in the United States, farm land is being lost to urban sprawl.

Make the Best use of Passive Systems First

We make better use of mechanical sys tems and size them appropriately by considering passive features first. The passive components of the home, such as orientation to the sun or the amount of insulation, are permanent. Mechani cal systems wear out and require diligent maintenance and replacement over time.

Use Space Efficiently and Strive for a Quality Living Environment

If a home is well designed and functional, it can be smaller and still meet the needs of the homeowners. Smaller homes are less expensive to build and maintain and use less energy and resources.

Use Resources Efficiently

Aim to reduce waste created by the building process.

Build for Durability

Energy-efficient building isn't effective unless the buildings are long lived.

Support and Strengthen the Local Economy and Community

When possible, use locally available materials. Consider using a locally owned bank to finance the home.

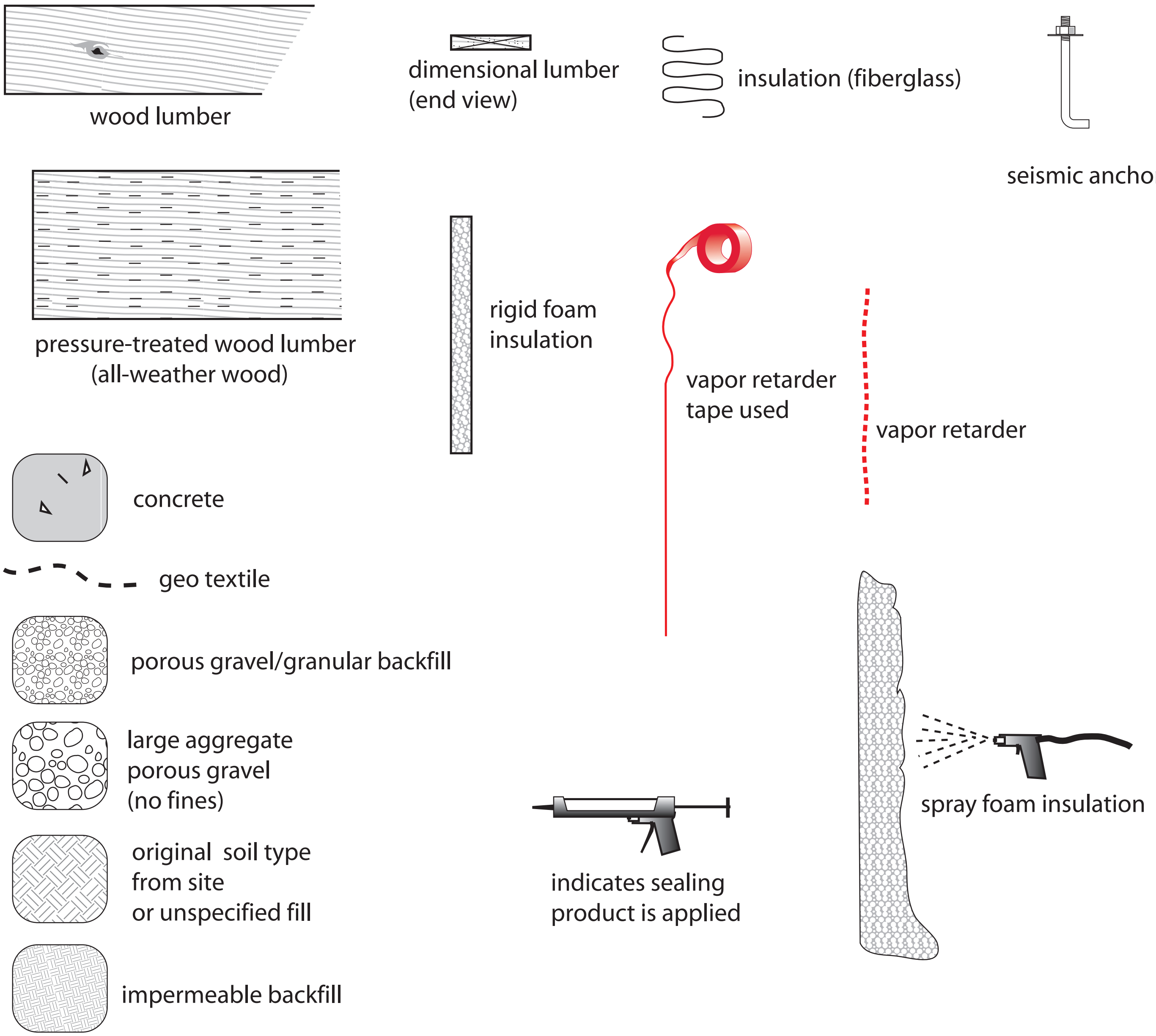
Conserve Natural Habitats

Critical habitats are better left undisturbed. Wetlands provide rich habitat and are also often troublesome to build on.

Build Affordably

Sustainable building cannot have a broad impact unless it is affordable.

Key to Symbols and Graphics



Shown here are a symbols key and typical elements for many of the illustrations on the following pages. It is placed here to help identify items that are not always labeled on specific designs.

Chapter 1
A History of Northern Energy-efficient Housing

Early Houses of Alaska's Native People

Originally, housing was necessary for early man to survive in harsh natural elements. Beginning with the earliest Neanderthals, people designed housing that would protect them as a means of survival. Energy efficiency, comfort and health are quite recent concerns that have spawned developments to provide occupants with better convenience at less cost. As our social sophistication has increased, so has our concept of shelter.

First Contact

At one of the very first contacts between Alaska natives and Europeans, an artist accompanying Captain James Cook on his third voyage was put ashore in Golovin Bay then Golovnin Bay on Alaska's Seward Peninsula. A small village had been observed, and the artist was charged with drawing it for documentation of the journey. This sketch is perhaps the first Western rendering of Alaska Native houses and living conditions by a European artist.

During the Russian colonial period, many drawings and sketches of the Aleutian *barabara* were made and are in the historical archives of Alaska and Russia. The early habitations had to use local materials: rocks, sod, animal skins, snow, moss, and the like. These homes were not durable and spring thaw could render them useless. However, some of the design features were elegant.

In Yupik Inupiat skin dwellings, an opening near the top of the domed skin hut was left to provide for air and smoke release. It was called the *qanaq*, which is the same word in that language as the word for "nose." Clearly the purpose of the opening was to ventilate.

Also, homes in Yup'ik and coastal Inupiaq regions were often designed with a very low subterranean entrance, which served two very useful purposes. First, it kept cold air from entering the dwelling when people came or went, since a low entrance is really a trap for cold air. Cold air, which is heavier, stayed low in the entrance and kept warmer air from leaving. Second, it provided a form of household defense, because anyone entering had to be stooping and in a vulnerable position. If they were undesirable, they could be fended off more easily.

Wood houses were used in southeast Alaska, especially for important community dwellings like clan houses. In the interior of Alaska, some log structures were used, but mainly Alaska Natives were too mobile to erect any permanent wood buildings, except in southeast Alaska.

More Contact: Whalers Come to the North

The technique of insulating houses became predominant in the era before Western contact with

Alaska Native people   a time when fuel was gathered by hand.

In his book *My Life with the Eskimo,* Vilhjalmur Stefansson 1913 describes the effect of Western-style housing on the fuel consumption patterns of Pt. Barrow Eskimos. It is an exceedingly in sightful and lucid description and gives us all a valuable perspective to consider in our approach to northern housing:

> The fuel problem has, of recent years, become a difficult one everywhere in the vicinity of Point Barrow. Up to thir ty or so years ago the beach was thickly strewn with driftwood, for the Eskimo used only oil for heating, cooking, and lighting purposes, and whenever a stick of wood was thrown on the beach it remained there until it decayed, which in the cold North is a matter of cen turies. The houses the people lived in then were of such type that not much fuel was needed in order to keep them warm. They were not underground dwellings, but the wooden frames of which they consisted were covered with earth to such a thickness that the houses were practically cold proof. These houses were entered through a long alleyway by a door that was never closed all winter, and the ventilating hole in the roof was always open, so that a current of air circulated through the house at all times. For this kind of a house two or three seal oil lamps were abundantly sufficient to keep the tem perature uniformly at 60° to 70° Fahr enheit the twenty four hours through,

Figure 1.1: Artist's rendering of an Alaska Native village in Golovin Bay

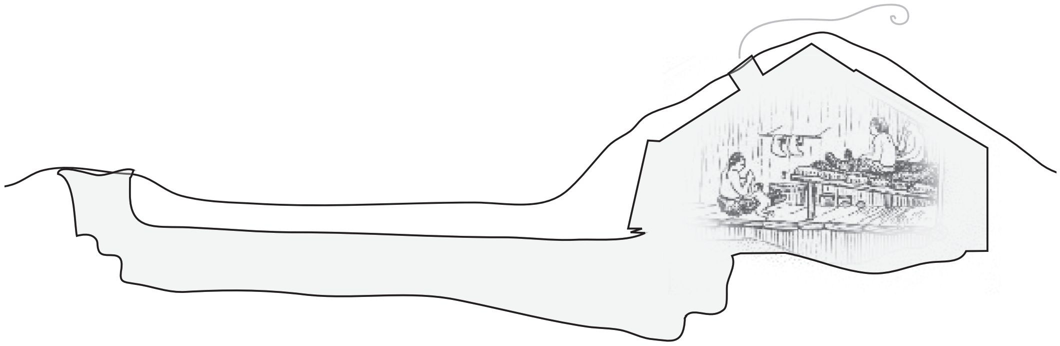


Figure 1.2: A low entrance to a semisubterranean house.

> and the winter through. With the white men of the last half century there came to the Arctic the white men's lofty and commodious frame dwellings. Although these are thoroughly ill adapted to the country they soon became the fashion, and the Eskimo began to build their poor hovels in the best imitation they could make of the pretentious homes of the foreigners. The flimsy walls of these new dwellings admitted cold by con duction so that the seal oil lamps were no longer sufficient for keeping them warm, and even the sheet iron stoves in which driftwood could be burned had difficulty in keeping them at a com fortable temperature. Driftwood lay in apparently inexhaustible windrows along the seashore, but these were the accumulations of centuries, which the Eskimo, having no use for wood as fuel, had allowed to grow. Now, instead of being used as formerly only in the construction of the house frames and in the making of sleds and implements, the drift wood was used for fuel in an attempt to keep the flimsy new-style houses warm. The result was that the drift wood disappeared so rapidly that in thirty years, by the use of stoves, all of it is gone, from Point Hope to thirty miles east of Point Barrow. With the increasing scarcity of fuel the ventila tion of the houses had to be curtailed gradually, so that the modern Eskimo house is practically hermetically sealed against fresh air. If there is a key hole in the door you will find it stuffed with chewing gum.
>
> Not only is the fuel problem serious from an economic point of view, it is even more serious as a question of sani tation. Although a few of the Eskimo are able to import coal from Seattle, and others can get it through difficult labor from the coal mine at Wainwright Inlet, the majority have not the means to secure fuel of any sort sufficient to keep the new style houses warm. Instead of the comfortable, well venti lated, and therefore healthful dwellings of a few years ago, we now have hoar frost coated and unventilated frame houses which look well in photographs to those used to frame houses in tem perate climates, but which are among the chief causes of the high death rate among the Eskimo, through their en couragement of pulmonary consump tion and other diseases that flourish in filth and foul air.

Russian Influence on Early Alaskan Housing

Another excellent description of indig enous housing is also given in the 1925 annual report by Mr. and Mrs. Samuel P. Troutman, school teachers and mis sionaries at Gambell on St. Lawrence Island, one of the last northern coastal areas to be settled by Westerners. At the time, Gambell was a small Russian Yupik village of around 240 residents on the northern tip of the island, with only 35 miles of Bering Sea separating it from the Russian mainland. To put this loca tion in perspective, Gambell is almost 200 miles from Nome, on the Alaska mainland.

Troutman's description of housing in 1925 begins:

> The typical native house is polygonal in shape averaging about 40 feet in diameter. The wall, which is from five to six feet high, is made of two inch planks and driftwood placed on end and firmly nailed together. The roof is dome shaped, supported by poles, and cov ered with walrus skins fastened to the wall by means of skin ropes and weight ed down with large pieces of wood, iron, bone and large stones. The highest point of the dome is about twelve feet from the ground. On the west side of the house is the entrance which is a rectangular opening about two and a half by three feet placed about two and half feet above the ground. This makes it awkward for one to enter who is not to the manner born.
>
> Inside this larger house and quite inde pendent from it is a smaller house eight feet wide and from ten to twenty feet long with a five foot ceiling, the walls of which are of double construction made of a light frame and walrus skin the

intervening space being filled with dry grass. The dome shaped top is a single frame overlaid with old walrus skin cov ered with thick grass mats. Along the entire front part is a curtain of reindeer skins fastened firmly at the top and sides but left free at the bottom. Under this one must crawl on hands and knees to enter. The floor consists of walrus skin covered with layers of grass over which another walrus skin is stretched. Under the lower edge of the curtain and extending the entire length of it is a log about six inches in diameter, which serves as a headrest while sleeping. The air space for each person averages 88 cubic feet.

In this small area the natives live, move and have their being. All the functions of family life are performed here. There is no furniture, not even a stool on which to sit. Everybody sits and sleeps on the floor. Shelves for a few dishes and tools may be found in the corner while the seal oil lamps usually three , which furnish heat and light, are placed on the floor. There are no windows. The only means of ventilation is through an opening six inches in diameter cut near the ceiling in the curtain, which forms the front wall.

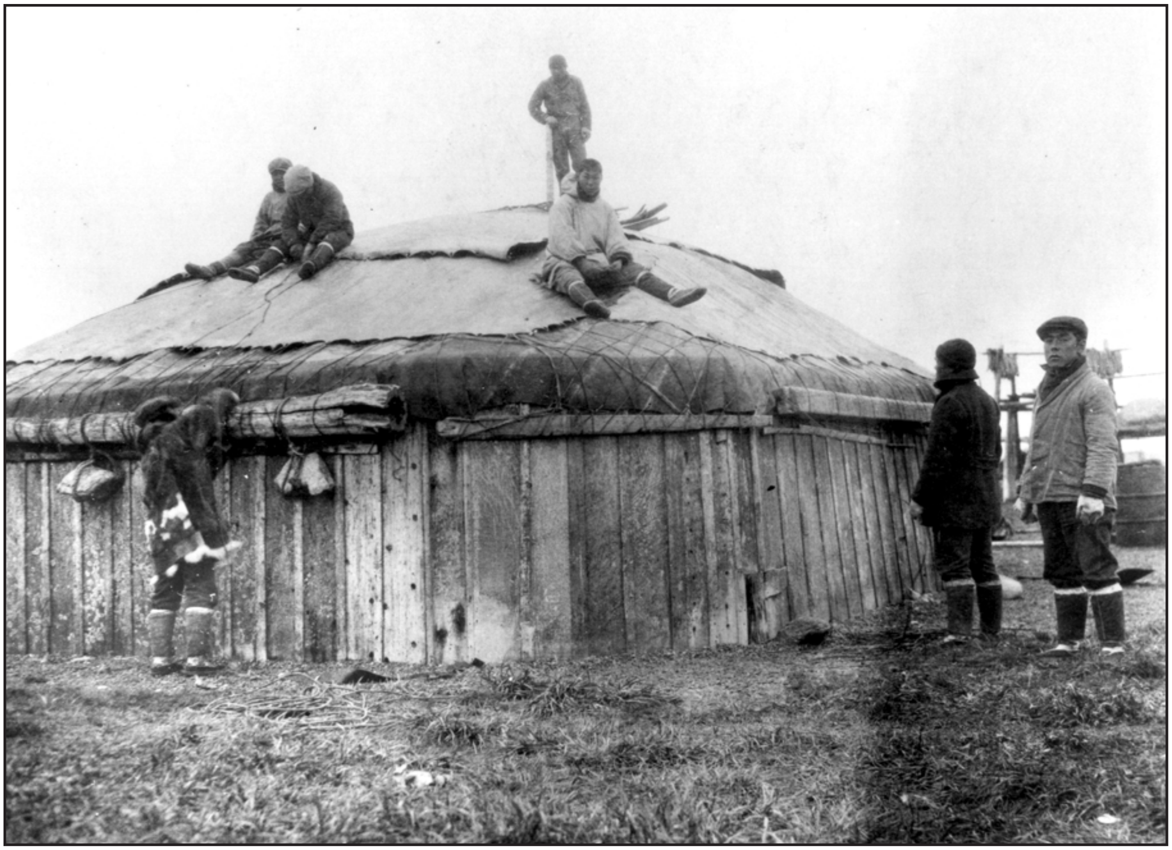
Since there may be from six to eigh teen people in one house, each person has his allotted place to sit and sleep. Everyone sleeps side by side on heavy reindeer skins, with their heads on the wooden head rest mentioned above and is disposed as to keep order and propri ety. Their coverings consist of blankets and reindeer skins. The room is kept so warm that the natives wear no cloth ing inside except a loin cloth worn by adults of both sexes, while children up to ten to twelve go entirely naked.

Cooking is done over the seal oil lamps and the table consists of a long wood en plate from which each helps himself as he feels disposed. Many use spoons although some still find it more con venient to eat with no more aid than their fingers.

The house described by Troutman is similar in shape and construction to those found on the Siberian mainland.

Photographer, Riley D. Moore, 1912. NAA Smithsonian Institution, Negative SI 85 820 Reprinted from: *Akuzilleput Igaqullghet. Our Words Put to Paper* 2002, p.415 .

Figure 1.3: A St. Lawrence island Yupik family in front of the traditional winter house [*mangteghapik*] in Gambell.



Photographer, Riley D. Moore, 1912. NAA Smithsonian Institution, Negative SI 85 819 Reprinted from: *Akuzilleput Igaqullghet. Our Words Put to Paper* 2002, p.416

Figure 1.4: Men in Gambell, St. Lawrence Island, put a new skin cover on the traditional winter house, *mangteghapik*.

Though construction of subterranean houses on the Alaska mainland was similar, some divergence of design is apparent. The polygonal shape was not popular in the Alaska designs, nor was the double wall construction. This Siberian domed design allowed for rain and meltwater to flow to the building's exterior, and the house within a house approach facilitated a dry inner sanctuary with additional dry storage around the perimeter.

Out of necessity, material used in construction was entirely sustainable in nature. The fact that only two or three seal oil lamps could heat such houses in extreme cold weather is impressive. Calculations show that the typical seal oil lamp was capable of a BTU output ranging from 500 to 2,500 BTU per hour, making these homes some of the most efficient constructed, again out of necessity.

Even with their understanding of the need for ventilation, occupants of early Eskimo housing were not healthy due to infrequent use of the building's *qanaq* to ventilate the house. Later research has proven the human organism to be a poor judge of when ventilation is needed for reasons of health and comfort.

Early Interior Dwellings

Not all Native dwellings were patterned after Inupiat and Yupik houses. Bands of Athapaskan Indian people traversed Alaska's interior as recently as sixty-five years ago. Their seasonal movements were timed with fishing, hunting, and gathering. Protection from wind, rain, and snow was important to early Alaskans because of our cold climate. Efficient heating and easily acquired fuel allowed them to incorporate lightweight

Figure 1.5: The main Native groups in Alaska

natural materials as insulation and designs that minimized air leakage.

Early prehistory interior Athapaskans used the Western Plains tepee or similar designs. In common with the Crow band in Montana, the tepee consisted of up to twenty long 24 foot straight poles with bases set in a circle and tops gathered together and lashed with animal gut rope. This pole frame would be covered with numerous overlapping layers of large animal skins such as bear, moose, and caribou. The floor would be built up with layers of dry grass and then covered with moose or caribou hide to provide for a warm, insulated floor that could be swept clean. Outer portions were usually dedicated to sleeping quarters because the slope of the walls made standing upright easy only in the center of the tepee.

A heating and cooking fire was set in the center surrounded by rocks, and by mov ing one or another pole to which a skin flap was attached at the top, the occupants could control heat and ventilation by natural con vection. Tepees were portable dwellings that provided shelter from the elements in a wide geographic area. It is difficult to find remains of prehistoric tepees because all elements of its construction were biodegradable.

As the Europeans moved north, many lo cal tribes adopted the log cabin but still used Western-style tents in summer fish camps. Figure 1.9 depicts the Athapaskan village of Moosehide on the Yukon River with an early log cabin and tent, circa 1898.

Tlingit and Haida Houses

Traditional Tlingit territory in Alaska includes the Southeast panhandle between Icy Bay in the north to Dixon Entrance in the south. Tlingit people have also occupied the area to the east inside the Canadian border. This group is known as the Inland Tlingit. The Tlingits have occupied this territory for a very long time. The Western scientific date is about 10,000 years, while the Native version is "since time immemorial."

The original homeland of the Haida peo ple is the Queen Charlotte Islands in British Columbia, Canada. Before contact with Eu ropeans, a group migrated north to the Prince of Wales Island area in Alaska. This group is known as the Kaigani, or Alaska Haidas.

Today, the Kaigani Haida live mainly in two villages, Kasaan and the consoli dated village of Hydaburg.

The original homeland of the Tsimshian is between the Nass and Skeena rivers in British Colum bia, Canada, although at contact in southeast Alaska's Portland Canal area, there were villages at Hyder and Halibut Bay. Presently in Alaska, the Tsimshian live mainly on Annette Island, in New Metlakatla, Alaska in addition to settle ments in Canada.

Before and during early contact with the nonaboriginal population, the people built their homes from red cedar, spruce, and hemlock timber and planks. The houses, roofed with heavy cedar bark or spruce shingles, ranged in size from 35 to 40 feet to 50 by 100 feet, with some Haida houses being 100 by 75 feet. All houses had a central fire pit with a centrally located smoke hole. A plank shield frames the smoke hole in the roof. Generally, each house could hold twenty to fifty individuals of one clan, with a village size between 300 to 500 people.

The people had winter villages along the banks of streams or along saltwater beaches for easy access to fish-producing streams. The winter villages were lo cated to give protection from storms and enemies, drinking water, and a place to land canoes. Houses always faced the water with the backs to the mountains or muskeg/swamps. Most villages had a single row of houses with the front of the house facing the water, but some had two or more rows of houses.

Each local group of Eyak, Tlingit, Haida, and Tsimshian had at least one permanent winter village with various seasonal camps close to food resources. In each Eyak village, there were two potlatch houses, outside of which were

Figure 1.7: An artist's drawing of a barabara at Ounalaska (Unalaska) from the "Report of the Cruise of the Revenue Cutter Corwin in the Arctic Ocean in the Year 1885" by Capt. M. A. Healy, USRM, Commander. Washington: Government Printing Office, 1887.

posts topped with an Eagle or a Raven. The dwelling houses were unmarked. The southern Tlingit had tall totem poles in front of their houses. The northern Tlingit houses had fewer and shorter frontal totem poles.

Aleut Housing

To build an Aleut house, called a *barabara*, they would start by digging a rectangle in the ground, no more then fifty feet long and twenty-five feet wide. Then they would build the roof using driftwood and whalebone. Over that they would put sod and moss. Inside the house they portioned off rooms for the separate age groups occupying that house. Usually extended families cous ins, aunts, etc. shared a house. They would dig trenches inside the separate rooms and line them with fur. That was where everyone worked and played. Inside the main hall there was a trench along one wall that was used as a com mon bathroom. They would soak skins in it to try to reduce the smell. Above is from http://library.thinkquest.org/11313/Early_History/Native_Alaskans/aleuts.html

These early designs for northern people living in extreme climate zones provide insight into what is possible without written communication and training in modern engineering and architecture. Some indigenous Alaskan people say, "Before the Europeans came we built our houses in the ground and buried our dead above. Now we build our houses above ground and bury our dead below. We haven't been warm since."

Our present understanding of build ings has become a true science, building science. The awareness for how build ings perform is based on physics and accurate long term weather records, heating content of fuels, occupant be havior and many other related elements. Knowing how we came to our current understanding is important because it explains many of the problems that have been encountered along the way.

Discoveries Along the Way

Five distinct climate zones are recognized in Alaska. Because of the broad expanse that it covers, the original people used widely varying housing designs. While this was true before the impact of Western civilization, Alaskan climate zones still require greatly different approaches to our modern construction methods.

It is common, and really quite comical, to encounter someone unfamiliar with our state who asks the question "What is the climate like in Alaska?" Using the largest community of Anchorage as the starting point, the following distances indicate the expansive area covered by Alaska.

Distances from Anchorage

- Adak is 1,300 miles southwest
- St. Paul Island is 750 miles west
- Barrow is 725 miles north
- Metlakatla is 800 miles southeast

Insulation

As European influence settled across the territory of Alaska, new designs and materials became available for construction of housing. One of the major changes to construction was using insulation in attics and walls. Early insulation consisted of sphagnum moss used as chinking between logs and then above ceilings in attics. When dried, the moss would become rigid, similar to a fibrous insulation. This dried moss would reduce air movement, in effect adding resistance to heat flow.

Early pioneers brought whip saws with them to make boards and lumber for construction. Sawdust from these whipsaw pits would be collected and dried for use in attics and walls. Numerous early log houses in Fairbanks have been framed over and new siding placed around their exterior. In many of these buildings still standing, the space

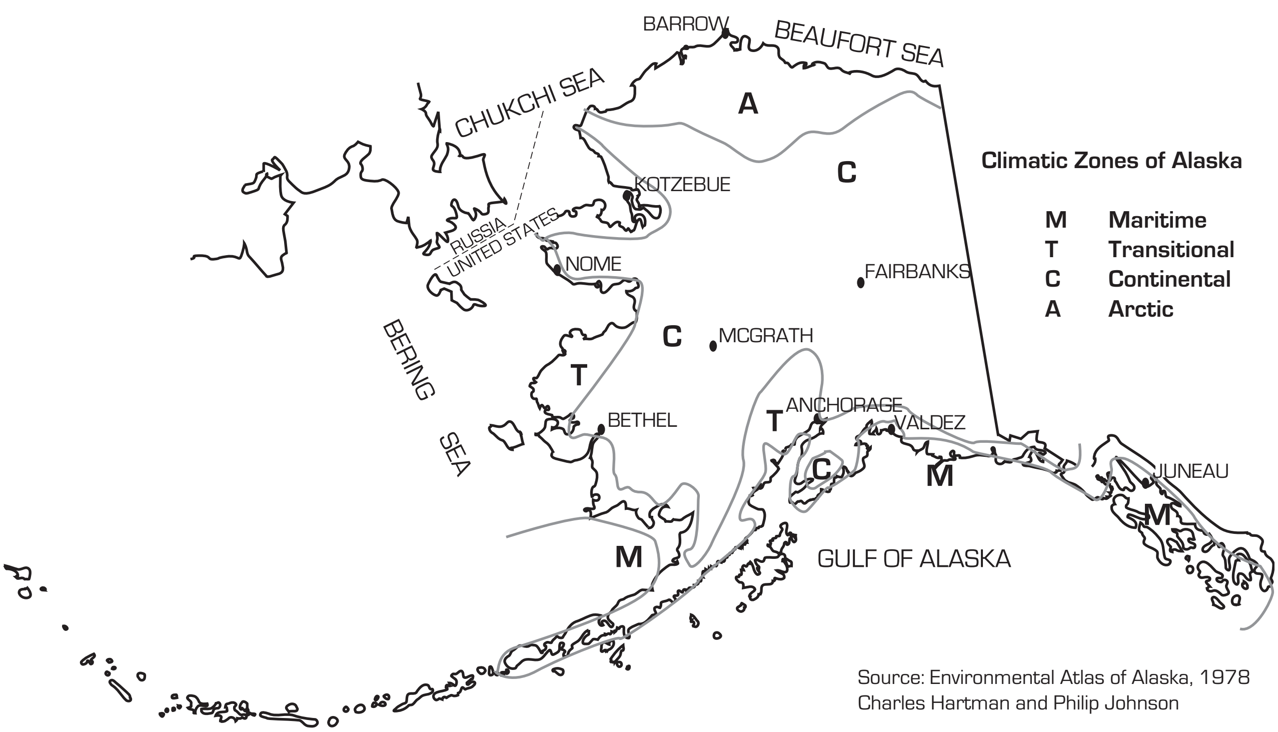


Figure 1.8: Climatic zones in Alaska

between the siding and logs is filled with sawdust from lumber mills. Our experience with the insulation properties of sphagnum moss and sawdust led to the invention of different types of insulations.

Framing Design

Another change occurred with improved design of walls. Early multiple story buildings were framed as one section that would allow air to easily move upward between floors. This movement of air from the lower wall would take heat with it, increasing fuel use and reducing comfort. Balloon framing required sixteen foot studs, and the walls required a large crew in order to stand them up. Around 1915, we learned that smaller trees could be used in wall construction with eight foot stud framing. On top of this wall a platform would be placed and the second and subsequent floors were then built above the first. Crew size could be reduced and the shorter studs were less expensive than those used in balloon framing. Platform style construction, while improving the use of wood resources, also brought reduced fuel use by effectively blocking air leakage between floors.

Plywood

Plywood was the first type of engineered wood to be invented. It is made from thin sheets of wood veneer, called plies, which are stacked together with the direction of each ply's grain differing from its neighbors by 90 degrees. The plies are bonded under heat and pressure with strong adhesives, making plywood a type of composite material. Plywood is believed to be an invention of the Egyptians, who first thought of putting

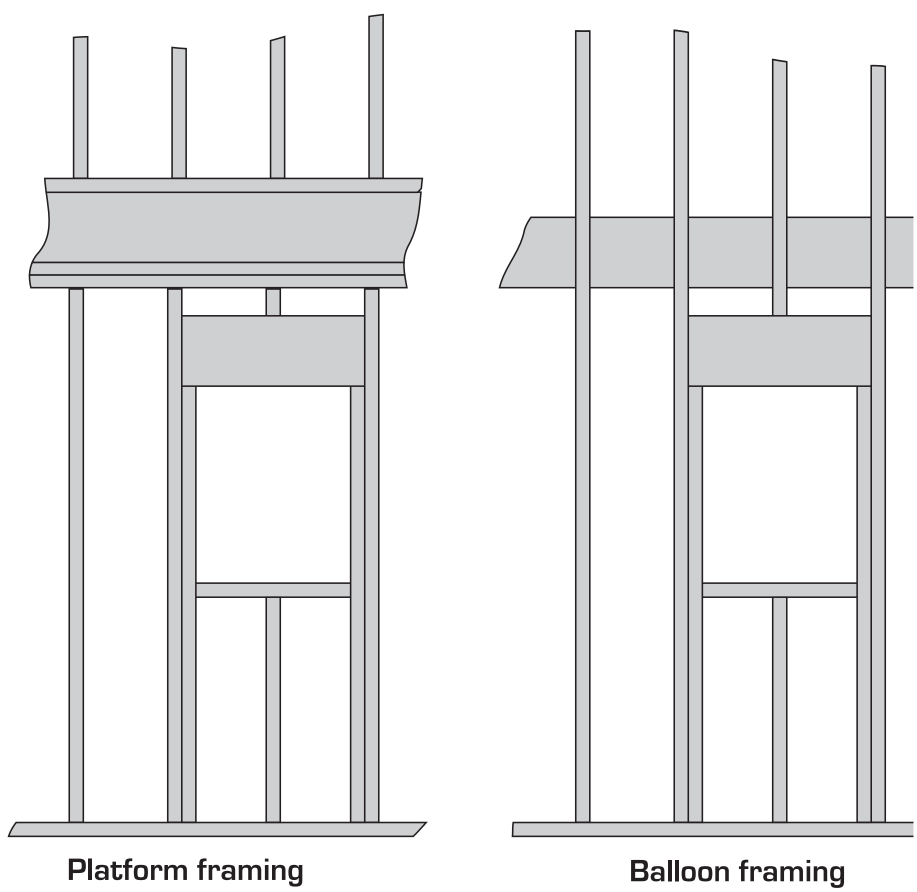


Figure 1.9: Two kinds of wall framing

together several thin layers of wood to make one piece of wood. This was done around 2,800 BC, primarily because they had a severe shortage of good qual ity wood. However, the plywood as we know it today was invented by Imman uel Nobel, the father of Alfred Nobel, inventor of dynamite. It was Immanuel Nobel who worked out that several slim layers of wood glued together would form a stronger piece than just one single layer of wood.

There are many varieties of plywood, tailored for all manner of conditions and uses. Plywood production requires a good log, called a peeler, generally straighter and larger in diameter than that required for processing by a saw mill. The log is peeled into sheets of veneer, which are then cut to the de sired dimensions, dried, patched, and glued together to form the plywood panel. The panel can then be patched, resized, sanded, or otherwise refinished, depending its intended use. The most common varieties of plywood come in three, five, or seven plies with dimen sions of 1.2 m x 2.4 m 4 feet x 8 feet .

Modern plywood, in which the ve neer is cut on a rotary lathe from soft wood logs, is of relatively recent origin. The first such lathes were set up in the United States in the mid nineteenth century. With the advent of World War II, wood resources became increasingly more important. A material that would cover a large area and have strength be yond that of naturally found materials was needed for aviation and vehicle con struction. Plywood was the answer.

After World War II there was a sur plus of plywood manufacturing equip ment, and it naturally evolved into being one of the most predominant building materials used today. Plywood allowed an even tighter building by eliminating the many cracks and joints common with earlier plank and shiplap construc tion. Tighter buildings meant less natu ral air leakage and even less fuel use. When plywood was combined with in sulation in building walls and attics, the fundamental materials of today's hous ing industry came into being. Plywood has since evolved into numerous types of particleboard and oriented strand board OSB , making use of smaller wood particles and using advances in adhesives and manufacturing processes.

Post World War II Developments in Alaska

More Frame Houses

World War II also radically changed much of Alaska. The construction of airfields brought air freight and infra structure to Alaska, and the construc tion of the Alaska highway made an au tomobile trip and truck freight from the lower forty eight states possible.

Although techniques for frame construction were brought with many immigrants during the mining era, after World War II, everything accelerated, and frame houses were the norm. But air sealing, insulation, and various other aspects of housing were not adapted well to the much colder and longer win ters of interior Alaska, and so housing quality left much to be desired.

The roots of superinsulation pre date the energy crisis, extending back to the mid 1960s when two men, Harry Tschumi and Les Blades, promoted the use of heat pumps. Tschumi sold heat pumps and Blades worked for the Arkansas Power and Light Company. Around 1961, they discovered that by increasing insulation levels and improv ing window thermal performance, heat ing houses required less energy for heat ing and thus were better suited for heat pump applications. At that time low en ergy prices prompted few homeowners to pay the extra construction cost.

The 1970s

The first oil embargo in 1973, which was followed by the assertion of the Organization of Petroleum Exporting Countries OPEC , of price control by cartel economics. This is a sort of clique of countries that produce oil, and agree to sell it at a fixed price from each to the rest of the world, thus controlling the price of oil. Prices soon doubled from what they were before 1970, and the world paid attention. Much of the original impetus for superinsulation and housing energy efficiency stems for the price shocks and the application of building science to the new attempts to build more energy-efficient houses.

It wasn't until 1974 that housing analyst Frank Holtzclaw of the U.S. Department of Housing and Urban De velopment HUD , brought Tschumi's ideas to fruition. Holtzclaw initiated the Arkansas Project, a series of radically designed superinsulated houses that were not only very energy efficient but also inexpensive. Between 1974 and 1975, thirty-five homes were built and moni tored for energy consumption. Annual heating and cooling costs were about 130, considered low even at 1975 energy prices. The Arkansas houses had 6 inch walls with R-19 fiberglass insulation and a special raised heel roof truss, now commonly referred to as the Arkansas truss.

The man usually credited with coin ing the term "superinsulation" is Wayne Shick, an architect with the Small Homes Council at the University of Il linois at Urbana Champaign. He had worked since the 1940s with several other faculty members on methods of increasing the thermal performance of houses. While lecturing about energy savings from increased levels of insula tion, Shick made reference to a maxi mum practical level and called it "super" insulation. In 1976, Shick's team devel oped a design called the "Lo Cal" house. It included double 2 x 4 walls with R 30 insulation and ceilings insulated to R 40, and double glazed windows with most of the glass on the south side of the house. Computer simulations in dicated that a house built with the Lo Cal design needed one third as much heating energy as specified by the newly created HUD standards. Shick's team never built a Lo Cal house, but many of the details of that design are incorpo rated into present day superinsulation techniques.

However, Shick may not have actual ly coined the term "superinsulation." Ac cording to Alaskan lore, the person who first used the term was Bob Roggasch. The Fairbanks designer used the term to refer to a house he built in 1971, which had walls filled with 9-inches of ground-up urethane. Roggasch, his Fairbanks neighbor Ed McGrath, and University of Alaska Cooperative Extension engi neer Axel Carlson monitored, analyzed, and evaluated the Roggasch house. The three men became acknowledged au thorities on energy conservation.

At the same time, environmental is sues and awareness were raised with the passage of the National Environmen tal Policy Act of 1971. Alaska pioneers such as Dr. Eb Rice, professor at the University of Alaska Fairbanks in the Civil Engineering Department, and Axel Carlson, University of Alaska Exten sion engineer, were doing basic research on all aspects of heating, permafrost design, and vapor barrier attention that became hallmarks of appropriate design for the north. These scientific people were working in Alaska and would lead us to a solid position in the area of hous ing adapted to the climate.

The first of these was Dr. E. F. (Eb) Rice. Rice developed the arctic en gineering curriculum for Alaska. The oil development at Prudhoe Bay was pumping research money into the sci ence departments, and Rice was leading the way toward solutions to engineer ing problems, including housing. His book, *Building in the North,* is still a very readable and entertaining look at the problems and solutions to living in the North. The book was the first major Alaska-specific treatment of the prin ciples of heat, moisture, frozen ground, insulation, and other details pertinent to building in subarctic and arctic cli mates. The chapters cover all the major principles that make building in the north unique.

Many of the things Rice pointed out in his original work are still crucial today. One of the first he attended to is the threat of fire. He recognized that once fires start, they are more difficult to fight in the far north than elsewhere. Here temperatures are below freez ing for a large portion of the year, and firefighting may involve freezing while fighting the fire. Frostbite can occur, and the necessity to rotate fire fighting crews to protect them from freezing and hypothermia is clear. Fire still re mains a major threat in Alaska, which has one of the highest fire loss rates in the United States. Many of the concepts that Rice first suggested are now stan dard practice.

Rice also pointed out a list of things that the builder in the arctic ought to consider. First go heavy on fire warning equipment: smoke detectors, periodic inspections, good housekeeping. Today we would add to the list, carbon monox ide detectors and hand fire extinguish ers that are familiar to people and are placed regularly within a building and within easy access. We must ensure that every structure has ample escape routes egress . Buildings should antici pate snowdrifts, prevailing wind direc tion, and windows that are operable for egress; these have all trapped people in burning buildings.

Finally there is the clear advantage of having duplicate facilities in small com munities that are well separated. If a structure burns, there should be another one nearby that can accommodate the displaced people and provide them with food, warmth, and communications. It can save their lives. It also gives them time for rebuilding or rescue.

Another aspect of northern life that Rice pointed out has become a tenet of our basic building philosophy: Alaska is full of disasters waiting to happen. For this reason all kinds of redundancies should be designed into a house. As security issues become more important in the world it is even more crucial to recognize the necessity for sources of heat and perhaps water that are not dependent on electricity or outside power. Often this means a wood or propane stove backup for heating and cooking. For every reason in all locations this is good planning.

Along with the history of building issues comes the history of foundations and their performance under permafrost conditions. Because of Alaska's climate, our military and mining experience, and general difficulties encountered in dealing with all sorts of permafrost issues, the University of Alaska became a major center of permafrost research throughout the circumpolar north. Rice talks about this in great detail in his book. Rice actually lived on permafrost for all his Alaskan life and loved the challenge it gave him. He has a chapter in *Building in the North* called "Permafrost, Its Care and Feeding." Permafrost is always a threat in most of the areas north of the Alaska Range and west of the Cook Inlet region. It is not an issue in the Aleutians and southeast Alaska, areas of southcentral Alaska below 2,000 feet, and close to the coast.

Rice also mentions the design advantage of minimizing the surface to volume ratio in a building. The smaller the area exposed to weather, the less heat and materials needed, so the larger volume the you can enclose with the least material, the better. A sphere is the minimum surface to volume ratio, but a cube is much easier to build.

Inaccessible piping needs to be avoided. The old nemesis of placing plumbing in exterior walls where it can easily freeze and therefore fail at the wrong time and cause complicated problems must be avoided.

An entrance must be arranged so that it can be easily adapted to varying wind conditions. Entries that are regularly covered by blowing snow are a problem for the life of the building.

Finally there is simple material resistance to heat and moisture flow. Trapped heat and controlled air leakage can actually lead to overheating, so at times you must ventilate. Materials that are vulnerable to moisture degradation are a continuous problem, and that leads us to the idea of a vapor barrier to control moisture condensation and water damage in buildings.

Axel Carlson was another pioneer in Alaska building techniques. He was the agricultural engineer for the Cooperative Extension Service from 1968 to 1980. He was instrumental in bringing the concept of vapor control to the Alaskan building industry. He made it his life's work, and he was known as "Mr. Vapor Barrier" for the duration of his professional career, and long after. He was one of the first to recognize and make publicly known in several useful publications through the Cooperative Extension Service that most of the problems with moisture were created by indoor air and water vapor leaking through a building shell and causing havoc when it condenses into liquid water. Once this was widely understood it became an easy case to make vapor and moisture control an integral part of good housing designed for the north. Carlson's work enabled us to have a good understanding of how heat and moisture flow work in buildings and showed how the exterior environment affects buildings.

Working independently, Richard Bentley developed and patented in 1976 a design for a double wall house using an innovative truss system. His patent stresses the need for airtightness and includes a site built heat recovery venti lation system air to air heat exchanger . Bentley and his family built a few hous es using his design. Although he hasn't gained much publicity, he is definitely one of the originators of the modern superinsulation concept.

The excellent performance of energy efficient houses was demonstrated to the American public through two well publicized houses in distant parts of the continent: the Saskatchewan Conserva tion House, built by the Canadian gov ernment, and the Leger House, built by Gene Leger in eastern Massachusetts.

Saskatchewan House

The Saskatchewan Conservation House was built in 1977 by a Canadian team headed by David Eyre of the Saskatche wan Research Council. It may have been the first superinsulated house to demon strate airtight construction as practical, drastically reducing energy consump tion. It may still be one of the most energy-efficient houses ever construct ed. The 12-inch-thick walls are filled with R 44 insulation, and the ceiling is insulated to over R 60. The house's most distinctive feature is its airtight ness. Harold Orr of the Canadian National Research Council supervised the careful installation of a continuous airtight membrane. This resulted in an air leakage rate far below conventional houses. To ensure adequate fresh air and indoor air quality, a ventilation system with an air to air heat exchanger was incorporated into the design.

The most desirable aspect of this house is its energy performance. When the outdoor temperature is -1°F, the total heat demand is about 3,000 watts 10,640 BTU per hour , less than the average output of a clothes dryer. In the Saskatchewan house with shutters closed, no people in the house, and no heat inside source, the house cools at a rate of less than one degree per hour. According to Harold Orr, the total an nual heating cost would be about 35 in 1978 Canadian energy costs. Originally, an expensive array of solar collectors us ing evacuated tubes was installed on the roof. However, project managers were quick to realize it would be difficult to justify a 10,000 solar heating system to displace a 35 annual fuel cost, so the solar collectors were removed.

The Saskatchewan Conservation House is an example of extreme applica tions of insulation and building technol ogy. Neither its enormously thick insula tion systems nor its general design were immediately accepted by the general housing market. But experience gained in building it affected superinsulation more than any other project. It proved that it is possible to design and build a comfortable house that needs almost no heat, even in a northern climate.

Leger House

About the same time the Saskatchewan home was built, builder Eugene Leger pronounced 'le jay' invented a superin sulated house design in eastern Massa chusetts. Leger's design included double walls and extremely airtight construc tion, although many of his framing de tails were quite different from those of the Lo Cal or the Saskatchewan House. His first house, the Leger House, re quired so little space heat that heating requirements could be met by using a regular sized domestic water heater with no need for a furnace or boiler. The annual heating bill was 40. Unlike the Saskatchewan House, Leger's house looks like millions of conventional American houses and costs only slightly more than standard construction. Leger and his house were widely publicized. The Leger House proved that energy efficient construction is practical and economical and impressed the public.

Leger wrote to William Shurcliff, a Harvard physicist and noted author of books on many energy related subjects. Shurcliff was so impressed by Leger's design that within a few days of getting the letter, he put a press release, saying that these new superinsulate homes had the following features:

1. Truly superb insulation. Not just thick, but clever and thorough. Ex cellent insulation is provided even at the most difficult places: sills, headers, foundation walls, windows, electric outlet boxes, etc.
2. Envelope of the house is practically airtight. Even on the windiest days the rate of air change is very low.
3. No provision of extra large thermal mass. Down with Trombe walls! Down with water-filled drums and thick concrete floors!)
4. No extra large south windows. Use normal number and size of south windows, say 100 square feet.
5. No conventional furnace. Merely steal a little heat, when and, if need ed, from the domestic hot water system. Or use a minuscule amount of electrical heating.
6. No conventional distribution system for such auxiliary heat. Inject the heat at one spot and let it diffuse throughout the house.
7. No weird shape of house, no weird architecture.
8. No big added expense. The costs of the extra insulation and extra care in construction are largely offset by the savings realized from not having huge areas of expensive Thermopane glass, not having huge well sealed insulating shutters for huge south windows, not having a furnace or a big heat distribution system.
9. The passive solar heating is very modest, almost incidental.
10. Room humidity remains near 50 per cent all winter. No need for humidi fiers.
11. In summer the house stays cool au tomatically. There is no tendency for the south side to become too hot because the south window area is small and eaves shade the windows.

Shurcliff continued investigating on his own and wrote the book, completed that same year, *Superinsulated and Double-Envelope Houses,* published privately by the author and later by Brick House Publishing.

The 1980s

By 1979, a second oil embargo and oil price rise resulted in another wave of influences and increased use of the superinsulated house. However, prob lems with superinsulation immediately became apparent. These houses were ex tremely airtight, which led to problems with moisture. All kinds of bad publicity resulted from this early phase of experi mentation and development. Building scientists realized the need for moisture control using a good vapor barrier and a technology that came from Canada, the heat recovery ventilator. The heat recovery ventilators first presented to Alaskans were a home built kit advocat ed by the University of Saskatchewan.

It turns out that the first air-to-air heat exchangers were designed for hog farrowing barns. A mechanical engineer named Bob Besant at the University of Saskatchewan, explained that hogs produce a lot of heat and moisture and need a lot of ventilation for their fa cilities where farmers raise the young piglets. Consequently a system was designed that could be built by farm ers and do it yourself individuals. It was made of plywood and polyethylene sheets that were the heat exchange surfaces, with two fans designed to exchange heat and eliminate moisture from the inside of a building.

The size and scale of the system was just about ideal for a human habita tion, so they were adapted to the first superinsulated houses in the early 1980s and eventually tested at the University of Alaska by professor John Zarling for their efficiency and functional quality. This led to commercial development of similar systems and they were improved all through the 1980s, and necessarily so. Without the element of good ven tilation control, superinsulated houses would have never met wide public acceptance.

Canadian R-2000 Program

In Canada, the Canadian Department of Energy, Mines, and Resources set up a subsidized program to train builders to construct energy-efficient homes. Called the R 2000 program, it has been extremely successful and paved the way for much activity in the U.S. Our own Alaska Craftsman Home Program, de veloped in 1987, was derived from the Canadian R-2000 effort. Some of the information in this manual is derived from R 2000 publications.

In 1979 another Alaskan, Ed McGrath, published a book entitled *The Superinsulated Home Book*, one of the first to use the concept in a title for a book. McGrath's book was seminal, and he eventually worked with Axel Carlson to publish even better documented techni cal ideas through the Alaska Coopera tive Extension Service.

When Roggasch, McGrath, Carlson, and others began experimenting with energy-efficient design, they were trying to improve the technology of housing. The technology they helped develop is now implemented in thousands of American homes, driven by energy prices. But even without that economic whip, these houses make sense. They are within the economic reach of most homeowners and the scope of most homebuilders. They preserve basic con struction, while adding new dimensions in comfort, air quality, and efficiency.

By 1985, major conferences were being held throughout the country on the issue of superinsulated housing and improvements in housing technology. A particularly good conference was held at Rochester, Minnesota, in 1985, where Joe Lstiburek began putting together el ements of his airtight drywall approach to housing. This was the concept that if you controlled air leakage through gaskets, a vapor barrier was not really necessary. This became one of the major controversial discussions all through the 1980s. The Alaskan contingent gener ally held that vapor barriers made out of polyethylene on the warm side of con struction, although difficult to install and keep from being damaged during construction, were the desirable alterna tive to control air leakage and moisture penetration. Airtight drywall also had some vulnerability to racking, more so than was the case with the airtight poly ethylene vapor barriers.

At the same conference, the Energy Efficient Building Association came into existence. Also at about the same time, Canada began its development of the Canadian R 2000 Program. This program set a standard specification for new housing design aimed at designing durable, high-efficiency housing for cold climates that met the specification for a new millennium.

Through efforts of the Alaska De partment of Community and Regional Affairs and Cooperative Extension Service at the University of Alaska Fair banks, a plan to improve building con struction in Alaska was put into place. A meeting in Anchorage in 1986 between six Alaskan representatives and consul tants Oliver Drerup and Ned Nisson, initiated what was to soon become the Alaska Craftsman Home Program.

Using materials from the Canadian R 2000 program and numerous publications, including *Energy Design Update*, the program was roughly drafted into a builder education program for energy-efficient construction. Beginning with twenty four volunteers selected from around Alaska to teach two day workshops in every climate zone, the program fused many current housing technologies and incorporated many aspects of the Canadian R 2000 Program into an Alaskan version of energy-efficient construction training. Rich Seifert and Don Markle worked to develop the first ACHP Building Manual in 1987, and followed it up with a second more detailed and comprehensive manual in August 1988.

The acknowledgements from the 1988 manual are instructive. They include detailed information from the Norwegian Building Research Institute booklets, *Trehus* which means wooden house , and the Norwegian Building Research series. Also cited are Alchem, a company in Anchorage known for its very durable, high-efficiency panelized construction using urethane foam-filled panels. These panels were ultimately tested by the National Research Council of Canada and found to be durable and still performing to specification twenty years after they were first used in a building in northern Alaska.

The Canadian Society for Civil Engineering allowed us use of material from their Cold Climate Utilities manual and an appendix in the second edition of the manual. Many of the utility concerns for the North are still quite relevant. And the present Bible of energy-efficient design, *Energy Design Update*, is cited in this second edition of the Cold Climate Homebuilding Manual and has since become a staple in keeping up with the technological and professional developments in energy efficient design.

By 1990, the Alaska Craftsman Home Program had become a central focus of the energy-efficient housing industry in Alaska. In 1994 a third edition of the manual called *Northern Comfort* was released. By this time many subtle changes had occurred, moving housing toward a standard practice of a much higher quality: for instance, going from 2 x 4 stud construction to 6 inch studs, and a slow but improving incorporation of energy-efficient design using the Alaska Craftsman specification. This specification was originally appended as a chapter of technical requirements to the second and third edition of the Alaska Craftsman manual.

About this same time the Alaska State Legislature mandated minimal thermal standards for residential buildings financed with state funds. The State of Alaska through the Department of Community and Regional Affairs, developed the Building Energy Efficiency Standards BEES , which became effective in July 1992. Although this standard only affected residential buildings financed by the Alaska Housing Finance Corporation (AHFC), it set the pace for the industry because it required this energy specification be used if funding for the mortgage was provided by the Alaska Housing Finance Corporation. Currently BEES sets the goal for many Alaska builders who strive to incorporate energy efficiency into their designs, whether using financing by AHFC or any other available source. Due largely to the success of BEES, construction of Alaskan dwellings is some of the best in the world today.

Today

Much has happened in the eighteen years after the legislature first mandated a minimum thermal standard be developed. As this manual is being produced, the BEES standards are in revision and are reviewed for improvement with some regularity. Along with the building energy efficiency standard came an energy efficiency rating system and a mortgage interest rate reduction program, which gave people incentives to build higher efficiency structures. This system had modest success; but it was especially effective when interest rates were high. In the early part of the new millennium, interest rates steadily dropped, and consequently energy mortgage incentives had less appeal. This has not meant that energy efficiency has become any less important, however. It is now much easier to persuade both the industry and homebuyers to buy into energy efficiency.

The desire for energy efficient, comfortable, and healthy housing has led to what is perhaps the next evolution of housing, which is the Health House, a specification originally developed in Minnesota by the American Lung Association of Minnesota. This is currently being adapted to the Alaska situation and approved by the Alaska Housing Finance Corporation for use in Alaska. It adds to the specification of high efficiency and high technical quality in housing the concept that the home should also be healthy to live in. Much of this new specification can be seen on the web site for the Alaska Lung Association, www.aklung.org.

Global awareness of the importance of petroleum fuel conservation has recently increased due to high prices. Petroleum reserves are diminishing with time, and new sources are being sought. The International Energy Agency predicts that at our current rate of use there is only twenty to twenty-five years of remaining global oil and gas reserves, and political and economic realities are manipulating markets worldwide. To understand the important contribution that energy efficiency can make to our future one must only read the news or watch television.

In addition to diminishing resources, accelerated use of these resources contributes to global warming, a phenomenon where excess CO_2 in the atmosphere causes a significant and rapid increase in world temperature with subsequent sea level rise and unpredictable atmospheric disturbances. Using "green" materials in construction, materials that may easily be recycled and that use less energy to manufacture, we may slow global warming and extend the petroleum resource. Sustainability has become a key word in describing such issues, and building in a sustainable environment means we must use designs and materials that are easily replaced and are without high energy production costs, as well as construct houses that use much less fossil fuels to operate.

The environment that we live in has a tremendous effect on everything we do. People in each culture that we have looked at made decisions based on their surrounding environment. Inupiat people had to learn how to erect shelter by collecting driftwood and whale bone. The Aleuts built into the ground because they had to in a land with no trees. Haida people constructed huge houses from huge trees. All used materials that were common to their environment and necessary for their survival.

In 2006, modern man is still experimenting with materials, assembly, and operation of shelter in all regions of Alaska. What we do know is that the most appropriate design for Metlakatla may not be the best for use in Kaktovik. As we move down this path of applying science to buildings we are sure to arrive at many more premature conclusions. By looking back in time to when all that was available for Alaskans to build houses with were materials one could collect nearby, we gain an appreciation for the quality of housing today.

One issue remains clear. We must get back to that day when sustainable housing was the norm. Until we do so we are only repeating mistakes of the modern post war era, a time where consumerism and flashy advertisements overruled practicality and good old common sense. Building science can point the way but it can't save us all by itself. Only by integrating healthy, green, and sustainable concepts can we develop designs appropriate for any climate that are durable and affordable. Such build ings should have their useful lives mea sured by centuries, not years.

Chapter 2
Building Science Basics

Key Points to Learn

- Heat flows from warm to cold by conduction, convection, and radiation.
- Insulation must be installed carefully.
- Air tightness prevents major loss of purchased heat.
- Dew point is the temperature at which water vapor condenses into liquid water.
- A vapor retarder reduces moisture transport by diffusion and must be placed on the warm side of the dew point. It can also serve as a primary air leakage retarder.
- An air retarder controls air leakage. It can be placed on the interior, exterior, or both.
- Movement of heat, air, and moisture must be controlled. Controlled mechanical ventilation is a necessary element of Alaska homes.

Introduction

Building science is the study of how buildings function under varying conditions. The ability to predict how the building functions as a system allows the builder and designer more flexibility in designing an energy-efficient home. A study of the concepts of building science helps explain how the house as a system and its occupants can work together to achieve the most economical, energy-efficient home possible.

We build houses to create safe and comfortable living environments so that we may be comfortably sheltered from the outside environment. We want our homes to be warm when it's cold outside, cool when it's hot outside, dry when it's raining, light when we're awake, secure from buffeting winds, comfortably humid at all times, filled with fresh air when doors and windows are closed against the elements, enlivened with sunlight, and resistant to earthquakes and other natural events. We also want them to be long lasting, affordable to build, and economical to operate.

Our success in designing and building these homes depends upon our understanding of the physical forces that create a tug of war between the outside and inside environments. The study of these forces, which helps us understand how houses work, is called building science.

This chapter summarizes the building science basics that affect the durability, comfort, and energy efficiency of houses. The following sections on energy flow, air flow, and moisture flow present the principles that are the foundation for the construction techniques discussed in later chapters. Understanding these principles is the first step toward building quality housing.

The designer must look at the building as a system of interconnected components or subsystems, each of which contribute to a unified whole.

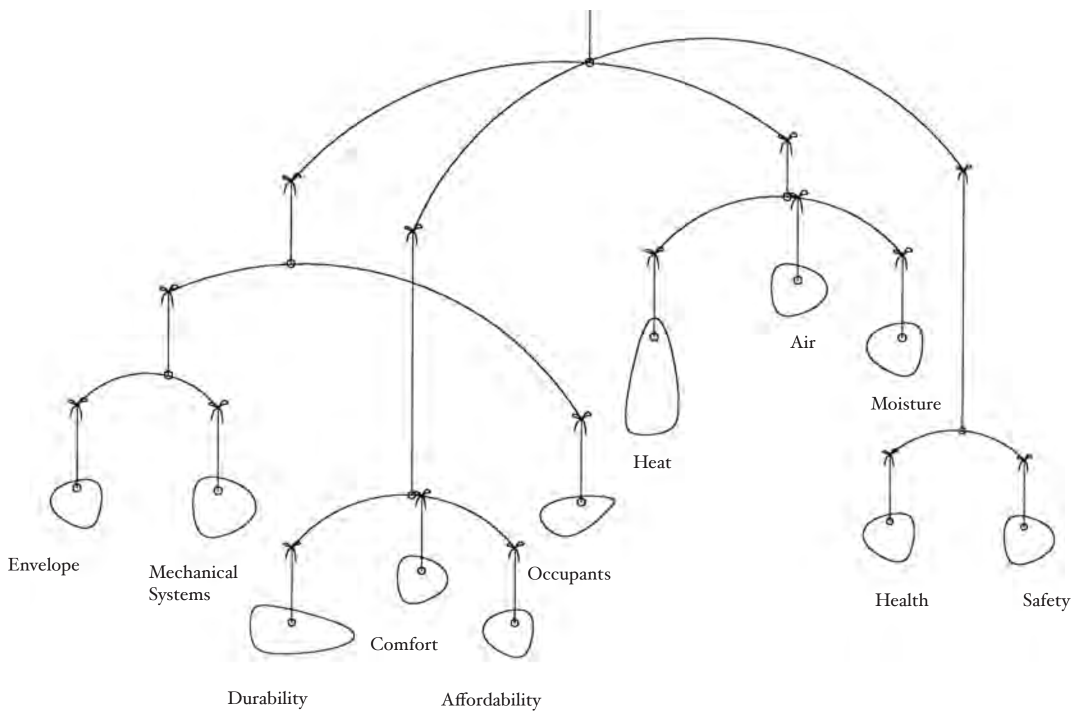


Figure 2.1: The total performance of the house as a system depends on a balance of envelope, mechanical systems, and occupants. All these parts of the house affect the flow of heat, air, and moisture into and out of the house.

These subsystems include the building envelope, mechanical systems, building occupants, and the external environment. These subsystems must operate in balance. Any change in any of these components will have an effect on the performance of all the other parts of the system.

There are ten fundamental concepts that must be understood before designing a new structure or retrofitting an existing building. Every subsystem should be designed with these concepts in mind to minimize the flows of heat, air, and moisture through the building envelope. Heat flow out of a building wastes precious fuel, air leaking out carries both heat and moisture, and moisture that escapes from the interior of a building can condense or freeze in the insulation, reducing the effectiveness of the insulation and causing damage by mold and rot.

The following concepts of building science provide the foundation for designing a building as a system:

Top Ten Building Science Concepts

1. Heat flows from hot to cold.
2. Heat does not rise   warm air rises.
3. Heat is transferred by conduction, convection, and radiation.
4. Heat flow through insulation is slowed by trapped air or other gases.
5. Airtightness prevents major loss of heat.
6. Air flows from higher pressure to lower pressure.
7. Air leakage is the primary moisture transport mechanism.
8. Diffusion is a secondary moisture transport mechanism.
9. Dew point is the temperature at which airborne water vapor condenses into liquid water. Water vapor is not a problem   liquid water is.
10. The vapor retarder should be placed on the warm side of the thermal envelope.

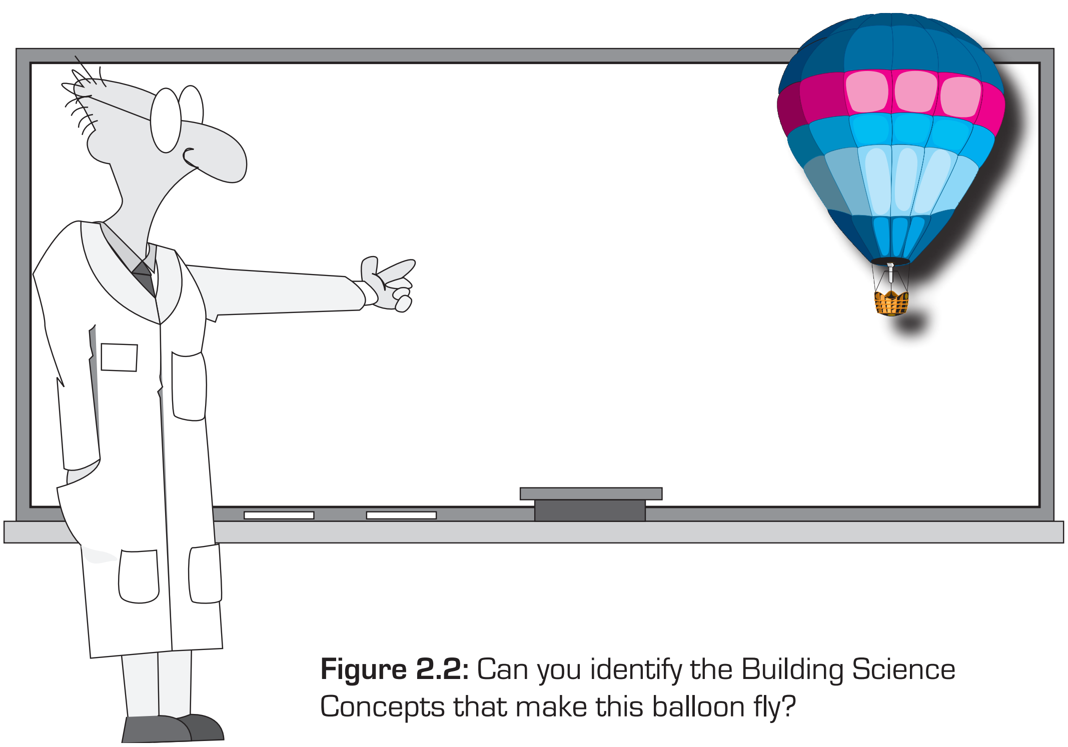


Figure 2.2: Can you identify the Building Science Concepts that make this balloon fly?

Mechanisms of Energy Use

Heat is a form of energy. Heat flows naturally from warm areas to cold areas in all directions. Without provisions for controlling this flow, heat quickly escapes from the home in cold weather. Construction of quality homes requires a good understanding of how energy enters the home, how energy is used in the home, and how energy leaves the home.

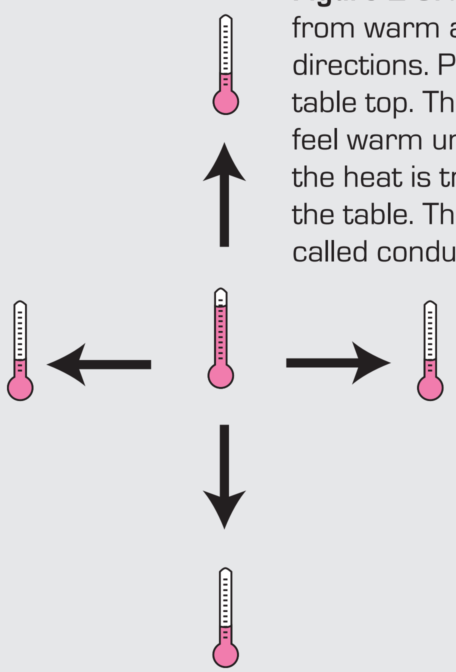
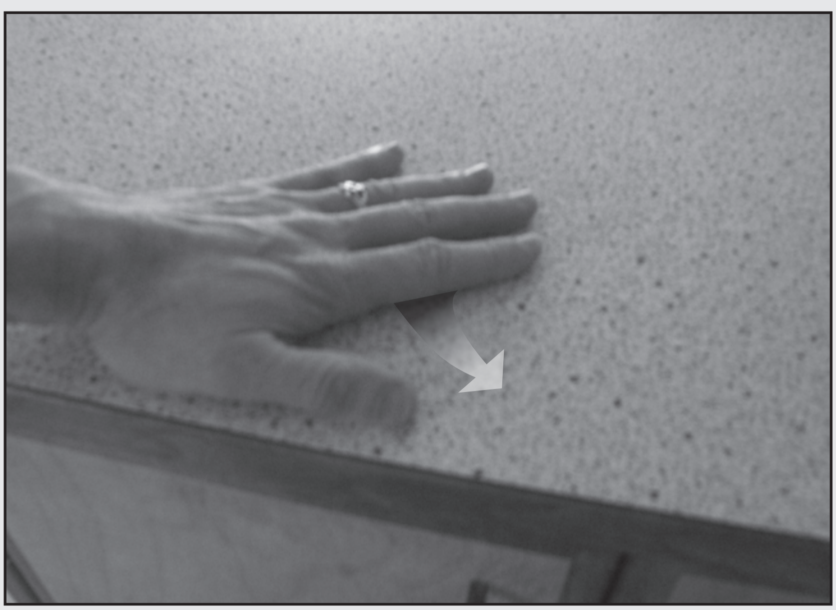


Figure 2.3: Heat flows naturally from warm areas to cold areas in all directions. Press your hand onto a cool table top. The table surface will soon feel warm under your hand because the heat is transferred downward into the table. This type of heat transfer is called conduction.



Energy enters a home from three primary sources:

1. Purchased energy is usually in the form of electricity, oil, natural gas, propane, or wood.
2. Solar energy is energy captured from sunlight, either through solar collection systems or transmission through windows.
3. Internal energy is heat gain generated by the occupants. An average person at rest gives off about the same amount of heat as a 100 watt light bulb.

Energy is used in conventional homes in the following ways

- Space heating and cooling account for as much as 70 percent of energy use.
- Water heating is typically 15 percent of total energy use.
- Lighting and appliances, including stoves, refrigerators, washers, dryers, computers, televisions, etc., account for approximately 15 percent of total energy use. Energy consumption for appliances will vary by model and amount of use, while energy consumption for lighting will vary by the model, amount of use, and the amount of natural lighting used.

In contrast, in an energy-efficient home, space heating and cooling use about one third of the energy, water heating uses one third, and lighting and appliances use one third. Total energy use will be much less.

Today it is clear there is a limit to the earth's ability to provide fossil fuel energy. By learning about the mechanisms of energy flow and how to control heat loss, it is possible to analyze where the greatest energy loss is in a house and how to minimize energy waste.

How Energy is Used in Homes and Buildings

The chart in Figure 2.4 shows where the energy comes in and goes out of a typi cal building.

When we translate energy to dollars, it soon becomes very interesting to the person paying for all this energy to run a home or building.

The goal for energy use in modern homes is to reduce purchased energy input while increasing natural or free energy input when desired. Of course, solar energy needs to be reduced when unnecessary as on uncomfortably hot days.

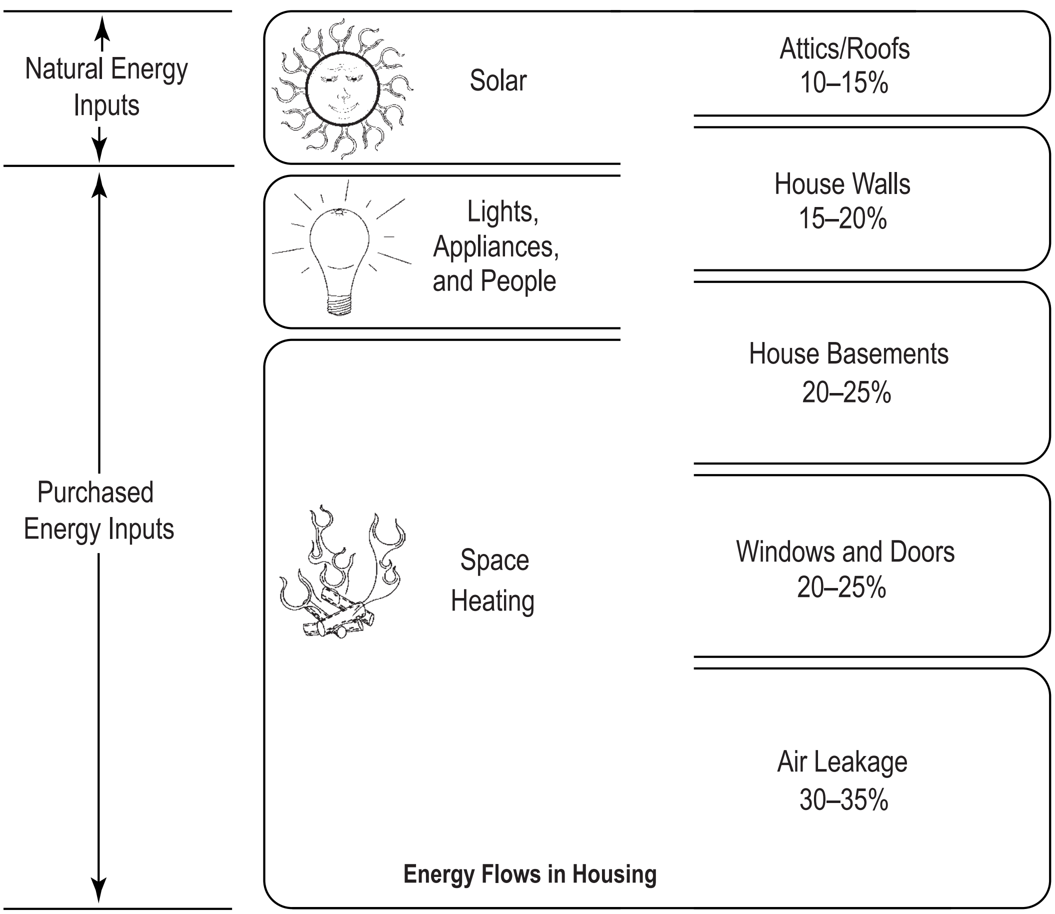


Figure 2.4: Energy flows in housing.

The total performance of the house as a system depends on a balance of en velope, mechanical systems, and occu pants. All these parts of the house affect the flow of heat, air, and moisture into and out of the house.

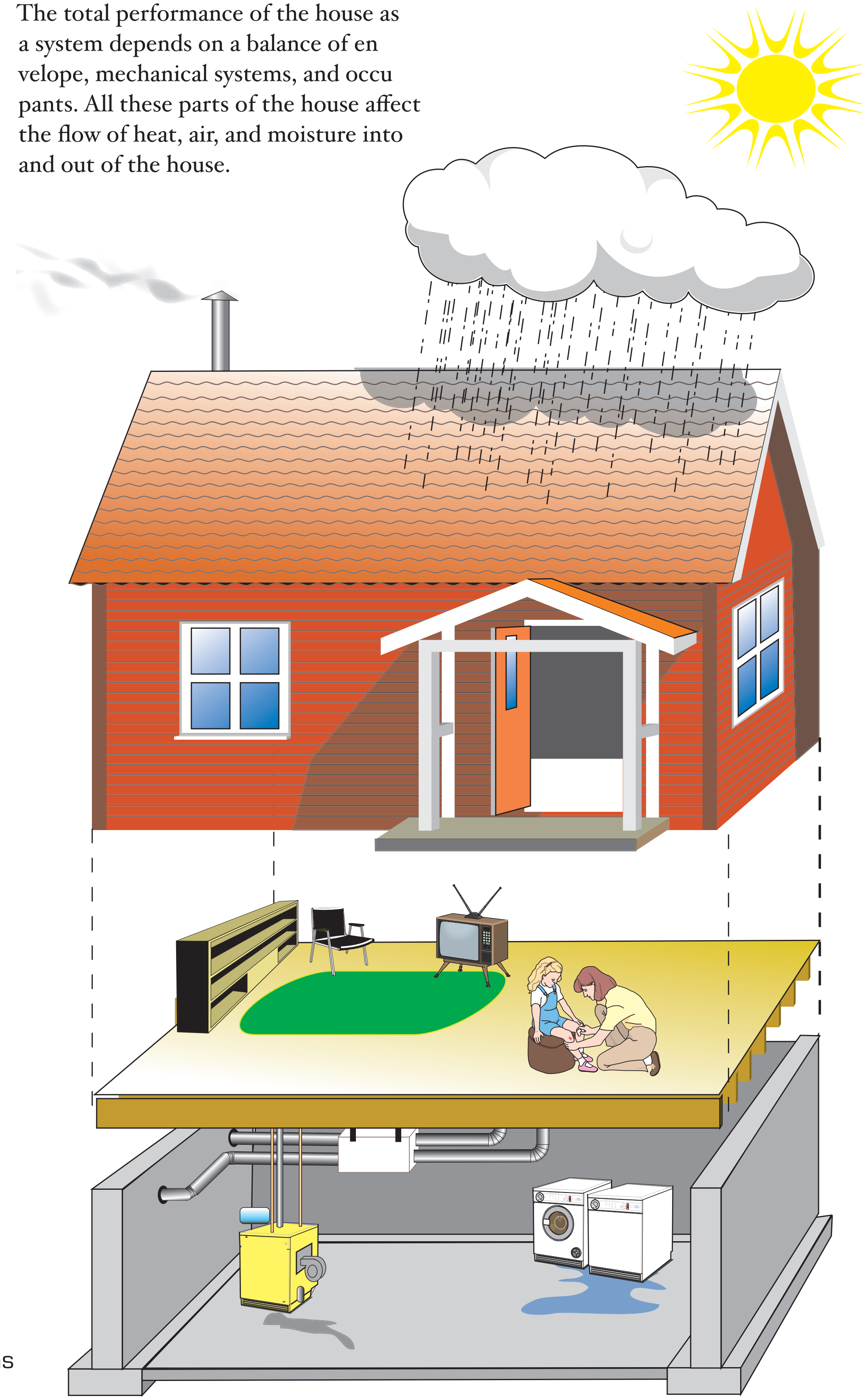


Figure 2.5: The house as a system.

The Way Heat Moves: Radiation, Convection, Conduction

There are three ways that heat moves from one place to another: conduction, convection, and radiation (Figure 2.6).

Conduction

The conduction of heat takes place by means of direct contact. Because it is a relatively efficient and fast means of heat transfer, especially through solids, it can be the major cause of heat loss in houses.

Fortunately, we can slow down the conduction of heat from inside our homes to the outside by using building materials that are poor conductors in sulation and minimizing or eliminating the number of direct heat paths from inside to outside that are formed by good conductors wood framing materi als, aluminum window frames, etc. . In later chapters, we will examine window technology and advanced framing tech niques that help reduce heat loss by conduction.

Convection

To better understand convection, we will focus on the movement of air in houses. There are always currents of air moving and colliding inside our homes, and there is always some air flow into and out of our homes. Unintentional holes in the building allow air to move in and out. These holes are a convective heat loss mechanism.

Warm air is lighter and more buoy ant than cooler air, which is more dense. This causes warmer air to natu rally rise above cooler air, and it is the source of the mistaken belief that heat rises Building Science Concept #2 . In leaky houses, there is a steady sup ply (infiltration) of cool air. This dense air displaces the warmer air, which is lighter and is forced upward, resulting in the stratification (cold feet, hot head phenomenon that we rightly associate with poorly designed houses. The warm air then leaves the leaky house through gaps in the ceiling vapor barrier. The movement of warmer air up and out of the house through holes (exfiltration) can account for as much as 35 percent of the heat loss of a conventional house. Only if we eliminate the holes in our buildings can we heat them efficiently and comfortably. A home without holes and their consequent air leakage can have uniform temperatures throughout.

Convection can also take place with in insulation, as we will discuss later.

Radiation

The most evident source of radiant heat in our lives is the sun, the source of radiant energy which, having traveled

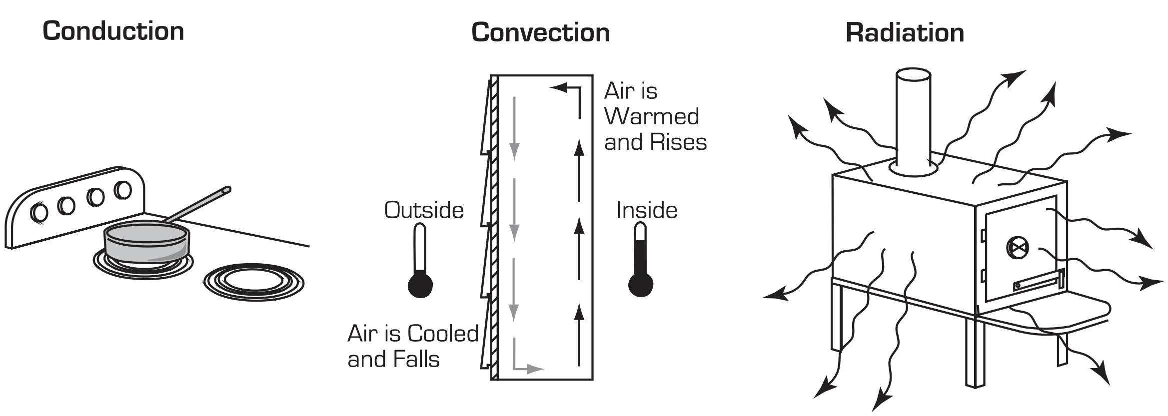


Figure 2.6: Three methods of heat transfer (Building Science Concept #3)

through the vacuum of space, warms the earth, including the contents of our homes. These contents store this heat for a while, but inevitably reradiate some of it to cooler objects in the room or through the windows to the cooler world outside. In fact, radiant heat loss in houses takes place primarily through windows, which is why glazings glass panes are now made resistant to the transmission of infrared radiation from the inside to the outside of the house. But these glazings low "E" or Heat Mir ror glazings still allow warmth from the sun to enter the house. This type of bar rier to radiant heat loss will be described further in Chapter 8, Windows.

Insulation Rating

Insulation materials are rated with R-value. This helps when different types or thicknesses of insulation are compared with each other. The larger the R-value the greater the insulation value. It is useful to consider the R-values of all components of any given assembly to determine the average overall R-value of an entire system. By adding up the R-values of all the components of any given section of the building envelope, the total R-value can be determined. The total system R-value can vary greatly, depending on design, materials, and installation.

For example, a wall section using two-by-six studs on two-foot centers holds batt insulation with an initial R-value of 21. The interior and exterior sheathing and finish materials can also increase the overall R-value. However, as discussed in the next section, using an R-21 batt does not guarantee an R-21 wall.

Knowing the R-value and area of a given section of the building envelope allows you to calculate the rate of conductive heat loss in BTU. The basic design heat loss calculation for conductive heat loss is:

Heat loss (in BTUs per hour) x area x ΔT

Calculating Heat Loss—Terms and Definitions

Understanding how heat moves allows the designer and builder to evaluate different sections of the building envelope and their relative importance to energy use. The rate of heat loss across the building envelope is controlled by Delta T, R value, and surface area through which the heat flows.

There is no simple formula for calculating radiant heat loss. Here are a few definitions that will help in understanding the following discussion about calculating or measuring heat loss.

BTU

Heat is commonly measured in British Thermal Units BTUs . One BTU is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The amount of heat given off by the burning of a typical wooden kitchen match is roughly one BTU. Houses will typically use millions of BTUs each year and require tens of thousands of BTUs each hour to stay warm during cold days.

U Factor

The ability of a material to transmit heat is sometimes called the total conductance or U Factor. The lower the conductance, the less heat loss through the material. The U Factor is the rate of heat loss in BTUs per hour through a square foot of surface for each degree Fahrenheit temperature difference between warm and cold surfaces.

R-value

The ability of a material to resist heat transfer is measured in R value. The higher the resistance to heat transfer, the less heat transfer through the material. The R value of most common construction materials is included in Appendix 1. R value is the reciprocal of the U Factor or conductance (R-1/u or U='/R .

Delta T

The difference in temperature between inside temperature and outside temperature is represented by Delta T (ΔT). Delta T is an engineering term using the Greek letter delta (Δ), which means "a change in."

Heating Degree Days

Heating degree days is a measure of the need for heating based on the cumulative days below 65 degrees and the daily temperature. The lower the daily average temperature, the more heating degree days. Barrow, Alaska, has the most heating degree days in the United States (about 21,000). Miami, Florida, has no heating degree days.

Insulating materials only retard heat flow, they do not stop heat flow entirely.

The difference between inside and outside temperature is called Delta-T (ΔT).

The greater the Δ-T, the faster the heat is lost.

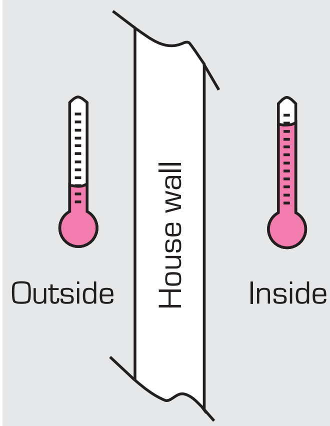


Figure 2.7: Delta T (ΔT)

Energy Modeling by Computer

Although it is possible to calculate the rate of heat loss and total heat loss of a house by hand, computer programs to do these calculations are an indispensable aid in designing efficient houses. Computers allow you to compare various energy strategies quickly and then decide what is the best use of the money to resist heat loss. We must decide, for example, the relative value of better windows, more insulation, or a higher efficiency boiler, and a computer analysis is the only practical and timely way to examine these and other options. This computer examination will help to ensure that the components of the house are in balance with each other: that the house will work as a system.

AkWarm Energy Use Software

AkWarm is Alaska Housing Finance Corporation's new computerized home energy audit tool. It was developed to help energy raters, weatherization assessors, builders, designers, and homeowners evaluate the energy performance of homes. AkWarm was designed in Alaska specifically for Alaska's residential housing needs.

AkWarm will allow you to:

- Create, modify, and save a house data file.
- Analyze energy use.
- Show compliance with the Alaska Building Energy Efficiency Standard for new construction.
- Generate a Home Energy Rating that is accepted by all the major lending institutions (Fannie Mae, Freddy Mac, VA, FHA, AHFC) for use in obtaining energy efficient mortgages, and by AHFC for obtaining an energy-efficiency interest rate reduction.
- Compute the savings of individual energy conservation measures.
  - Produce reports on home energy use and improvement recommendations.

Controlling Heat Loss

The primary method of controlling heat loss is by restricting heat flow, i.e., conduction, convection, and radiation. To restrict heat flow, the designer and builder need to consider proper installation of the optimal amount of insulating materials.

Insulating materials only retard heat flow; they do not stop heat flow entirely. Insulation restricts heat flow by trapping air or gasses. It is the trapped, still air or gasses that perform the insulating role, not the glass fibers or other fibrous materials, which will conduct heat. Insulation performs best when it traps air in small spaces that minimize conduction, convection, and radiant heat transfer.

There are six primary factors that affect the overall R-value:

1. Thermal bridging is a "short circuit" route for conductive heat transfer. Heat is conducted through a "bridge" to a colder area. For example, a wall stud can form a bridge between the warm interior finish and the cold exterior finish. Wall studs, which have a lower R value than insulation, occupy a portion of a wall system. Although 89 percent of the wall section is R 23.76,

conductive transfer of heat across the studs causes the overall average R value of the two by six stud wall to be R 19.90.

2. Insulation voids are areas without insulation because of improper installation. The effect of insulation voids varies with the level of insulation installed. If three percent of an R 21 wall consists of insulation voids, the average R value is degraded to less than 16. Gaps, folds, or unfilled corners can also permit convective loops within the cavity, causing heat to bypass the insulation. Heat is conducted from the interior of the house into the wall cavity. Warm light air in gaps or voids in the wall rises upward, where the heat is lost through the building envelope. The cool heavy air drops back to the bottom of the void, picks up more heat, and the convective loop repeats. Many batt types of insulation can have insulation voids if they are not properly installed (Figure 2.8).

   There are some manufactured high-density fiberglass insulations that have a higher R value per inch than standard density insulations. Although these are more expensive, they might be a good investment in some instances. A computer analysis will help the builder to examine the cost effectiveness of these products. To reduce the likelihood of leaving voids, insulation should be carefully cut and fit.
3. Air intrusion results from air penetration of insulation. Insulation must trap still air or gasses to work effectively. Air allowed to pass through insulation severely reduces its performance. Even air that penetrates from only one side affects insulation performance. For example, in some attics air is allowed to pass over and penetrate the upper surface of the insulation, capture heat, and transfer the heat to the outside environment (Figure 2.9). Performance of some types of insulation, such as fiberglass, is affected to a great degree by air intrusion while others, such as rigid insulation, show little or no decrease in performance. Air intrusion can also affect the performance of wall insulation, especially in windy locations.
4. Compression also affects R-value. Insulating products are designed for an optimal density to achieve maximum R value. Compressing an R 19 batt into a two by four stud cavity will only result in an R value of 13 to 14.
5. Moisture reduces insulation value as it accumulates in insulating materials. Moisture susceptibility varies greatly between types of insulating materials. Fiberglass and cellulose insulations can be reduced to essentially no insulating value when saturated with moisture. Some rigid insulation material is not severely affected by moisture.
6. Temperature also affects overall R-value of insulating materials. Most insulating materials have a slightly higher R value at lower temperatures.

Now that we've examined the three mechanisms of heat flow and the main reasons for heat flow from our houses, let's summarize. To reduce the rate of heat loss from houses, the designer and builder must:

Reduce conductive losses by:

- correctly installing insulation appropriate to the climate,
- minimizing or eliminating thermal bridges by reducing excessive framing materials,
- avoiding compressing insulation and thereby reducing its overall R value,

- preventing moisture from reaching the insulation from the inside or outside the house, and
- using windows with advanced edge spacers that reduce thermal bridges.

Reduce convective losses by:

- installing the insulation in a way that prevents voids,
- preventing moving air from enter ing the insulation from the outside intrusion ,
- sealing the house to avoid holes through which air infiltrates and ex filtrates, and
- using windows with a dense gas filling (for example argon) that sup presses convection between the panes

Reduce radiant heat losses by:

- using windows with low emissiv ity "low U" coatings that retard the transmission of short wave radiation.

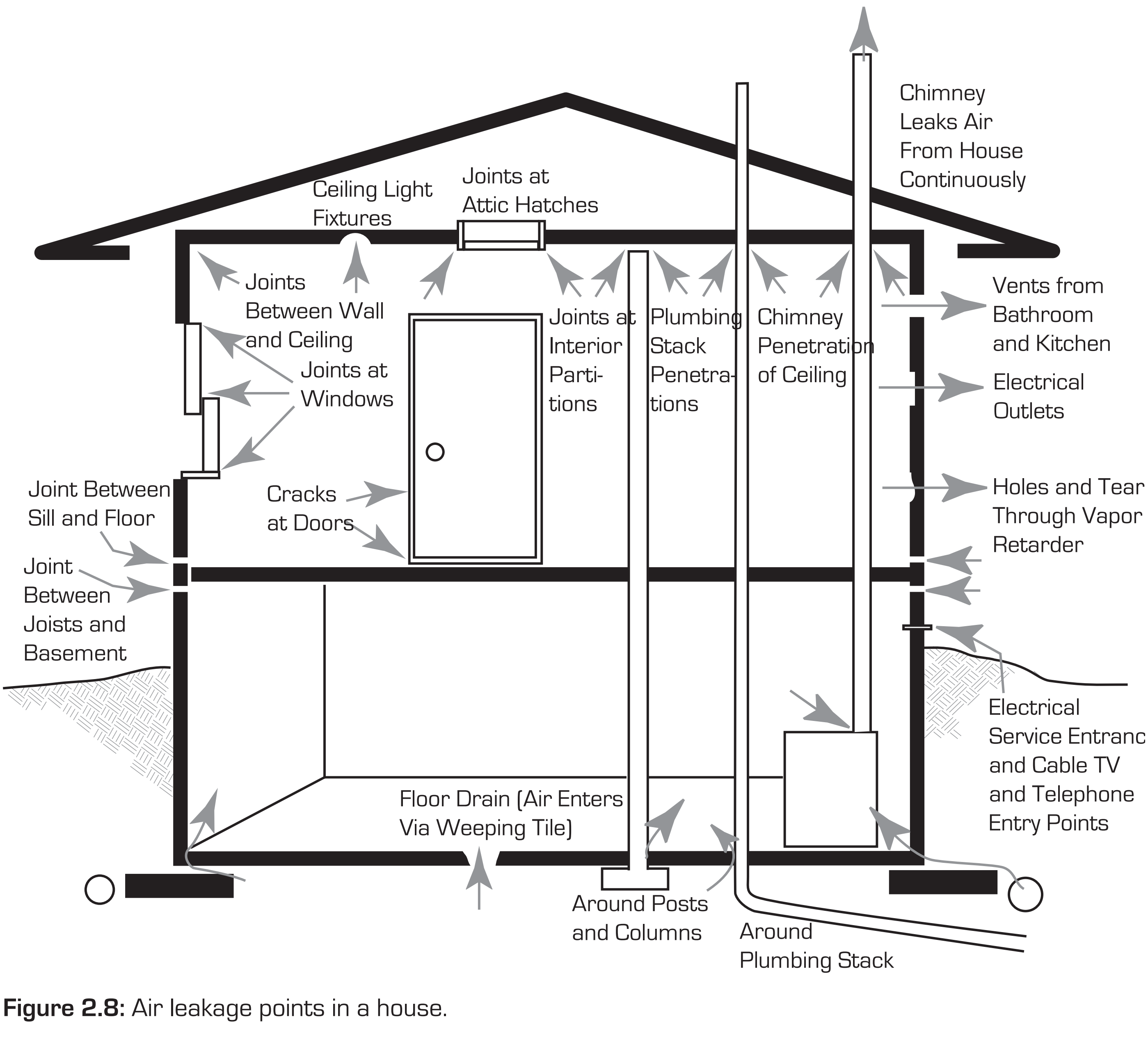


Figure 2.8: Air leakage points in a house.

Air Flow

In our discussion of convection, we briefly examined air flowing in and out of houses. This air leakage is uncon trolled and has no benefit to us. Air movement causes heat loss, makes the occupants uncomfortable, lowers in door humidity to uncomfortable levels, introduces soil gasses and other con taminants to the house, forces damaging moisture into insulation and structural elements, and causes cosmetic damage inside and outside the house.

In some homes, the total air volume of the house, along with heat and mois ture, can leak out two or three times each hour. It is not possible to build a comfortable, durable, and efficient house without understanding this air flow more completely and employing field-proven construction techniques to stop it. Many of the most significant failures in houses are a direct conse quence of unintentional air flow. Fortu nately, basic building science is the basis for strategies and techniques that can virtually eliminate these problems.

The solution is simple: no holes. There are two requirements for air to be able to leak from a house: first, holes, and second, pressure differences from one side of these holes to the other, which causes air to flow through them. We cre ate air pressure differences between the top of the building warmer air press ing to escape causes a higher pressure and the bottom of the building air is cooler, but being heated, so the pressure is lower). Other pressure differences are the result of natural phenomena, like the wind, and are also beyond our ability to control. But we can fill the holes. We do this by design and construction, using air and vapor retarders.

Houses generally have two kinds of holes through which air can flow. Holes that result from framing typically are found at bottom and top plates, around windows and doors, etc. Holes also result from the penetrations that we intentionally make electrical wires, outlets and light fixtures, water lines and vent stacks, exhausts for dryers and ranges, etc. but do not intentionally seal. All potential flow paths in and out of houses must be sealed and blocked. If they are not, three major pressure dif ferences will cause serious problems:

- wind effect
- stack effect
- flue and vent effect

Wind speed and direction can cause large pressure differences across the building envelope. A positive pressure on the windward side of the house drives air in through cracks and holes. At the same time a negative pres sure is created on the leeward side of the house, drawing air out through cracks and holes (Figure 2.9).

The **stack effect** demonstrates how air flow is influenced by temperature. Warm air is more buoyant than colder dense air. When the temperature inside the building is higher than the outside, a positive pressure is created inside the building envelope along the ceiling and upper area of the exterior walls and a negative pressure is created along the floor and lower area of the exterior walls. The negative pressure in the lower portion of the building envelope causes colder air to infiltrate through cracks and holes along the floor and lower por tion of the exterior walls. The positive pressure caused by the temperature dif ferences pushes air upward and the air exfiltrates out through the cracks and holes in the ceiling and upper portion of the building envelope. The greater the temperature difference between the inside and the outside, the larger the potential for pressure differences to be created by the stack effect. Preventing holes limits this kind of heat loss.

The **flue and vent effect** contributes to pressure differences when equipment such as wood stoves or bathroom fans are operating inside the home and forcing combustion products and stale air out of the house through vents and flues. While the equipment is operating, air is exhausted out through the chimneys and flues, causing negative pressure in the house. Outdoor air is drawn in to replace the air being exhausted.

An area of neutral pressure separates the regions of the house where air pressure is neither positive nor negative compared to outside pressure. This concept is typically referred to as the neutral pressure plane. This is an imaginary line separating the positive and negative pressure areas. The plane may be horizontal or diagonal, and its location varies constantly depending on the wind effect, stack effect, or flue and vent effect.

Negative pressure on one side of the plane draws air into the building envelope through any cracks or holes, while the positive pressure on the other side of the plane pushes air out of the building envelope through any cracks or holes. There is no infiltration or exfiltration through cracks or holes at the level of the neutral pressure plane itself, because there is no pressure difference there.

Measuring Air Leakage

A common device for determining air leakage is called a blower door. It consists of a calibrated fan, an adjustable door frame, and metering equipment. It is placed in the door opening of the house. The fan blows air out of the house to depressurize the building envelope, causing air to enter the house through the cracks and holes in the building envelope to equalize the pressure. We measure the amount of air that must be removed to maintain a constant house pressure difference, to calculate the air changes per hour and the total equivalent leakage area of the building envelope. One air change per hour means that all the air volume in the house totally leaks out and is replaced by incoming air in one hour. Equivalent leakage area is the total area of all cracks and holes in the building envelope added together and expressed as the size of an equivalent single hole in the building envelope.

Pressure difference is measured in Pascals. House air leakage tests are typically conducted by maintaining a constant pressure difference of 50 Pascals. Fifty Pascals is equivalent to the amount of pressure exerted by 0.2 column inches of water at 55 degrees F or a 20 mile per hour wind on all six sides of the structure.

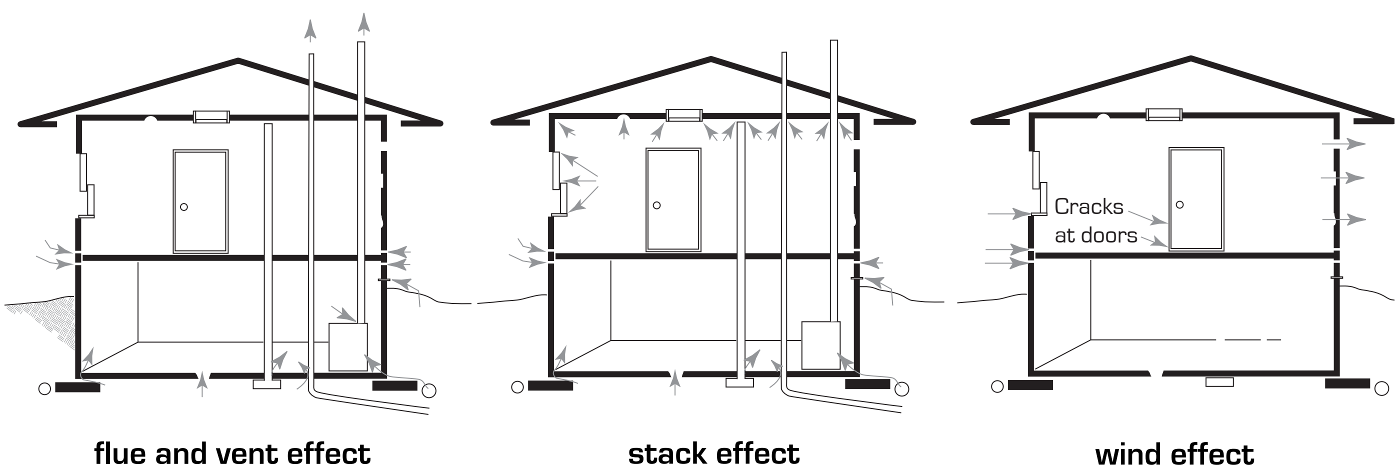


Figure 2.9: Three ways air is forced out of houses through leaks

Controlling Air Leakage

By understanding the mechanisms of air flow and how to calculate air leakage rates, the designer and builder can choose the most economical and effective materials and the best installation procedures to minimize wind effect, stack effect, and flue and vent effect.

Air leakage is reduced by installing a continuous air retarder. Air retarder materials are highly impermeable to air. They should be applied to the exterior of the envelope. The most important concept is that to be effective, an air retarder must be continuous and all seams or penetrations must be sealed with an appropriate caulk, sealant, or tape over solid backing. It is also important that it have the property of ample vapor permeability, so that if any water vapor does get into the wall or roof cavity, it can escape relatively easily, rather than be trapped in the building envelope.

Wind effect can be reduced by planting trees and shrubs near a building.

In many homes, a bypass, or intentional opening for electrical, mechanical, or plumbing, runs from the crawl space to the attic. Although most building codes require bypasses to be sealed, they seldom are. Unsealed bypasses are a major avenue for the stack effect mechanism of air leakage.

The problems associated with flue and vent effect are minimized by using direct vent heating equipment and properly designed and installed ventilation systems. Direct vent heating equipment uses combustion air supplied from outside the building thermal envelope rather than air from inside the building envelope. Homes need to have intentional openings for controlled ventilation.

Figure 2.10 is a photo of a log home in Fairbanks, taken in February when the outdoor temperature was −40°F. The house in Figure 2.10 was built in 1973 and the joint above the gable wall of logs is "sealed" with fiberglass sill sealer, a good air filter but not a barrier to air leakage. We have better materials today that are ideal for sealing in just such locations: polyethylene foam sill sealer.

The resulting hoarfrost accumulation under the eave of the house on the gable end is a clear and visible indication of air leakage resulting from warm moist air streaming out the top of the building under rather extreme conditions. This process is going on most of every winter in every heating climate, but only when the temperature gets very cold is it actually so visible! Alaska makes building science easier to understand, because natural leakage like this, shown by the deposition of hoarfrost as the warm moisture laden air leaves the top of the house, is visible, whereas in most climates, although it happens in the same way, it is invisible, and therefore few really appreciate its magnitude or effect like we can in Alaska. We can feel air leakage into the house under door sills and around cracks, but we don't live at the top of the building so we rarely notice the air leakage out of the building at the top. We live on the floor. If air is leaking in low, such as under the door, it must also be leaking out somewhere near the ceiling. This photo shows the reality of that leakage and also demonstrates that sealing the air leakage at the top of the building is a crucial detail. A good air/vapor retarder at the ceiling allows better control of air leakage and indoor humidity, and also protects the roof insulation from moisture damage, which could occur if air leaked regularly into it.

Figure 2.10: This photo shows air leakage at the top of an older log home. Because the air temperature at the time of this photo was −40 degrees F, air leakage is made visible by the accumulating hoarfrost under the eave. The air leakage is normally invisible, and because it is occurring at the ceiling and eaves, is undetected by the occupants. This photo clearly shows that the air leaking out is not only substantial, but it takes moisture with it, which is deposited under the eaves as hoarfrost. Sealing at the roof–ceiling interface and at the gable ends of the roof are very important control measures to ensure this leakage is minimal. Controlling this leakage is not only helpful for good interior humidity but also saves energy by keeping heated air in the house.

Moisture Flow—Terms and Definitions

Water that has condensed on or in building elements is responsible for many common problems found in conventional housing, such as:

- condensation on windows;
- mold, mildew, rot, and resulting deterioration of window frames, structural framework, rafters, trusses, etc.;
- paint blistering and peeling; and
- staining of ceilings and walls along joists, studs, or nail and screw heads.

Water in its liquid form within the building envelope is the single most destructive force in housing. We must understand the sources of moisture and the mechanisms of water vapor flow and choose the most economical and effective materials and the best installation procedures to minimize water vapor flow and its related damages.

Mechanisms of Moisture Flow

The following definitions will help in understanding moisture flow:

Condensation

Condensation is the physical change of water from a vapor to a liquid. Condensation occurs when air temperature cools to the point that the air can no longer hold all its water vapor and liquid water forms.

Dew Point

Dew point is the temperature at which the air can no longer hold moisture. It is the temperature at which condensation will occur. There are charts available, called psychrometric charts, to help de termine dew point. Chapter 3 contains more information on how dew point is related to relative humidity.

What is a Dew Point?

The dew in "dew point" is just moisture condensed to form water droplets. The dew point is the temperature at which dew begins to form. Humidity and pressure can affect the dew point.

During cold weather, the walls of buildings get cold on the outside and warm on the inside. Then the dew point (temperature) for condensing moisture out of the air is often found somewhere inside the wall, and you will get water in your insulation and rot in your wall.

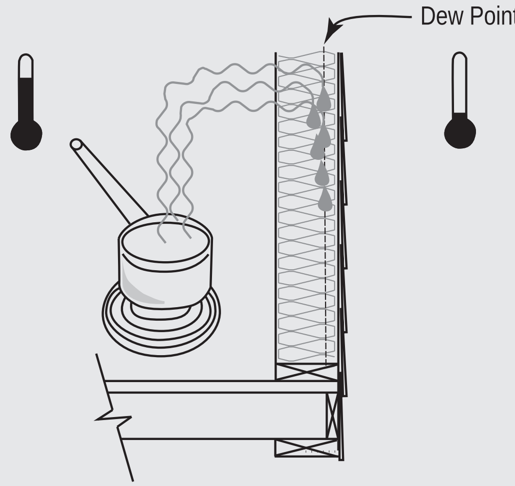


Figure 2.11: Dew point

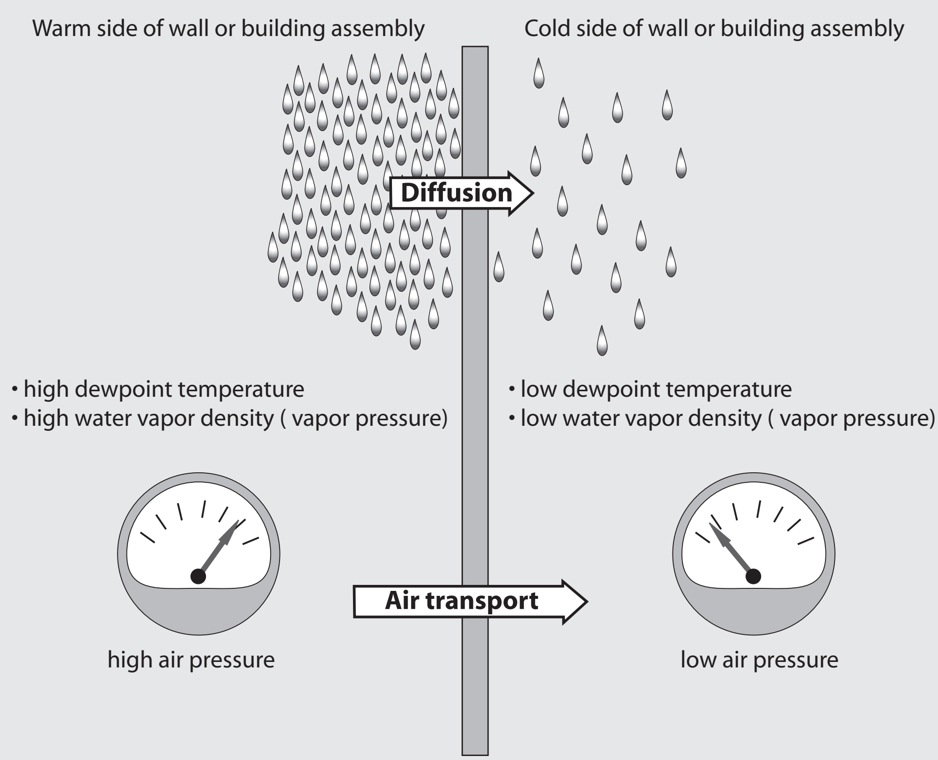


Figure 2.12: The relationship between pressure, diffusion, and air transport.

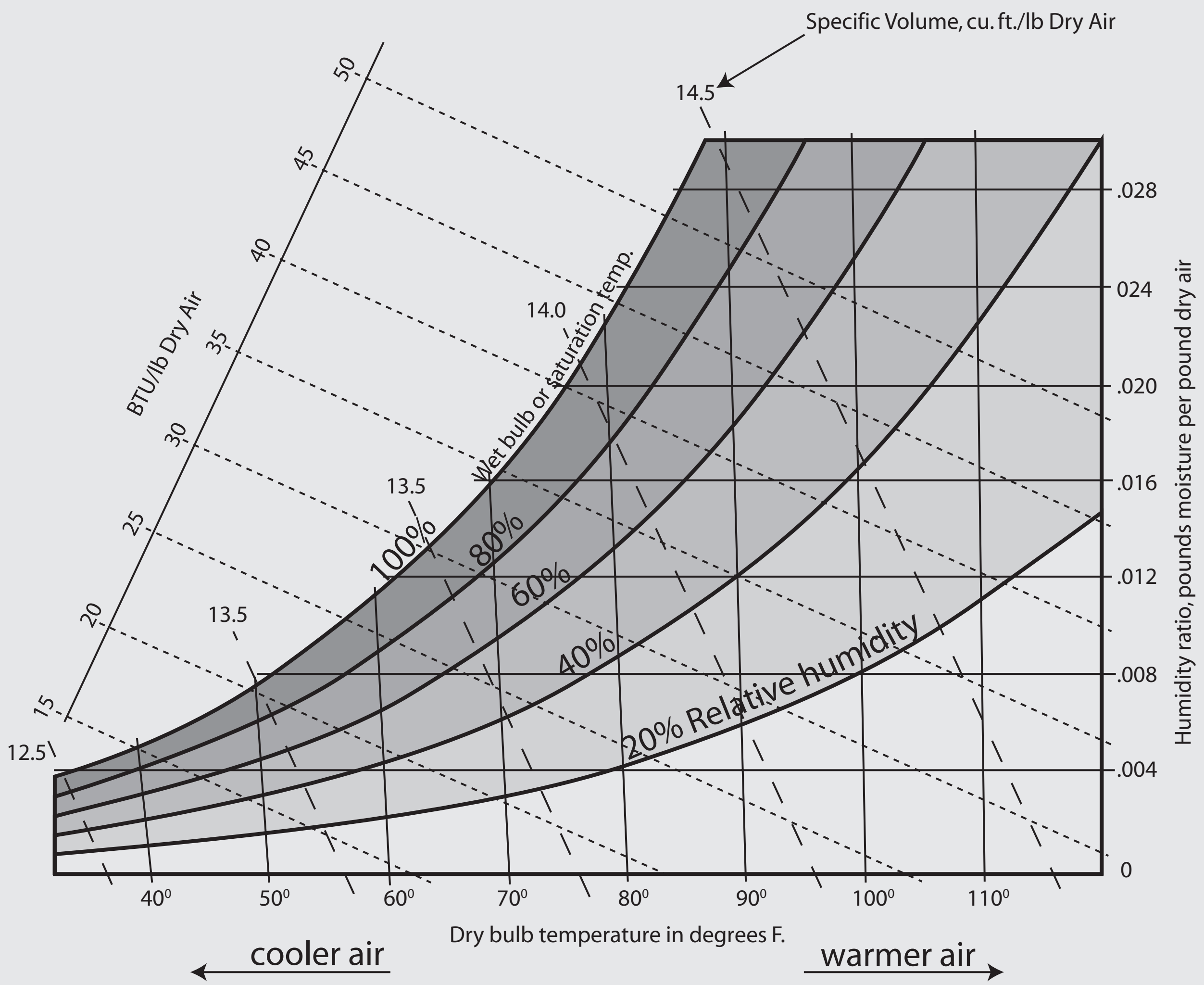


Figure 2.13: A psychrometric chart presents physical and thermal properties of moist air in a graphical form. This chart contains a lot of information packed into an odd-shaped graph. Note that cooler air (located along lower, left region of chart) will not hold as much moisture (as seen on the y-axis' humidity ratio) as warm air (located along right side of chart).

Relative Humidity

Relative humidity is a measure of the amount of water vapor that is held by air at a given temperature, expressed as a percentage of the maximum amount of water vapor the air can hold at that tem perature. Warm air can hold more water vapor than cold air (see Figure 2.13).

The way our houses dry out in the winter is by the exchange of exterior air for stale interior air. However, when that cold outside air is brought inside and heated, its relative humidity drops because the warm air is capable of holding more moisture. Typical relative hu midity of outdoor air in the winter at 0 degrees F is 75 to 90%, but heated to 70 degrees the relative humidity would be about 5 . Figure 2.14 shows the health affects of various relative humidities.

Research indicates that the optimal range of relative humidity for human health is between 40 and 60 percent. If relative humidity is too low, people may experience respiratory irritation. If rela tive humidity is too high, condensation occurs on cool surfaces, such as win dows and outside corners, where mold,

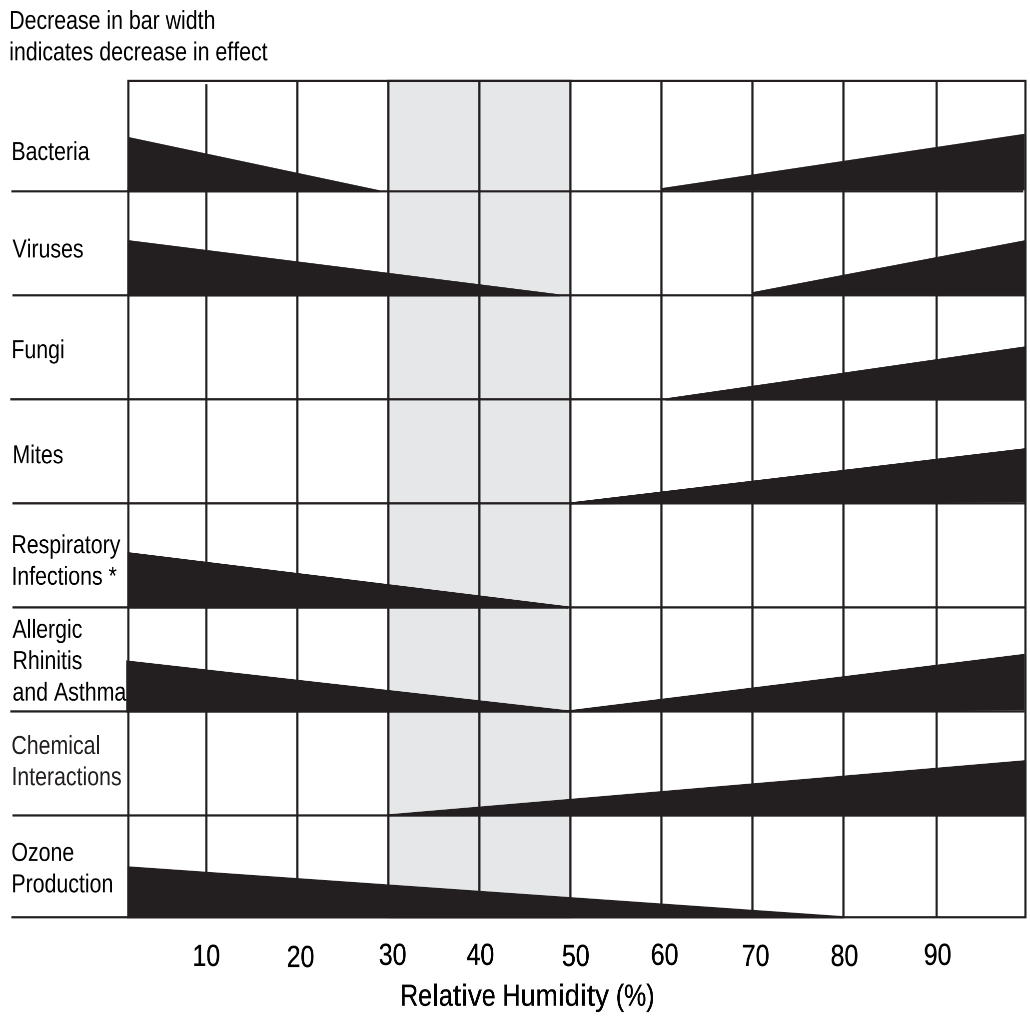


Figure 2.14: The effects of indoor humidity on health. Source: Sterling et al. 1985. Optimum zone moved 10% to left by the authors.

mildew, fungi, and bacterial growth are stimulated. In Alaska, we do not have the window technology to tolerate a relative humidity much above 50% during the coldest temperatures we see, so we must design in a lower anticipated relative humidity for Alaskan homes. This is more of a concern in the subarctic and arctic climate zones where lower winter minimum temperatures are more common.

Permeance

Permeance is a measure of the ability of a material to allow water vapor to diffuse through it. Some building materials retard or slow vapor diffusion better than others. A material with a high permeance rating allows water vapor to diffuse through it relatively freely. Permeance (or perm) ratings of most common building materials are listed in Appendix 2.

Moisture is generated during normal household activities through cooking, bathing, washing and drying clothes, and human respiration. A great deal of moisture can be given off by building materials such as wood and concrete, especially during the first year in a new house.

In an insulated wall there is typically a difference in temperature across the wall from the warmer indoor temperature to the cooler outside temperature. If water vapor enters the wall along with air leakage and the temperature decreases as the air moves toward the outside, cooler surface, ultimately the dew point is reached and condensation will occur. Building assemblies should be designed and constructed so that each layer used from the inside to the outside has a higher perm rating than the previous material. This will prevent any moisture that penetrates the wall from being trapped at any point inside the wall. This is sometimes called the flow-through principle. Whenever possible and practical, place materials with low permeance perm on the warm side of the dew point. For stick-framed walls, the flow-through principle requires that no layer on the cold side of the vapor retarder have a perm rating less than 1.0, so water vapor will not be trapped within the building materials.

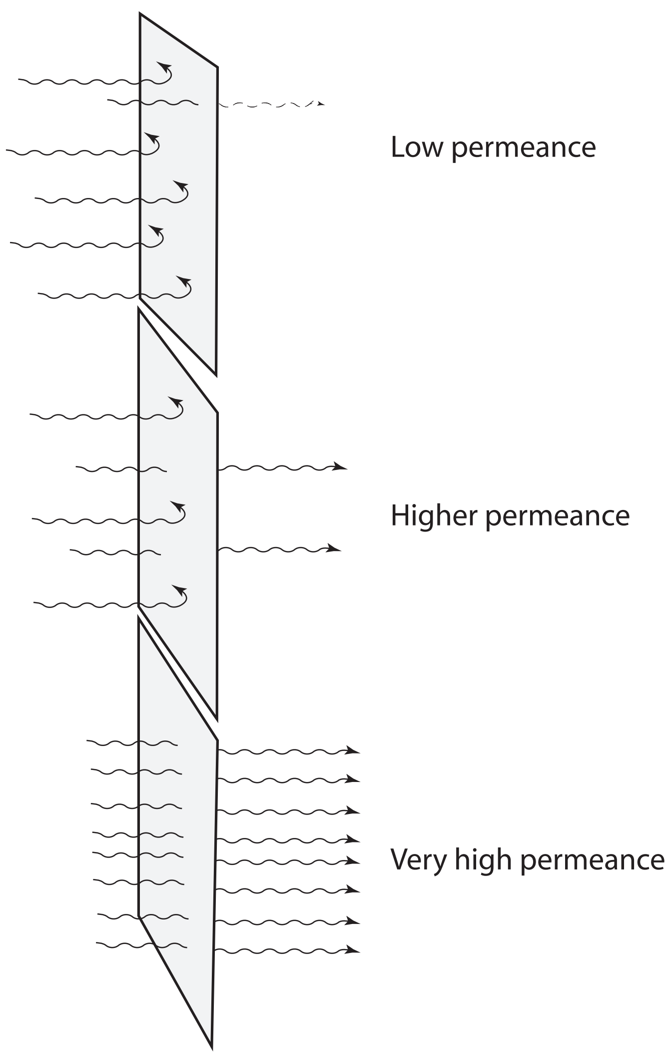


Figure 2.14: This cartoon suggests different levels of permeance. The moisture is represented by arrows.

Air Leakage

As air leaks into the house through cracks and holes in the building envelope and flows through the house via the wind, stack, and flue and vent effects, the air warms and accumulates moisture, then leaves the house through cracks and holes in the upper portion of the building envelope. Nearly all moisture removal from a conventional house occurs as a result of air leakage.

Vapor Diffusion

Vapor diffusion is the transport of water vapor through a solid material. Just as heat flows from a warm area to a cold area and air flows from a high (positive) pressure area to a low negative pressure area, water vapor flows from an area of high vapor pressure to an area of low pressure. The vapor pressure depends on the level of humidity and temperature. Water vapor can move independently of air flow, by diffusion, and can pass through some materials through which air cannot flow. Vapor diffusion is a minor mechanism for moisture flow. A comparison between the amount of moisture transferred by diffusion through a typical wall section during a heating season and the corresponding amount of moisture transferred by air leakage through a one inch square hole is shown in Figure 2.15.

Capillary Action

Capillary action is the ability of a liquid to rise by absorption. A wick placed in a kerosene lamp is a common example of how capillary action occurs and how the level of the liquid in the wick can rise higher than the level of the liquid in the lamp. No pressure differential is neces sary for capillary action to occur. Porous material, like concrete used in founda tions, is another example. Through capillary action, water in the ground will rise up through the foundation's absorbent material and be released into an area with a lower water vapor pres sure. Capillary action is the least obvi ous mechanism of moisture flow in a house, but can be a major contributor to moisture entering the building envelope through the foundation.

Gravity

Gravity causes water to flow downward. Surface runoff, ground water, and driv ing rain can enter the building envelope through cracks and holes. Gravity will also transport water resulting from condensation or melting ice into the structure or down along the foundation. All drainage of water should be directed away from the house and its foundation.

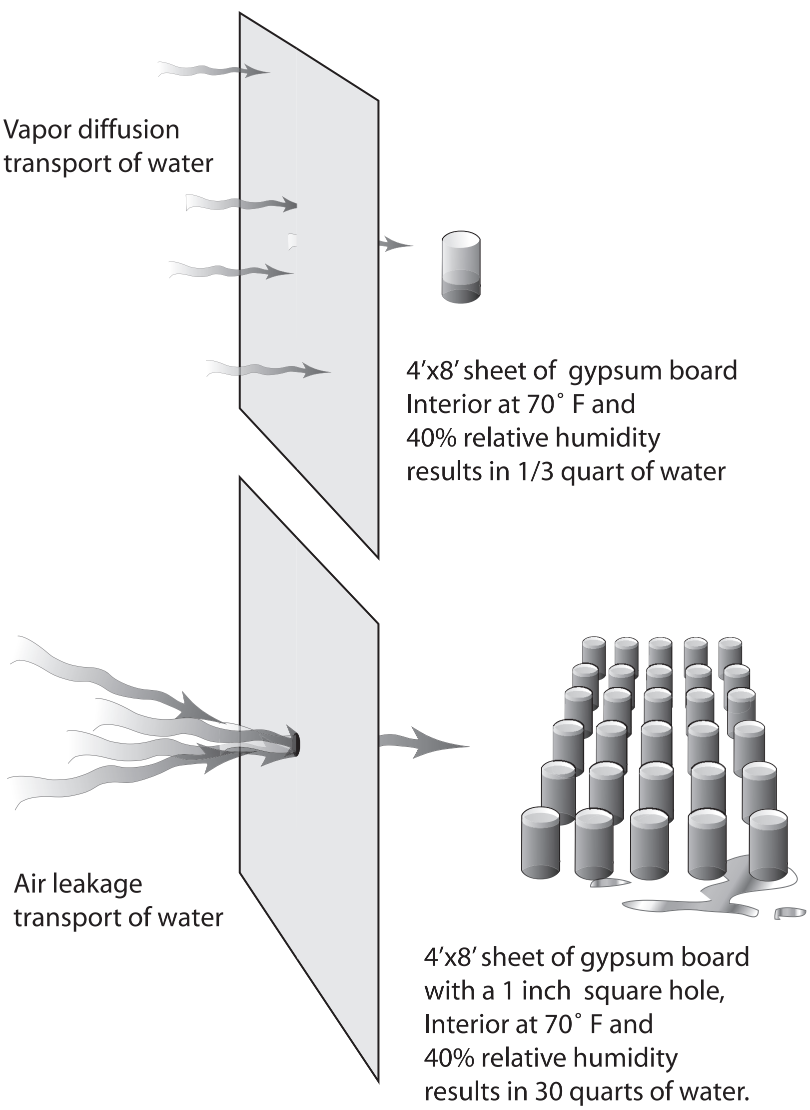


Figure 2.15: Air Leakage is the primary moisture transport mechanism (Building Science Concept #7)

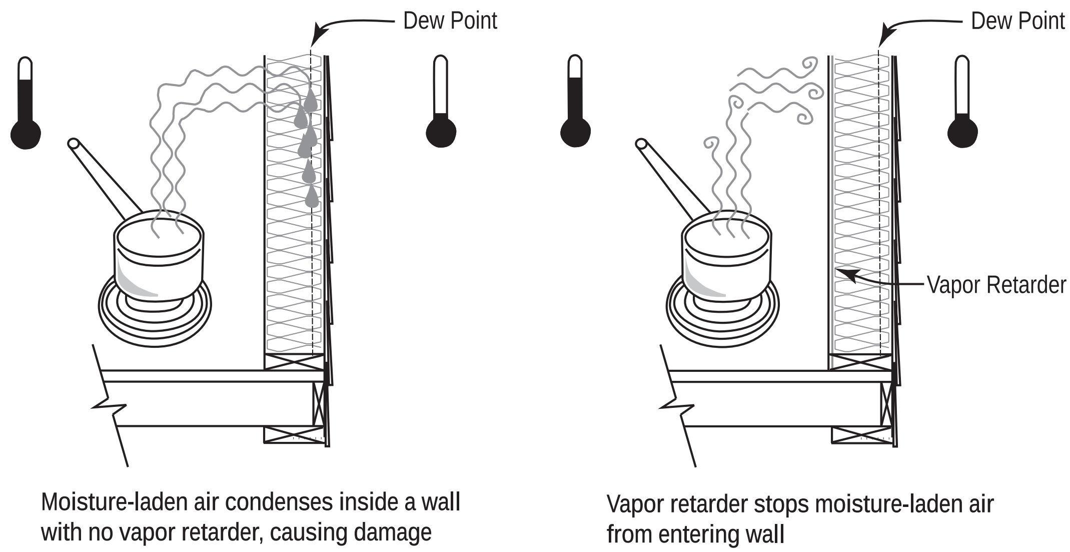


Figure 2.16: Dew point and vapor retarder (Building Science Concept #9)

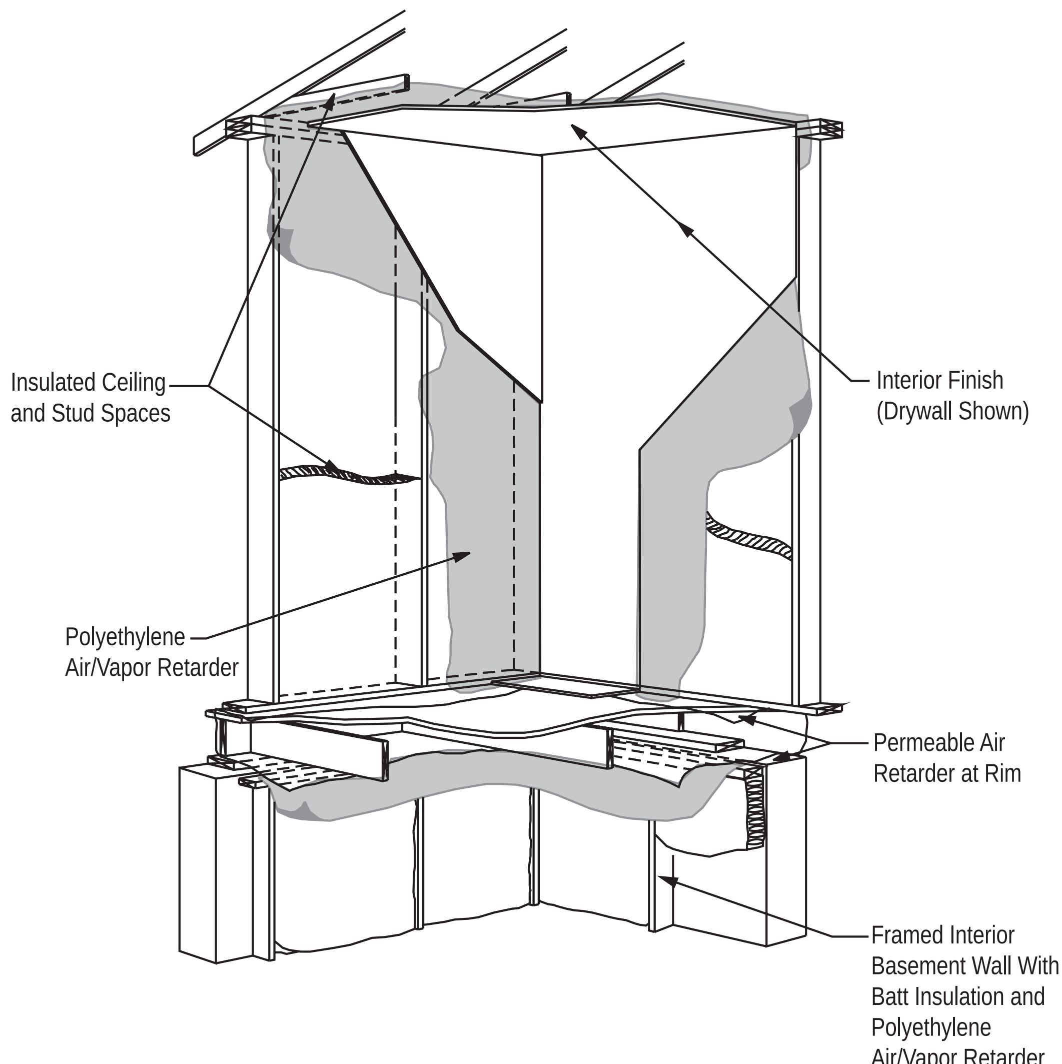


Figure 2.17: Placement of vapor retarder.

Controlling Water Vapor and Condensation

Vapor must be prevented from reaching the dew point temperature in the wall. To control the movement of vapor throughout the building envelope, two distinct functions are required: an air retarder and a vapor retarder.

Moisture movement also occurs through the air where there are gaps in materials. If there is no associated air leakage, the amount of moisture transferred to the wall cavity is usually very small. If there are gaps in the warm side air or vapor retarder, convection can also carry moisture and deposit it on the cold side of the envelope.

An air retarder is necessary to prevent moisture being transported by air leaking into the wall cavity. The air leakage is enhanced by wind and stack effect. The air retarder must be continuous, without holes or cracks. In most instances an air retarder is an external element of the wall section, usually applied at or directly under the exterior siding.

When an air retarder wind retarder is placed under the exterior finish, it should have a high permeance to water vapor and a low air porosity, which means it is a block to air leakage. It should be tear resistant. Some types of hardboard siding can buckle when damp, which makes the interior of the wall vulnerable to air leaks and wind driven rain. Air and water leaking into the wall cavity will increase energy requirements by wetting the insulation and increasing its thermal conduction. Wet insulation can settle, which may leave air gaps at the top of the wall, further increasing energy requirements.

The specifications of plastic air-retarder materials vapor permeance, thickness, weight, available size, tensile strength, tear resistance, and air porosity are listed in Appendix 1.

A vapor barrier retarder is used to reduce diffusion of water vapor across the building envelope. Few materials stop diffusion completely; they only slow the rate. Thus the term vapor retarder, rather than barrier, is more accurate. The water vapor that does get past the interior vapor retarder should be allowed to pass through the exterior surface of the assembly to the outside. The vapor retarder must be installed on the warm side of the dew point to reduce the transport of water vapor through the building envelope and minimize moisture condensing in the walls or roof cavity.

In short, it should be difficult for moisture to get into the building envelope. If it does, it should be easy for it to escape to the outside. This escape could be by diffusion through holes such as unsealed seams in siding or sheathing. However, removal of water from the wall by air circulation is not recommended because it could drastically reduce the effectiveness of the insulation.

The air vapor retarder should be at or near the inside surface, which is the warm side of the dew point, so that most of the water vapor within the house will never get inside the wall and so will never reach the dew point. This method of vapor retarder installation corresponds to the traditional method in which a polyethylene sheet is positioned just under the interior finish.

Research has demonstrated that the air vapor retarder can be positioned within the building envelope, as long as roughly two thirds of the R value of the insulation is outside this retarder, leaving the remaining one third inside. This has permitted some novel approaches to construction.

This one third/two thirds rule for placing the vapor retarder is suitable for moist temperate climatic regions of America and coastal Alaska. How ever, in extremely cold climates, above 12,000 heating degree days, the vapor retarder should be recessed no more than one quarter of the way in from the warm side of the building assembly. In climates above 14,000 heating degree days (see map Figure 2.17), the rule is that only one-fifth of the insulating value should be on the warm side of the vapor retarder. These rules of thumb for vapor retarder placement allow some flexibility in construction and air-vapor retarder placement.

The builder or designer must keep in mind the separate functions and re quirements of the air retarder and the vapor retarder. While in the past most energy-efficient houses have combined these functions into one air vapor retarder, it must be realized that this element is performing two functions. There are times when it is convenient to separate those functions (Figure 2.18).

There have been investigations into alternative treatments of air retarders and vapor retarders that may simplify construction techniques and provide a more durable replacement for poly ethylene.

One successful approach is to use foil backed foam insulation on the in terior walls and seal the joints between the sheets of foam with vapor barrier tape. Wiring can be run between fur ring strips that are fastened through the foam to the studs.

Another technique takes advantage of the resistance to air flow provided by drywall. Continuity of the air retarder is provided using gaskets and sealants between different components of the building envelope, as with wall plates or headers. In such a system, a separate vapor retarder must be provided. This system is called the airtight drywall ap proach. Because there isn't enough test data in areas of high seismic activity and magnitude, we do not endorse its use.

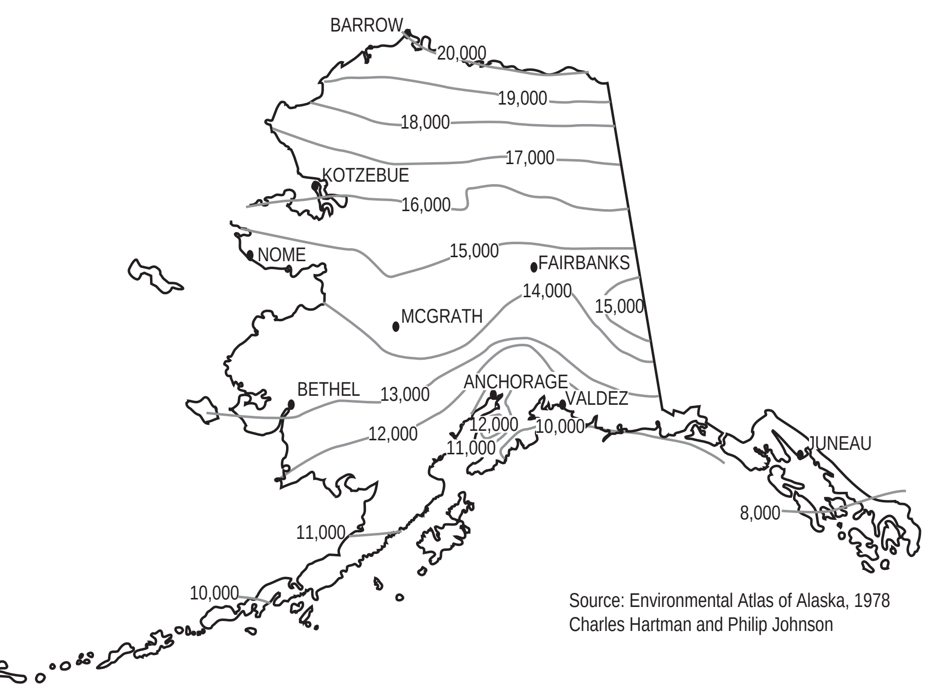


Figure 2.17: Heating degree days in Alaska (map from somewhere

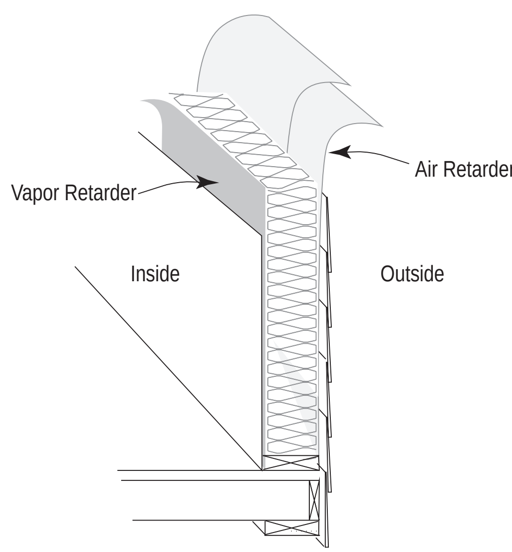


Figure 2.18: The difference in placement of an air retarder (on the outside) and a vapor retarder (two-thirds/one-third rule)

Controlling Liquid Water

An often neglected function of the building envelope is that of controlling the movement of liquid water not to be confused with water vapor . Liquid water, such as driving rain, must be prevented from entering the build ing envelope. This is usually done with the exterior siding or roofing material. The important point to remember is that this barrier, while preventing the passage of water from outside into the envelope, should permit vapor to pass from the envelope to the exterior. It must also restrict liquid water and air penetration.

Flashing is used in the conventional manner to direct water to the outside if it has penetrated the siding or roof ing. In regions with a low drying index wet, humid climates such as southeast Alaska , consider isolating the exterior siding from the wall cavity and sheath ing. Ventilating the wall can reduce the potential for moisture that has been absorbed by the siding from moving into the wall assembly. Most typically this would involve the use of furring between the air retarder and the siding, allowing a drainage cavity and an air cavity that can dry the back side of the siding see Figure 2.19).

An air retarder should also stop convection currents and cold air from blowing through the insulation, which restricts the performance of the insula tion. It is becoming common practice to install an outer air retarder consisting of a permeable air retarder material that is taped or caulked at the seams, especially in wind dominated climates.

When an air retarder is used on the exterior of the building, its purpose is to stop air intrusion. It must also be highly permeable to water vapor so that it does not trap water vapor in the wall. The standard six mil polyethylene vapor retarder material that is now recom

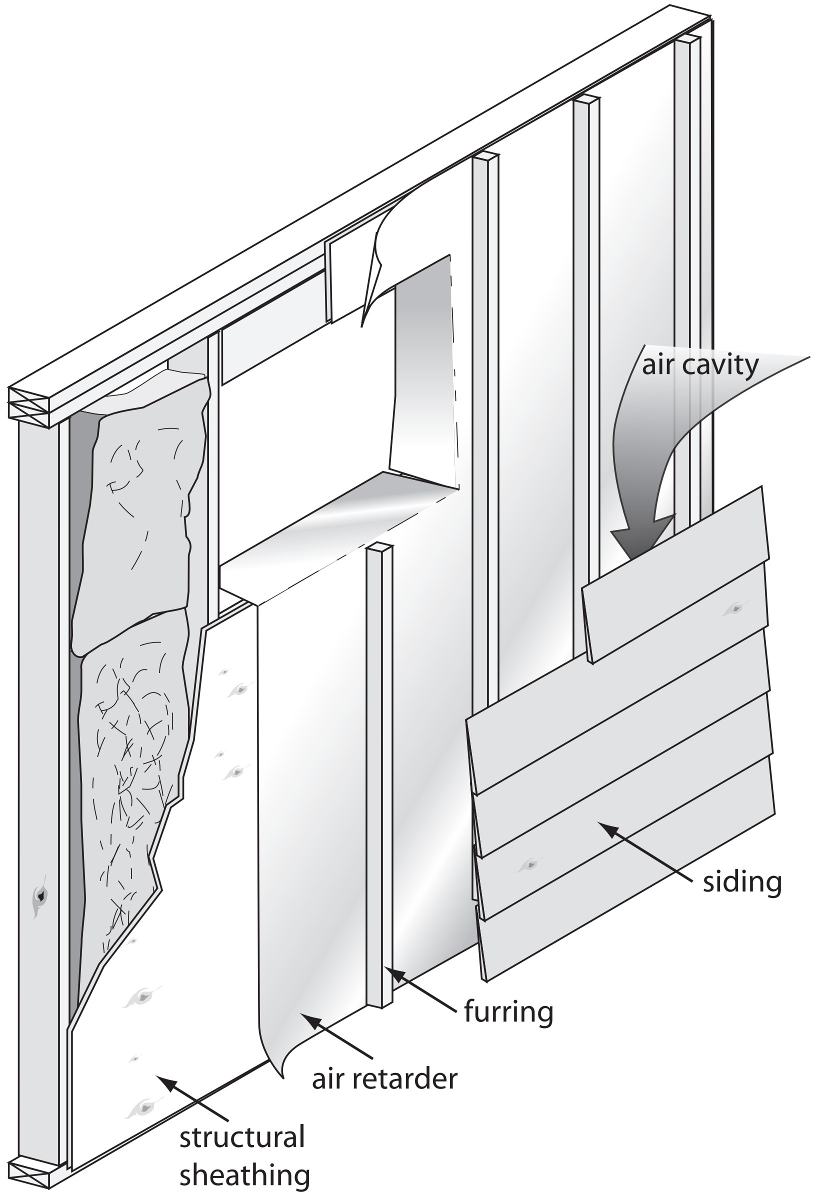


Figure 2.19: A wall with a drainage cavity to allow water to escape in rainy climates

mended practice, installed on the warm side of the insulation the high vapor pressure side , constitutes both an air and vapor retarder. In cold climates, water vapor control is more crucial be cause vapor movement into wall cavities can quickly cause damage and diminish insulation value when framing members and insulation get wet. For this reason, the vapor transfer control function of the air vapor retarder on the warm side becomes a focus of attention.

The vapor or retarder is inherently an air retarder too, but it is not always perceived that way, and thus the confu sion. It is easy to get into the habit of calling the warm side air vapor retarder simply a vapor barrier. Air retarder products are specifically named air bar riers and are designed for exterior cold side use on walls, making the separate function implicit in the separate loca tion of the air retarder from the interior vapor retarder. Air retarder products are also not adequate for, nor intended for, use as a vapor retarder.

Capillary Action and Gravity

Controlling air leakage and vapor dif fusion reduces the potential for exfil tration of vapor through the building envelope. In addition, controlling the capillary action and gravity mechanisms of moisture flow prevents infiltration of water into the building envelope. We can prevent capillary action by using a nonabsorbent material and prevention techniques. Moisture flow by gravity is reduced primarily by designing and con structing roofs, walls, and foundations to shed water. This is done by installing proper flashing, rain gutters, and footing drains and by properly sloping the finish grade away from the building.

Understanding how air leakage, vapor diffusion, capillary action, and gravity can transport moisture from inside or outside the home into the building thermal envelope and how to control the mechanisms of moisture flow allows the designer and builder to choose the most cost effective methods and materials to improve the comfort, durability, and performance of the house as a system.

Vapor Retarder Design: What, Why, Where

What is a Vapor Retarder?

Commonly called vapor barriers, vapor retarders are most simply described as a film or sheet of material to prevent or retard moist air from moving into the wall of a building. They also help to stop warm air from moving through a wall (see Figure 2.20).

Why Do We Need Vapor Retarders in Buildings?

If we prevent moist air from getting inside of a building's walls and roof, we can avoid damage to the building from rot and decay. Also, mold growing in walls and poorly vented cavities can be a serious heath problem.

Where Do We Put Vapor Retarders?

A vapor retarder is built into a wall to form a balloon or envelope to keep warm moist air inside. This vapor retarder is hidden inside the wall in a finished build ing. A vapor retarder must be placed with careful design and craftsmanship, because a poor vapor retarder can some times cause as much or more damage as none at all. Different climates require different placement of vapor retarders.

The TwoThirds/One Third Rule for Vapor Retarders

To prevent moisture from reaching the dew point inside the wall, no more than one third of the total R-value of the wall should be on the warm side of the vapor retarder in areas of the country with less than 12,000 heating degree days (Figure 2.21).

In areas with heating degree days of 12,000 to 14,000, no more than one quarter of the insulation should be on

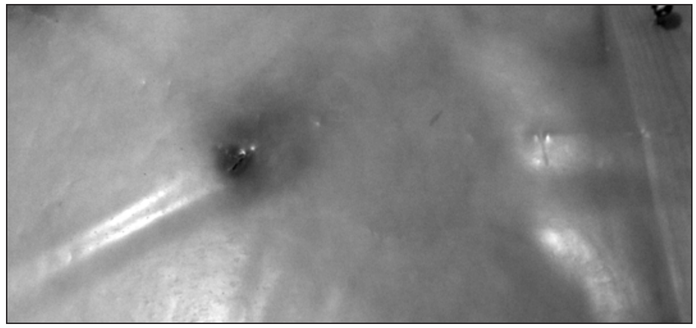
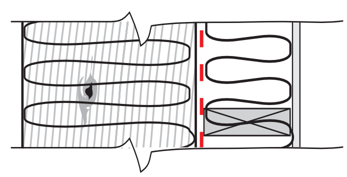


Figure 2.20: This small hole in the vapor barrier was made during construction: there was no hole in the drywall. The dark stain around the hole shows airborne contaminants trapped in the insulation like an air filter. This shows that over time a lot of air is passed through even this small hole.

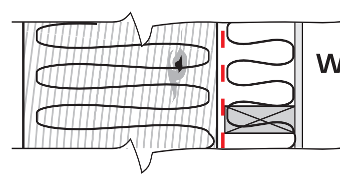


2/3 of total R-value

less than 12,000 heating degree days.

Cold side

(outdoors)

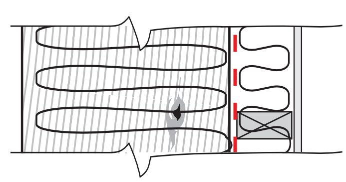


Warm side

(indoors)

3/4 of total R-value

12,000 to 14,000 heating degree days



4/5 of total R-value

over 14,000 heating degree days

Figure 2.21: The two-thirds/one third rule: three different wall designs showing placement of vapor retarder (dashed line).

the warm side of the vapor retarder, and in climates of over 14,000 heating degree days, no more than a quarter (one-fifth is recommended of the insulation should be on the warm side of the vapor re tarder. Following this rule prevents water vapor from getting too cold and con densing before it is stopped by the vapor retarder. (For the heating degree days in your location, see map on page 46 .

All construction should comply with local building codes and the Uniform Building Code, the Uniform Mechanical Code, the Uniform Plumbing Code, the Americans With Disabilities Act, and the National Electrical Code as well as the energy efficiency standards set forth here. All mechanical components, includ ing doors and windows, should have the manufacturer's name, the model, and a customer service phone number clearly marked on a visible surface. This identifi cation will help if repairs are necessary.

Summary

This chapter has presented building sci ence basics that explain heat, air, and moisture flow and the principles that control them.

What is R-value?

R-value: The ability of a material to resist heat transfer is measured in R-value.

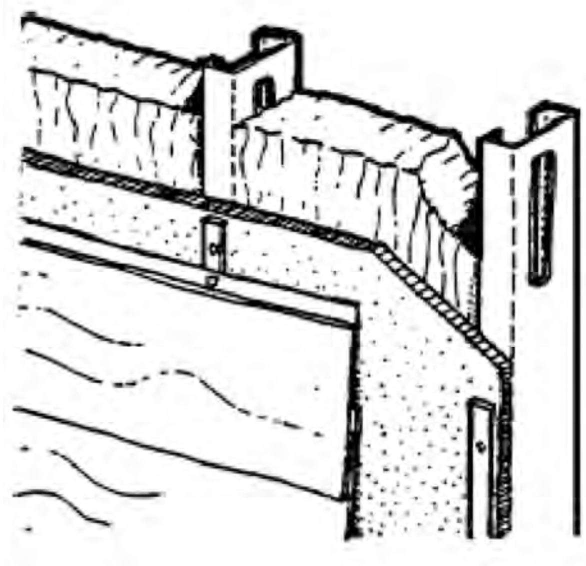
What is a dew point?

A dew point is the temperature at which water condenses and dew begins to form.

What is a heating degree day?

Heating degree day is a measure of the need for heating based on the number of days the outside temperature is lower than 65 degrees F.

Steel Framing



Every time the price of lumber goes up, we start looking at alternative building materials. Even though wood is still the most flexible material for small structures, there is lots of interest in alternatives, partly due to the recognition that wise resource management is important. The pressures on timber supply mean that prices will stay high—we've just not managed our forest resources efficiently.

A material many builders are looking at steel framing. The framing methods parallel wood construction, but the materials and tools used are different.

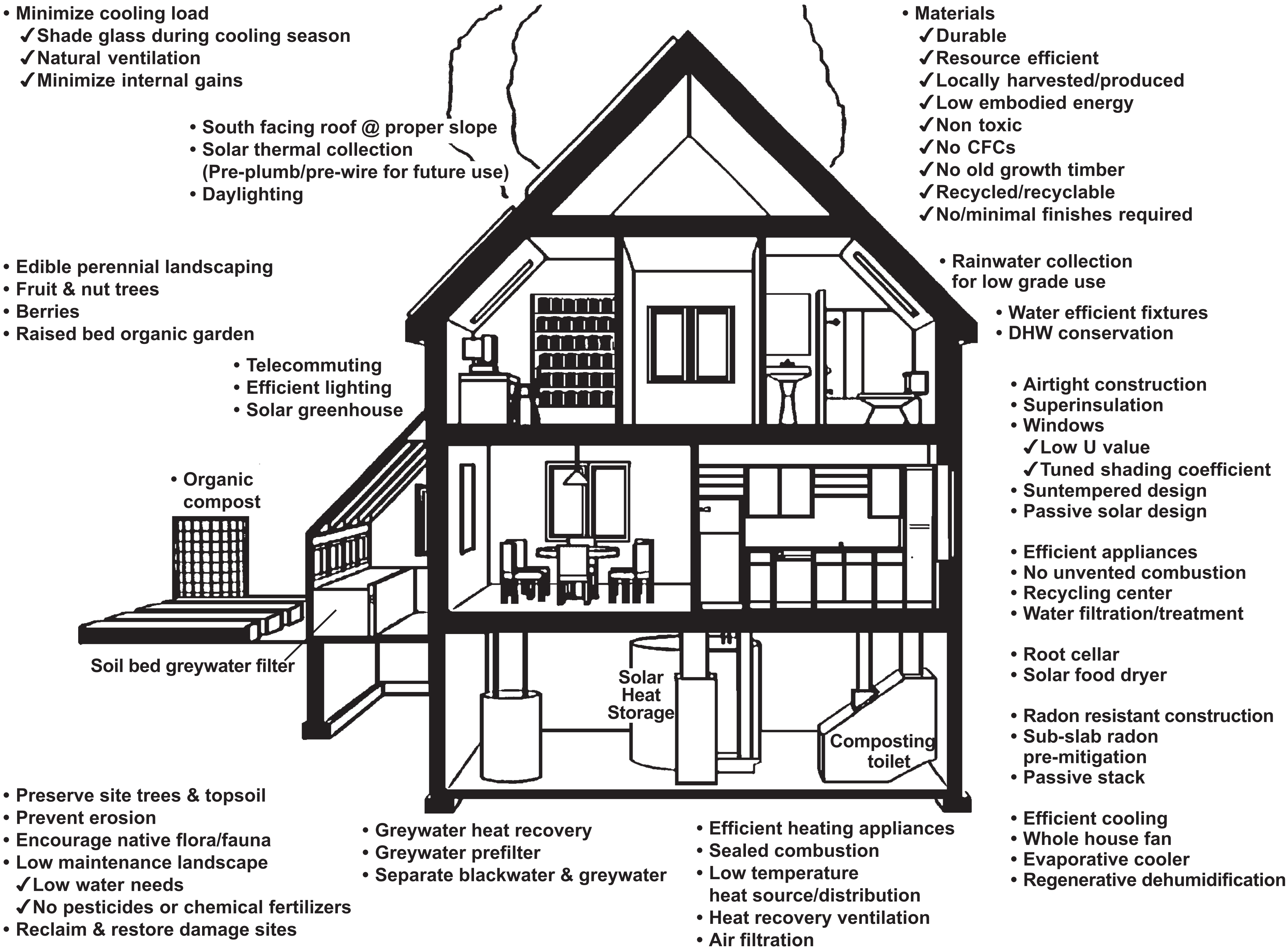
We've noted that distributors of steel framing systems are not telling the whole story. As a result there could be serious moisture problems under some situations and severe energy penalties in most situations. Conventional wood framing uses studs, with insulation placed between tile studs. While the wood studs have a lower R-value than the insulation (wood has an R-value of about 1.25 per inch thickness) the overall average R-value is still quite respectable.

In the case of steel studs it's the opposite as metal is a thermal bridge - there just is no insulation value to the steel because of the high thermal conductivity of the studs. How much of a thermal bridge was measured at recent tests at the National Research Council of Canada. A 2x4 steel stud wall section, with conventional stucco on the exterior and R-12 batt insulation was measured to have an overall R-value of 6.8, not the 13.08 that would be calculated using normal assumptions.

The proper way to built steel framing is with rigid insulation sheathing on the exterior. This provides a thermal break to the framing.

The reason metal framing works in commercial buildings is that the acrylic stucco used in commercial buildings is installed on a rigid frozen insulation base, which creates a thermal break. Those walls may not have much insulation, but at least there is a break at the stud face.

The moral of the story is, by all means experiment and use steel studs if it is appropriate in your situation, but be sure to review the construction details with care. And always make sure that the framing has a thermal break.


• Minimize cooling load
✓Shade glass during cooling season
✓Natural ventilation
✓Minimize internal gains
• South facing roof @ proper slope
• Solar thermal collection
(Pre-plumb/pre-wire for future use)
• Daylighting
• Edible perennial landscaping
• Fruit & nut trees
• Berries
• Raised bed organic garden
• Telecommuting
• Efficient lighting
• Solar greenhouse
• Organic compost
Soil bed greywater filter
• Preserve site trees & topsoil
• Prevent erosion
• Encourage native flora/fauna
• Low maintenance landscape
✓Low water needs
✓No pesticides or chemical fertilizers
• Reclaim & restore damage sites
• Greywater heat recovery
• Greywater prefilter
• Separate blackwater & greywater
Solar Heat Storage
Composting toilet
• Efficient heating appliances
• Sealed combustion
• Low temperature heat source/distribution
• Heat recovery ventilation
• Air filtration
• Materials
✓Durable
✓Resource efficient
✓Locally harvested/produced
✓Low embodied energy
✓Non toxic
✓No CFCs
✓No old growth timber
✓Recycled/recyclable
✓No/minimal finishes required
• Rainwater collection for low grade use
• Water efficient fixtures
• DHW conservation
• Airtight construction
• Superinsulation
• Windows
✓Low U value
✓Tuned shading coefficient
• Suntempered design
• Passive solar design
• Efficient appliances
• No unvented combustion
• Recycling center
• Water filtration/treatment
• Root cellar
• Solar food dryer
• Radon resistant construction
• Sub-slab radon pre-mitigation
• Passive stack
• Efficient cooling
• Whole house fan
• Evaporative cooler
• Regenerative dehumidification

EXHAUST FANS FOR A COLD CLIMATE

by Jon Eakes

WHEN BATHROOMS or kitchens are built or remodeled, it is standard practice today to install an exhaust fan or some sort. In the U.S., the Uniform Building Code recommends installing fans. Often there is very little detailing or specification relating to exhaust fans other than the number of cubic feet of air they move per minute (cfm), so the fan is simply installed in the "standard way," whatever that means. This works fine in a warm climate, and even works fairly well in a poorly insulated house, but in a well-insulated or reinsulated house in a northern climate, "standard" means something very different.

First of all, a builder should be sensitive to the fact that an exhaust ventilation system will do no good if the homeowner will not use it. There are three basic reasons why most systems are simply not turned on.

First, the fan may be plugged full of rags or the outside damper taped shut in an effort to stop the constant cold drafts. Many northerners seem to think fans are expendable energy-wasting devices, and most traditional installation techniques are not adequate for our well-insulated, cold-climate houses. Details on that in a minute.

Second, most fans are so noisy that they are used only when there is no alternative, such as when the kitchen is full of smoke. Rarely will a cook endure the whine, if not the rattle, of the range hood simply to remove a bit of steam. Specification sheets on fans include noise factors and this should be an item of prime, not passing, interest. Very quiet fans exist, but they do cost more. In general, squirrel cage fans are quieter and more efficient than blade-type fans. (Squirrel cage fans consist of a cylinder with fins along the sides and cost about $80, whereas the blade fans are in the $20 to $30 range.) Some manufacturers have separated the fan from the range hood or the bathroom grill, allowing the fan to be placed near the exhaust port, perhaps even in the basement. This helps immensely to eliminate the noise problem.

Third, people forget the fan, especially when doing ordinary cooking or when taking showers. Tying the bathroom fan to the light switch often creates noise when there is no need and does not assure removal of steam after someone leaves the room. A time-delayed off switch helps, but the best solution is to operate the fan on a humidistat switch with a manual override. If the occupants think about it, they can turn the fan on to remove odors or other forms of pollution but, whether they think of it or not, water vapor will automatically turn the fan on whenever the room is too humid, and leave it on until the condition is corrected. An exhaust fan with this kind of switch will also turn on of its own accord whenever the general household humidity becomes too high from whatever source, such as laundry drying or run shampooing. This control procedure is now standard for northern installations of air-to-air heat exchangers, but is equally valid for any other household ventilation system.

A quick look at the historical development of the installation of exhaust fans in dwellings on the Canadian prairies will help show why traditional installations cause drafts and other problems today.

It used to be standard practice to run a fan up through the ceiling, through the attic, and out any place on the roof. That worked, and worked well, as long as the attic was so poorly insulated that freezing temperatures in the attic were rare or at least not continuous for long periods of time. With the energy crises, we suddenly started to fill these attics with lots of insulation. This provided significant space heating savings but also had the important side effect of radically reducing the temperature of the attic air. This meant that the attic would now freeze almost every winter night, and often would stay frozen for weeks at a time. We immediately found bathroom fans dripping water.

There were actually two sources of this unexpected condensation. First, the fan was loosely installed through the ceiling vapor barrier, the fan box was full of holes, and the ducting was often full of holes. Water vapor escaped from the bathroom and the fan system into the attic, forming frost; on a warmer afternoon this frost would melt and drip into the insulation and eventually back into the bathroom. Also, we found that when the fan was turned off, the hot air would not longer heat the ducting that went through the freezing attic, and the water left in the duct, as well as the vapor that would diffuse up through the fan box during the night, would all freeze to the inside of the duct. The next morning when the fan was turned on, the frozen vapor would melt and flow back into the bathroom, dripping down the back of the neck of someone trying to shave.

The first efforts to solve these new problems consisted of carefully sealing the ceiling penetration and the entire exhaust system to keep the moisture in, and then wrapping the exhaust duct with R-20 insulation to try to keep it warm and avoid internal condensation. These efforts were somewhat successful, except that now even more vapor tended to freeze to the uninsulated portion of the ducting exposed on the roof—helping to freeze the damper open and creating a constant draft of cold air into the bathroom (or kitchen) while not eliminating all the dripping (Fig. 1).

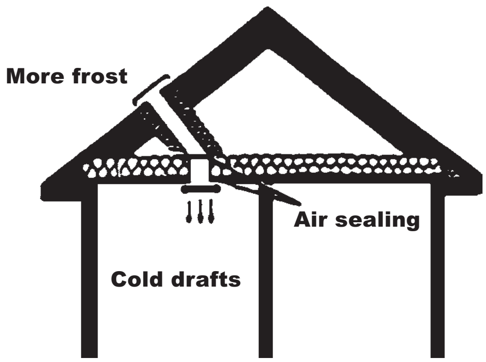


Figure 1. Attempts to insulate the exhaust duct for fans vented through a cold attic and the roof resulted in more frost forming on the exterior portion of the ducting.

Then a scheme was devised to run the ducting into the attic, slope it downward and out the side of the house, seal it tight and insulate it. This worked better, as the condensation drip now went down the outside wall (making a nice black line all the way down the wall) and cold air was less likely to creep back into the vented room. But the dampers still froze open and, if the exhaust port was poorly placed, exhausted vapor would rise up into the eve vents of the house and back into the attic (Fig. 2).

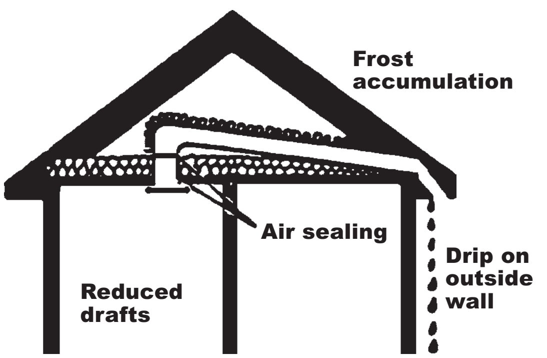


Figure 2. Exhaust fan vented ducting routed through a cold attic to the eaves allowed the condensation to drip down the outside of the building, rather than into the vented room.

Efforts to vent directly through a side wall were quickly dropped, as the lack of insulation led to immediate frost buildup and direct wind entry (Fig. 3). However, the side wall installation had the advantage of eliminating most of the complicated sealing requirements of ceiling penetrations.

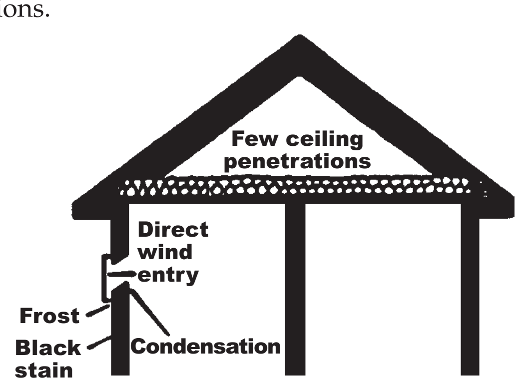


Figure 3. Exhaust fans vented through walls are easier to install, but frosting, condensation and cold air entry are still problems.

The trouble-free solution for the Canadian climate was finally found by routing the exhaust duct into or through an interior partition wall, down to the basement, out through a basement window (or a header penetration) on a downward-draining slope (Fig. 4). There is still frost buildup at the exhaust port outside the wall, the damper still freezes open most of the winter, and it still makes a black drip mark down the wall. But the frost doesn't drip back into the house, the wind doesn't blow up one or two stories of ducting (cold air does not "fall" up vertical ducting), and the black mark can be hidden behind the flowers. The entire ducting run is warm and condensation free and if the fan is placed near the exhaust port in the basement, the ducting is under suction, not pressure, which prevents smoke, vapor, and odors from escaping through unsealed joints. Not only is the noise of the motor distant from the living quarters of the house, but if someday the homeowner wants to upgrade from an exhaust-only system to a balanced air-change system, or an air-to-air heat exchanger, the exhaust ducting is already installed and in the right place.

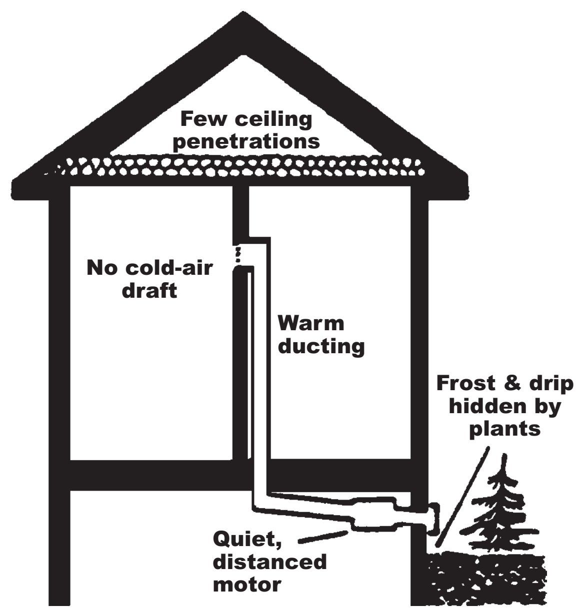


Figure 4. The best solution for venting humid air is to direct the ducting down through the warm interior of the house and out through a wall near gound level.

Even in renovations, we can usually sneak the ducting through kitchen cupboards or through a closet backed up to a bathroom. To go down and out does not occur to most people, but precisely because this direction is the opposite of the predominant thermal forces in a cold climate, it brings an exhaust fan into complete control.

BUILDING IN ALASKA

Special Considerations For Building In Alaska

by
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HCM-00952

UNIVERSITY OF ALASKA
FAIRBANKS
College of Rural Alaska
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INTRODUCTION

Special considerations for building in Alaska are recommended that are normally not included in structures designed for milder climates in the Lower 48 states. Plans and publications will be developed as new construction techniques are developed in Arctic construction.

A. FOUNDATIONS

1. Consult with an architect, engineer or contractor before building on soils subject to permafrost. This includes most of Interior Alaska and areas west and north of the Alaska range.
2. Enclosed crawl spaces or basements should not be constructed in soils subject to permafrost. Wood posts, mud sills or engineered foundations with open crawl spaces are suggested in permafrost soil.
3. In areas where masonry or concrete foundations are used, reinforce against seismic action in accordance with local or state codes. Reinforce masonry chimneys against earthquakes also. Other materials than masonry should be utilized for chimneys.
4. Consult with your local insurance agent and borough engineer before building in areas subject to flooding.
5. Foundations should be closed in and the building heated to avoid excessive heaving and settlement of footings during the winter.
6. All masonry and concrete foundations should be properly reinforced to minimize cracking due to heaving and settling of frozen ground.
7. Foundation Insulation
   a. A below-grade thermal envelope wall should be insulated to the minimum R-value shown in Table 1.
   b. A required R-value for crawl space wall insulation should be maintained for the full height of the wall.
   c. Exterior insulation may extend in a horizontal or diagonal manner out from a wall provided the length of insulation meets or exceeds that which would be placed in a vertical manner.
   d. An insulation material should have appropriate weather resistant properties for the intended use and should be applied as recommended by the insulation manufacturer.

B. FLOORS

1. In permafrost areas, floors should be constructed over open crawl spaces and insulated to minimize permafrost melting and to avoid uneven settling of the building.
2. The surface temperature of the floor is of particular concern in Arctic climates, since this is where we work, play and relax during our waking hours. The closer the floor surface temperature approaches room ambient temperature, the greater the comfort level.
3. A cold floor results in discomfort from direct radiation, stratification of cold air near the floor and warm air near the ceiling.
4. Floor insulation:
   a. A thermal envelope floor should be insulated to the minimum R-value shown in Table 1.
   b. A rim joist area of a thermal envelope floor should be insulated to the same requirement as given for an envelope floor.

c. A rim joist area of a non-thermal envelope floor (such as where a crawl space wall is insulated but the floor is not, or a second story floor) should be insulated to the same requirement as given for an Above-Grade or Below-Grade envelope wall, as appropriate.

SLAB-ON-GRADE FLOORS

a. A concrete slab-on-grade floor of a conditioned space or enclosed semiconditioned space should be insulated to the minimum R-value shown in Table 1.
b. An insulation material should have appropriate weather-resistant properties for below-grade application and should be applied as recommended by the manufacturer. Insulation damaged during construction should be replaced.
c. Insulation for a thickened edge or grade beam concrete slab floor should extend downward from the top of the slab to the bottom of the footing, then horizontally beneath the footing for its full width. Alternatively, insulation may extend downward from the top of the slab to the bottom of the footing, then diagonally out from the footing for a minimum horizontal distance of 18 inches.
d. Horizontally placed insulation under the perimeter of a basement concrete slab floor should be continuous around the entire perimeter of the slab and should be a minimum of 24 inches wide. Additionally, a thermal break should be provided between the foundation wall and the slab edge.
e. Permafrost areas require engineering analysis for proper application of insulation in contact with the ground. Improper application can result in ground thawing and cause severe damage to the structure.

5. An uninsulated concrete slab on-grade floor is not recommended for the main living area, as ground temperatures in Alaska are near 33°F. If used as the living area, the entire floor should be insulated with at least two inches of rigid foam plastic insulation. Perimeter insulation is not adequate for Alaska.
6. A polyethylene vapor barrier should be placed under all concrete floors poured on grade, or laid on the ground of closed crawl spaces, to minimize the migration and evaporation of excessive moisture from the soil.

C. WALLS

1. Wall insulation.
   Above-Grade Walls:
   An above-grade thermal envelope wall should be insulated to the min-imum R-value shown in Table 1. This includes the floor rim joist area.
2. A polyethylene vapor barrier should be placed on the interior faces of the studs directly over the insulation (warm side). Be careful to seal all openings made to accommodate plumbing vent stacks, chimneys, electrical wiring, etc.

3. The vapor barrier should be installed on the ceiling first, before any interior partitions are installed. Place the wall vapor barrier on the inside (warm side) on ceiling lap.
4. Wherever possible, it is recommended that no electrical wiring be installed in the ceiling except as outlined in the section on ELECTRICAL WIRING.*

D. CEILING

1. Ceiling insulation.
   A thermal envelope ceiling should be insulated to the minimum R-value shown in Table 1.
2. To minimize condensation stains on the ceiling and glaciering on eaves and valleys, the roof cavity must be kept cool and free of moisture by combining adequate vapor barrier, insulation and ventilation. (see CES Publication HCM-00559, *Design of Roofs for Northern Residential Construction.*
3. A polyethylene vapor barrier should be placed on interior surfaces of the ceiling directly under the insulation, prior to erecting partitions. Leave 8 to 12 inches overhang on the walls.
4. Be careful to seal all openings in the vapor barrier that may be caused by installing plumbing, electrical outlets, chimneys, etc.
5. The roof cavity must be ventilated by a combination of 2-inch continuous slots at both eaves and louvres at the gable.
6. If the supporting beam of a flat roof must be recessed into the ceiling, then a cricket must be constructed in the roof deck over the beam to assure ade-quate eave-to-eave ventilation. All effort should be made to avoid flat roofs.
7. Framing of scuttle openings or stairways into uninsulated attics should be avoided as it will eventually lead to condensation and frosting problems.
8. Openings into a cold attic should be provided through the gable wall from the outside.
9. If an attic must be accessible from the interior of the house for storage purposes, then it should be adequately insulated, vapor proofed, ventilated and heated to avoid condensation and frosting problems.
10. The use of thick insulation for the ceiling, necessitates special precautions to ensure adequate insulation at the eaves of gable roofs.
11. The trusses may be cantilevered so that they extend over the wall 18 to 24 inches on both sides. This allows 12 to 18 inches between the roof deck and the wall plate, providing 9 to 12 inches of clear space over the top for insulating the roof cavity.
12. Lumber sizes of conventional rafters may be increased to provide sufficient ventilation space over the insulation at the eaves. The rafters may also be raised up on a special header, notched into the ceiling joists, instead of setting the rafter onto the wall plate.

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* *Building Energy Efficiency Standard*. State of Alaska Department of Community and Regional Affairs, September 1, 1991.

13. Do not taper the insulation at the eaves or pull the insulation back from the wall plate, as this increases the heat conduction through the plate, joists and rafters. Condensation and staining of interior finished surfaces may occur adjacent to the header and under the ceiling framing members.
14. Whenever possible, it is recommended that the installation of concealed wiring be avoided in ceilings of cold roof cavities. Refer to the section on ELECTRICAL WIRING* for alternative suggestions.

E. INSULATION

The Prescriptive Method establishes minimum thermal envelope insulation requirements for buildings. Exceeding these minimums is encouraged.

The Prescriptive Method does not require extensive calculations. It is the least flexible of the four possible compliance methods. This method should not be used to trade-off an R-value requirement between a different thermal envelope assembly or different element of the same assembly. For example, more insulation in the ceiling does not decrease the required insulation in the wall.

The Prescriptive Method does not dictate specific building methods or materials. Any method of constructing a building may be used provided clear compliance with the minimum insulation requirements is shown. For example, to meet a mini-mum R-18 wall insulation requirement, R-19 fiberglass batt in a 2x6 framed wall may be used, or R-13 fiberglass batt in a 2x4 framed wall with R-5 rigid insulation over the framing, or R-18 urethane foamed-in-place between 2x4 framing.

When using the Prescriptive Method as the means of compliance for the Alaska State Thermal Efficiency Standards, all mandatory measures given in Chapter 2 of the *Building Energy Efficiency Standard* should also be accomplished.*

Insulation Minimums

R-value minimums given in this chapter are for insulation installed between or over structural members. Only the insulation R-value is counted. R-value for an air film or a material such as sheetrock, paneling, plywood, siding, or earth backfill, for example, should not be included.

R-value minimums refer to the **installed** R-value. Compression of some insulating products results in a lower R-value. For example, placing a standard R-30 batt into a 2x8 wall compresses the batt from 9 inches down to 7-$\frac{1}{4}$ inches. This results in a decreased R-value from the listed R-30 down to approximately R-26. Table 2 shows nominal examples of resultant R-values when fiberglass batts are compressed.

* *Building Energy Efficiency Standard*. State of Alaska Department of Community and Regional Affairs, September 1, 1991.

TABLE 1
Thermal Envelope R-value Requirements

This table lists minimum thermal envelope insulation requirements for buildings. Any method of constructing a building's thermal envelope may be used provided clear compliance with the listed R-values is shown and is acceptable to approving officials. R-value minimums refer to the installed R-value which may be different from the listed product R-value. Higher R-values may be used if desired.

CAUTION: Permafrost areas require engineering analysis for proper application of insulation in contact with the ground.

Region Number	Region Name	Heating Fuel	Thermal Envelope R-Value Requirements: Ceiling	Above grade Wall	Floor	Below grade Wall	Slab Floor: Basement	Slab Floor: On-Grade	Window	Door[1]
1	Southeast	All Fuels	38	21	30	15	10	15	3.0	2.5,7
2	Southcentral	Natural Gas	38	18	19	10	10	10	3.0	2.5,7
2	Southcentral, Aleutian, Kodiak	All Fuels other than natural gas	38	25	30	15	10	15	3.0	2.5,7
3	Interior, Southwest	All Fuels	38	25	38	19	10	15	3.0	7
4	Northwest	All Fuels	38	30	38	19	10	15	3.0	7
5	Arctic Slope	All Fuels	52	35	43	—	—	—	3.0	7

Note:
1. Not more than one exterior door in a residential building in Region 1 or 2 may have an R-value less than 7, but not less than 2.5.

TABLE 2
R-value and Thickness

Example of resultant R-values when fiberglass batt insulation is compressed into a confined space such as in wall stud or floor joist spaces. Product thickness and density differ among manufacturers and therefore resultant R-values also differ slightly.

Nominal Lumber Size	Actual Width	Initial R-value and thickness: R-38 12	R-30 9-½	R-22 6-¾	R-19 6-⅛	R-13 3-⅝	R-11 3-½
		Installed R-value at final thickness					
2" x 12"	11-¼"	37					
2" x 10"	9-¼"	32	30				
2"x 8"	7-¼"	27	26				
2" x 6"	5-½"		21	20	18		
2" x 4"	3-½"		14	13	13		
2" x 3"	2-½"					10	9
2" x 2"	1-½"					6	6

F. VAPOR BARRIER

1. A 6-mil polyethylene vapor barrier should be installed over all interior surfaces directly over the insulation prior to installation of partitions and interior finishes.
2. Refer to sections on FLOORS, WALLS AND CEILING for further details. Also refer to section on INSPECTION.

G. INSPECTION

It is recommended that no interior finished floor, wall or roof covering be installed until the insulation, vapor barrier, concealed plumbing and electrical wiring have been approved by the prospective homeowner or his authorized representative, consisting of either the building inspector, the finance agency and/or the architect.

H. VENTILATION

1. Ventilation fans should be installed in the kitchen, bathroom and laundry room. Do not vent fans directly into the roof or crawl space cavities.
2. If electricity is not available, a simple exhaust duct installed over the cook stove and vented through the roof to the outdoors should be provided. The air flow may be controlled by an adjustable damper.
3. Automatic clothes dryers whether electric or gas heated, should be vented outdoors by an approved vent pipe.
4. Mechanical ventilation is now the norm for new energy efficient housing in Alaska. See CES Publication HCM-01551, *Ventilation in Small Houses*.

I. WINDOWS

1. Windows for Alaskan homes should be constructed with wood or vinyl frames and sash and fitted with double sealed glass. Single glass may be glazed into the sash and fitted on the outside of the sash with a second removable glass pane. Modern energy efficient windows should be used whenever now construction is undertaken.
2. Storm-type windows fitted onto the window frames are not suitable for prolonged periods of subzero temperatures, as migration of moisture around weather-stripping condenses out onto the storm window and will obscure the glass with heavy frost. Once the frost has formed, it cannot be removed except by warming the storm windows by special insulated storm shutters.
3. To eliminate condensation problems along the edge (rim) of double insulating glass panes, a third pane of glass may be installed over the outside of the wood sash.
4. Refer to CES Publication HCM-04458, *Windows* .

5. Window Insulation
   a. An exterior window RO-value (overall R-value, including the frame) should not be less than specified in Table 1.
   b. A sliding glass door should be considered a window for the purpose of determining total allowable glazed area percentage (see Paragraph "c" below) and required R-value.
   c. Total window and sliding glass door area should not exceed 15 percent of the total gross above-grade thermal envelope wall area. If more than 15 percent window area is desired. See Chapter 4, 5, or 6, which should be used as the method of showing compliance with the overall energy efficiency of a building.*
   d. A window for special architectural or decorative purpose may have an R-value less than required by Table 1 provided:
      1) it is double glazed or more, and
      2) total decorative window area does not exceed 5 percent of the allowable window area specified in Paragraph "c" up to a maximum of 16 square feet.

J. DOORS

1. Storm doors and closed entries are desirable for arctic climates.
2. Metal doors with an insulated core and special thermal separators between the inside and the outside shells are excellent for arctic conditions, Except adjustable door frames are necessary to compensate for the continual heaving and settling of the active frost layer of the soils of interior Alaska.
3. Insulation
   a. An exterior door RO-value should not be less than specified in Table 2.
   b. Door glazing should be minimum double glazed with a ½-inch minimum air space.
   c. A sliding glass door, should be considered as a window for the purpose of determining R-value and area requirements. See Section on WINDOWS.

K. STORAGE SPACES

1. The placement of closets, kitchen cabinets, and other built-in storages on exterior walls should be avoided wherever possible to minimize condensation and frosting problems. This includes storage placed under the eaves of 1-½ story houses.
2. If storage space must be placed along exterior walls, provide adequate ventilation with louvred doors, drapes or other openings. A section of baseboard radiation placed on exterior walls would be a positive aid in maintaining the storage above the dew-point temperature.

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* *Building Energy Efficiency Standard*. State of Alaska Department of Community and Regional Affairs, September 1, 1991.

3. Avoid storing boxes, magazines and clothing tightly against exterior walls. Install 1" x 1" wood slats on 2" centers on the wall and floor to facilitate natural ventilation.

L. ELECTRICAL WIRING

1. In order to avoid condensation problems caused by inadvertent puncturing of the polyethylene vapor barrier by present concealed wiring techniques, it is suggested that either the wiring be run in exposed raceways or concealed in special chases as outlined below.
2. Exposed Wiring.
   Electrical circuits and outlets may be run with exposed “Wiremold” raceways with surface outlets or “Electrostrip” narrow feed-in cable with adjustable convenience outlets. These circuits may be fed from wiring and outlets concealed in adjacent interior partitions.
3. Concealed Wiring.
   a) The wiring may be laid in chases constructed from 2" x 3" nailers that are installed perpendicular to the studs or rafters after the insulation and vapor barrier have been properly placed and sealed.
   b) Where circuits must pass through obstructions, such as at the sole or plate, the nailers should be cut out and the cable protected from possible shorting of nails with 1" x 1" x ⅛" angle iron caps.
   c) The added cost of the nailer may be partially offset by eliminating the need to bore holes and thread the cables through the framing members.
   d) The short construction season of Arctic climates necessitates enclosing the building as soon as possible. Installing temporary heat without having all of the concealed plumbing and wiring built into the wall before the insulation and vapor barrier can be properly installed and inspected can result in major condensation problems. Refer to sections on VAPOR BARRIER, INSPECTION, and UNVENTED SPACE HEATERS.
   e) A 6-mil vapor should be used when nailers are provided as electrical chases.

M. UNVENTED SPACE HEATERS

1. Do not operate unvented fuel oil or bottled gas space heaters as temporary heat until the insulation and vapor barrier have been fully installed and adequately sealed.
2. If the vapor barrier is not sealed, the invisible water vapor produced by the space heater will condense out in the insulation and other cold surfaces. The moisture may freeze and damage siding. During the spring thaw, melting of the ice will stain exterior and interior finishes.
3. Unvented combustion space heaters should never be used as heating sources in any living space.

N. CHIMNEY

1. The chimney must be tightly sealed at the ceiling penetration to minimize migrating moisture and infiltrating excess heat into the roof cavity.
2. Gas furnaces should be provided with an approved masonry chimney or **all-fuel** pre-fabricated metal chimney.
3. Lightweight uninsulated metal gas vents can result in excess heat formation in a poorly vented roof cavity, particularly a gable roof, resulting in excessive glaciering at the eaves.

O. HEATING

1. The packaged precut or panel home should include a complete set of plans and a tabulation of the heat losses of each room, the recommended size heating plant, the size of baseboard radiation, size of hotwater heating pipes, electric heating conductors, sizes of hot air and return registers, size of ducts, and an estimate of annual fuel or energy requirements for Alaskan climates.
2. All hot water heating plans should provide for approved zone control valves and balancing cocks for each heating zone.
3. All hot air heating plans should provide for adjustable dampers on each branch duct and adjustable blower pulleys for proper balancing of the air flow to each register.
4. If the prime contractor or subcontractor does not maintain service personnel in Alaska during the winter season, then a local heating contractor should be designated to correct any normal deficiencies in the heating system, such as excess noise, improper balancing, excessive fuel consumption, etc.

P. SEPTIC TANK

All septic and alternative on-site waste disposal systems are subject to Department of Environmental Conservation regulations and should be installed by a D.E.C. certified installer. Aerobic compost systems exist that are a low water use, very beneficial alternative to standard septic tank and leach field systems.

OTHER COOPERATIVE EXTENSION SERVICE PUBLICATIONS OF INTEREST

HCM-00559 *Attics and Roofs for Northern Residential Construction*
HCM-01551 *Ventilation in Small Houses*
HCM-01556 *Small House Construction on Bogs and Muskeg*
HCM-04458 *Windows*

Active Solar Heating

Factsheet

EEM-01256

Richard D. Seifert
Energy & Housing Specialist

Active solar heating is most commonly used to provide heating applications using the sun's energy to residences and businesses. Thermal solar energy is a very efficient way to use the sun's energy beneficially in our homes in Alaska. In active solar heating applications, heat from the sun is collected, stored and used primarily for domestic hot water heating. The reason the system is called active is because pumps and fans are used to transfer the captured heat to an area where it can be stored or used. The main components of an active solar system are the collectors, the collector controls, the storage tank, and the distribution system. This factsheet is only designed as an introduction to active solar heating systems in an Alaska context.

The interested reader who wants to further apply these technologies is advised to go to Web site: www.alaska-sun.org and look at the active solar heating chapter of the *Solar Design Manual for Alaska*, which is located at that Web site.

New Information as of 2007

Because of recent changes in Federal legislation, it is now possible to install active solar water heating systems in Alaska and receive a federal bottom-line tax credit equal to 30 percent of the actual capital cost of the solar collector system in total or $2,000, whichever is less.

This tax credit is available if you use the solar water heater on your primary residence, but only if the system is able to provide at least 50 percent of the hot water needs for your residence. Anything less than that would not quality for the tax credit. This tax credit is also due to expire at the of 2008 but it may be renewed. Please see any updates for information beyond 2008.

Solar Collectors

A flat-plate collector is the most common choice for domestic heat and hot water from solar energy. (See Figure 1.) Either liquid or air acts as the heat absorbing medium. Fluid-filled collectors can utilize a mixture of antifreeze and water, necessitating the use of a heat exchange loop in the system to avoid contamination and freezing problems.

Recently, solar collector technologies have been improved. Collector systems engineers are eliminating equipment and moving parts, which have made modern active collectors more efficient and maintenance-free.

WARNING: Solar heating systems must eliminate freezing risks in any Alaskan application. Anything less than an antifreeze system for circulation outside of the heated area of the house is an insufficient system for Alaska. Under no circumstances would we recommend that any system in Alaska be installed, which circulates liquid water without any freeze protection outside the house. Although this has been tried, it has never succeeded and systems ultimately fail that use this option. Only consider systems that use an exterior circulation loop of antifreeze for Alaska applications.

While solar active heating systems are most appropriate for heating hot water for domestic use, they are becoming more adaptable to all types of applications. A backup heating system is necessary in all situations, however, to ensure year round service.

The Solar Energy Resource

In Alaska, active solar heating will not economically meet all required domestic hot water and space heating needs. But, it can significantly reduce dependence on fossil fuels, especially when used in conjunction with passive solar heating and conservation.

Solar radiation is measured in terms of the number of BTUs striking a square foot of surface during a specific time period. The amount of radiation received at a given point in a day is dependent upon the percentage and thickness of cloud cover, as well as the sun angle and the number of hours of available sunlight. Because of the interplay of these factors, insolation statistics do not correlate strictly with latitude. For example, Juneau does not necessarily receive more solar radiation than Fairbanks. In Alaska, this means those regions with continental (Interior) and transitional (Southcentral, Southwest, and Northwest) climates are the area where solar heating would most likely be practical.

Maximum and minimum average monthly insolation data for Anchorage, Bethel, and Fairbanks are presented

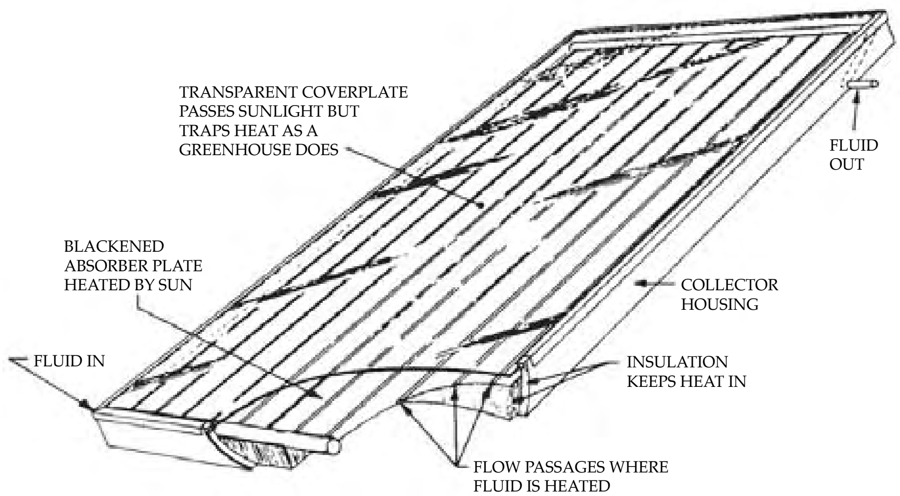

Figure 1. Schematic view of a typical flat-plate solar collector. Solar radiation (primarily visible wavelengths) strikes the surface of the glazings and is transmitted through them with a loss of 10-13 percent for each layer of glazing (only one glazing is illustrated). About 95 percent of the solar radiation striking the blackened collector plate is absorbed. This surface reradiates energy in the form of infrared radiation, which is trapped between the glazings and the absorber plate; this causes the collector plate to get hot. The collector fluid (liquid or air) is pumped through the collector to move the heat to where it is needed (figure from Seifert, 2005.)

for a vertical, south-facing surface in Table 1. The average solar radiation varies considerably with the seasons in a pattern that is out of phase with the highest heating loads. Economically, active solar heating cannot totally replace the use of fossil fuels for either space heating or domestic hot water in Alaska. Technologies are well developed for collectors and distribution systems.

			BTU/ft^2/day
Anchorage	Max.	April	1205
	Min.	December	190
Bethel	Max.	April	1364
	Min.	December	349
Fairbanks	Max.	April	1554
	Min.	December	95

*90° tilt (Andrew-Walker National Renewable Energy Laboratory - 2001)

Table 1. Average Solar Radiation on a *South-Facing Vertical Surface.

Sizing a Collector

Numerous factors must be considered in sizing an active flat-plate solar collector such as the available solar energy, the efficiency of the collector, local energy costs and the heating needs of the building. Collector efficiency, in turn, depends on location, orientation and collector surface tilt angle as well as the workmanship and insulation on all parts of the system. Computer programs have been developed to predict optimum collector size for particular combinations of physical and economic factors. Simulations have been run for several Alaskan locations. (See Seifert, 2005.)

Table 2 is an FChart computer simulation of an active domestic solar water heating system for Fairbanks, Alaska. This run was produced by Mr. Jake Tornatzky for a Solar Installers Workshop held in Fairbanks in the spring 2007. It shows the expected modeled output for a standard year in Fairbanks using National Renewable Energy Laboratory solar radiation data to predict the performance by month, of the output from a standard solar water heating system, in this case, a Heliodyne system manufactured by a company in Richmond, California.

The system has a collector panel area of 32.30 sq. ft. each and there are two of those for a total area of 64 sq. ft. At the bottom of the chart you see four columns listed by month with a million Btus in parentheses underneath three of the columns. The final column is interesting because it is the fraction of heating requirements for domestic hot water, which is provided by solar by month. As you can see from the chart, 27 percent is provided in February and at the bottom of the chart 54 percent is provided on a year-round basis. So this system would in fact qualify for the tax credit since it provides more than 50 percent of the annual heating required. Note that in April, May, June, July and August, the collector provides more than 80 percent and at times more than 90 percent of the heat required for hot water. But note that in the winter time during December and January no heating is obtained from the solar system. This gives a good indication of the variable annual performance and indicates why a backup system is necessary.

Active Domestic Hot Water System		
Location	FAIRBANKS AK	
Water volume / collector area	1.50	gallons/ft²
Fuel	Gas	
Efficiency of fuel usage	70.00	%
Daily hot water usage	60	gallons
Water set temperature	125.0	F
Environmental temperature	67.3	F
UA of auxiliary storage tank	0.00	Btu/hr-F
Pipe heat loss	No	
Collector-store heat exchanger	Yes	
Tank-side flowrate/area	14.000	lb/hr-ft²
Heat exchanger effectiveness	0.55	
Flat-Plate Collector		
Number of collector panels	2	
Collector panel area	32.30	ft²
FR*UL (Test slope)	0.870	Btu/hr-ft²-F
FR*TAU*ALPHA (Test intercept)	0.730	
Collector slope	50	degrees
Collector azimuth (South=0)	0	degrees
Incidence angle modifier calculation	Value(s)	
Collector flowrate/area	14.000	lb/hr-ft²
Collector fluid specific heat	0.84	Btu/lb-F
Modify test values	Yes	
Test collector flowrate/area	11.000	lb/hr-ft²
Test fluid specific heat	1.00	Btu

	Solar	**Dhw**	**Aux**	**f**
	[10^6 Btu]	[10^6 Btu]	[10^6 Btu]	[ ]
Jan	0.574	1.546	1.546	0.000
Feb	1.326	1.391	1.011	0.273
Mar	2.712	1.529	0.527	0.656
Apr	3.325	1.465	0.181	0.876
May	3.457	1.500	0.104	0.931
Jun	3.337	1.442	0.039	0.973
Jul	3.292	1.489	0.080	0.946
Aug	2.754	1.494	0.277	0.814
Sep	2.078	1.454	0.552	0.621
Oct	1.415	1.518	1.002	0.340
Nov	0.853	1.486	1.350	0.091
Dec	0.195	1.543	1.543	0.000
Year	25.319	17.858	8.213	0.540

Table 2. An FChart Computer Simulation of an Active Domestic Solar Water Heating System for Fairbanks, Alaska.

Economics

Solar energy systems are still fairly expensive, but with the tax credit and the ever increasing costs of fuel, solar water heaters have never been more economic or interesting than they are in mid-2007. Although it is certainly advisable and possible to home build solar energy collectors, these collectors would not qualify for the tax credit. That is because the tax credit also has the stipulation that the solar collectors used in a residential system must be certified by a national testing certification agency. The system modeled in the collector sizing example (Table 2) is a certified system tested at the Florida Solar Energy Center.

One must have reasonable expectations about performance. Solar radiation is at its minimum in Alaska during November, December and January. This does not mean that no energy can be extracted from the short duration and low sun angle of the winter sun—it can, but the amount of heat energy gained per dollar invested in the system falls short. During these months a back-up system is necessary. But an active solar hot water heating system is practical in several regions in Alaska where fuel prices are high and the climate is good. Why does a solar water heater work when solar space heaters won't? We use hot water all year long not just in the winter. So more solar heat is available for hot water heating than for space heating: it is more useful all year round, since we need hot water in summer, but don't need to heat our homes when the sunlight and heat are plentiful.

Recently at the Cold Climate Housing Research Center three different active solar water heaters were installed on the roof as a testing option to demonstrate their performance and make this information available to the public. This is a major step forward in promoting and proving up solar water heaters for Alaska.

One of the systems is an evacuated tube collector type system and as you can see from Figure 2, the efficiency of the three main solar thermal technologies is really a function of solar radiation and ambient temperature. This fact should be very strongly considered depending on what kind of heating you need to do. For instance, Figure 2 shows clearly that if you want to heat water to temperatures from 10° to 50°C above the ambient, which is mostly the case for when solar water heating is efficient in Alaska, a flat plate collector is the best choice.

However evacuated tube type systems are best for circumstances when more than 50°C above ambient is the application of choice. This seems to infer that evacuated tubes are best for very cold temperatures, but since very cold temperatures in Interior Alaska also mean short solar periods, the ultimate annual performance may not be that crucially advantageous with an evacuated tube collector. The true productivity from evacuated tube system remains to be seen in our climate as none has really been tested. That is the purpose of the new

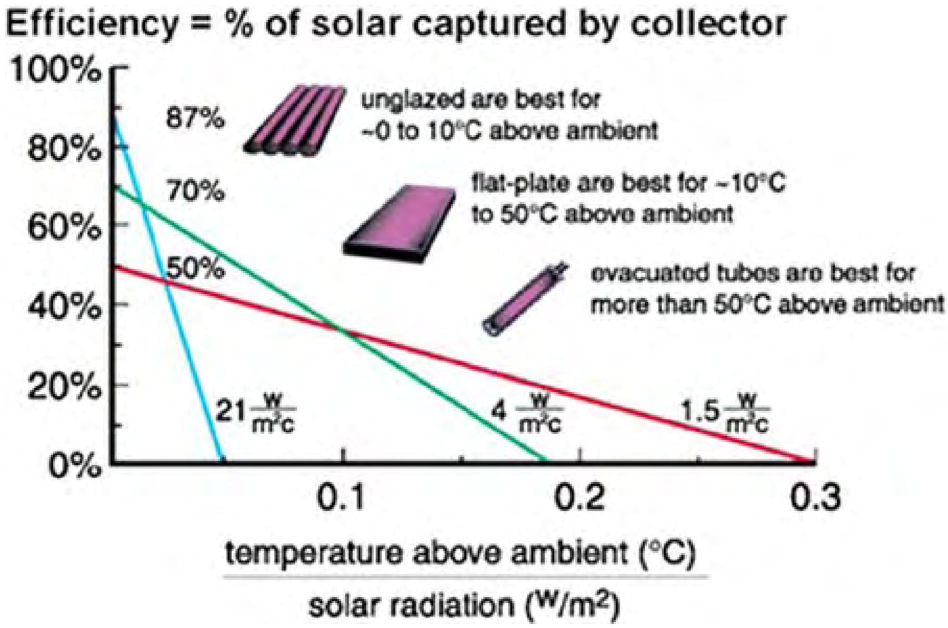

Figure 2. Efficiency of the three main solar thermal technologies as a function of insolation and ambient temperature.

installations at the Cold Climate Housing Research Center. We look forward to making this information available in the future and will do so through this publication.

For more information about solar heating technologies and applications, call the Cooperative Extension Service's statewide energy specialist at 474-7201 or 1(800)478-8324, or see the Web site www.alaskasun.org

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Beckman, Klein and Duffie. 1977. *Solar Heating Design by the F-Chart Method.* John Wiley & Sons.

Web sites: www.uaf.edu / ces / faculty / seifert
www.nrel.gov; www.ases.org; and
www.alaskasun.org

Visit the Cooperative Extension Service Web site at www.uaf.edu/ces
and Rich Seifert's homepage at www.uaf.edu/ces/faculty/seifert

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This publication (revised and updated in 2007) is an effort of Cooperatitve Extension and the University of Alaska Fairbanks to support a developing solar applications and commercial industry for Alaska to better serve our energy needs with renewable energy.

The use of trade names in this publication does not imply endorsement by the Cooperative Extension Service.

6-85 / RS / 500 Revised August 2007

Passive Solar Heating
An Energy Factsheet

EEM-01258

Solar energy is often discounted as a viable energy alternative in northern latitudes such as Alaska. In reality, the energy of the sun can provide a significant portion of Alaska's heating needs. The most efficient and least expensive way to tap this resource is through design and construction of houses that collect and store solar energy without fans, pumps or other mechanical devices. Passive solar heating makes use of warmth moved by the natural processes of reflections, radiation, conduction and convection.

The Solar Energy Resource

Passive solar heating, especially when used in conjunction with conservation, can significantly reduce Alaskan dependence on costly fuels. For example, two identical houses, sitting side by side and facing south, will receive the same amount of solar energy. However, if one is more heavily insulated than the other and has less cracks where air can leak in and out, it will retain more heat, and require less fuel over the heating season. In fact, insulation may prove to be the most important element of passive solar design.

Insolation (incoming solar radiation) is usually measured in terms of the number of BTUs striking a square foot of surface during a specified time period. The amount of insolation received at a given point in the day is dependent upon the area and thickness of cloud cover as well as the sun angle and the number of hours of available sunlight. Because of the interplay of these factors, insolation statistics do not necessarily correspond with latitude e.g. Juneau doesn't receive more solar radiation than Fairbanks.

In Alaska, those regions with Continental (Interior) and Transitional (Southcentral, Southwest, and Northwest) climates are the areas where solar heating would most likely be practical. In March, the average insolation on a vertical south-facing surface in BTU/ft^2/day is 1687 for Matanuska, 1892 in Bethel and 1808 in Fairbanks. A vertical surface receives its maximum insolation in March and April; a horizontal surface receives its maximum insolation in May and June.

For efficient passive solar heating, a house must serve as a 1) solar collector, 2) heat storehouse and 3) heat trap.

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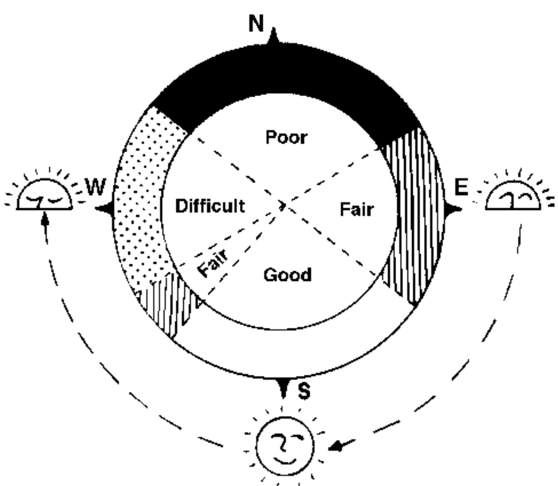
The House as a Solar Collector

Every surface of a building which is directly exposed to the sun's rays is collecting solar energy. Other surfaces, not directly exposed to the sun's rays, can be heated by convection, conduction and radiation. The passive solar house maximizes this collection by:

- Siting considerations. During the heating season, the sun's path makes an arc in the southern sky. When designing and constructing a passive solar house, the consumer should be aware of the placement of trees, other houses and mountains which might stand between the house and the sun's path in the sky. These objects may create shadows on a building and reduce the solar collection for that section of the house.



- House orientation and shape. South sides of houses receive the most solar radiation during the winter. East and west sides receive more solar radiation in summer than in winter. When designing a passive solar house, make the south side of the house longer than the east/west side. But don't build a long, one story California Ranch style house, because you have too much surface area of roof and walls where heat is lost.

- Window Placement. South-facing glass windows allow direct sunlight to heat the house interior. In an energy efficient house, south facing windows can provide up to 30% or more of the heating load. An overhanging eave or awning on south-facing windows will prevent overheating during the summertime. Also, too much glass on the west side of the house, where the low evening sun that hangs for hours, can easily overheat rooms that have already been warmed all day by the southern sun.

- Glass Design. Maximize the R-value of windows without inhibiting visibility. New low emissivity glass will decrease radiant heat loss and increase R-value, without markedly lowering visibility.

- House color. Dark colors absorb more sun energy that light colors do. Light interiors reflect more light and reduce lighting needs.

- Solar greenhouse. When attached to a south wall, a solar greenhouse provides additional collector area as well as space for house-plants and food production in winter months.

Storing Passively Gained Solar Heat—Not an Alaskan Strategy

The usual rule of thumb about passive solar design routinely includes an indexed amount of what is termed "Thermal Mass" in the home. This typically is accommodated by designing the solar gain space with a large amount of concrete masonry or other massive building material to store the solar heat during the day and release it (theoretically) back to the living space at night when the sun has set. But is this an economical strategy for Alaska? The answer is generally no! Why is this?

The rule of thumb for passive solar design which recommends one cubic foot of concrete for every square foot of solar aperture area was developed in the southern and southwestern U.S. where substantially more solar gain is to be had during the winter heating months than in Alaska. This thermal mass question needed to be tested with research, so in 1983-1984, Richard Seifert conducted a study of the effects of thermal storage mass for the heating of a test building in Fairbanks, at the University of Alaska. The conclusions from this testing indicate that it is not really feasible to size a mass system such that it can function well for any significant portion of the year. What happens is that for the major portion of the heating season (from mid November to mid February) the mass is of no practical use. Even during the best solar heating season of the year (March and April), the storage was useful on only 22 of 57 days (38%) . The fundamental conclusion is that sizing a storage system to moderate overheating and store useful heat for later release is, at subarctic latitudes, very limited. And there is the additional factor of high cost for inclusion of thermal storage in a building, so it is difficult to recommend this strategy for Alaskans. For the most effective utilization of Passive solar heating, we suggest south glazing, combined with a thermally efficient building envelope. Keep the mass to a minimum in the house, and ventilate when overheating occurs. This means solar gain is an economical source of opportunity, but not worth it to the average homeowner (at this time) to provide for its short term storage.

The House as a Heat Trap

Passive solar heating goes hand-in-hand with good building, insulation and conservation practices. High heat loss through walls, ceilings and windows increases both the area required for solar energy collection and the amount of additional energy source needed.

The recommended minimum insulation values for a passive solar house in Alaska are R-30 walls and R-50 ceilings. However, any increased insulation will increase the solar performance.

Well insulated walls and roofs, along with proper sizing and placement of windows can cut fuel bills by 50% and up. Single pane windows lose three times as much heat as triple pane and 40 times as much as an R-40 wall. Insulated shutters should be used to reduce nighttime heat loss. There are also a number of new glazings on the market, such as low emissivity, "heat mirror"®. These increase the insulating effect of glass and make the house more comfortable.

Economics

Depending on the type of system used, the builder's familiarity with the concept and, more importantly, the small details of passive solar design and construction, passive solar features can add 0 to 15% to design and construction costs. However, this is a one time cost for energy saving features that last the lifetime of the building. Many features such as proper siting, house color, house orientation and shape, and window placement can be considered without additional costs. Use of computer-aided design, and new windows can minimize the extra cost of solar design.

Passive solar heating requires the occupant to become more aware of the surrounding environment.

Passive solar heating is gaining market acceptability. In Alaska, passive solar houses have been built in Anchorage, Homer, Juneau, Delta Junction, Copper Center, Ambler and Fairbanks, among others.

Passive solar heating provides space heat which is inherently simple, clean, safe, cheap and lasts the lifetime of the building.

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The following web sites are very deep sources of information about solar design:

www.ases.org is the web site of the American Solar energy Society.
www.ises.org is the web site of the International Solar Energy Society.

Visit the Cooperative Extension web site at www.uaf.edu/ces
See also www.alaskasun.org

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The Attached
SOLAR GREENHOUSE

by
Richard D. Seifert
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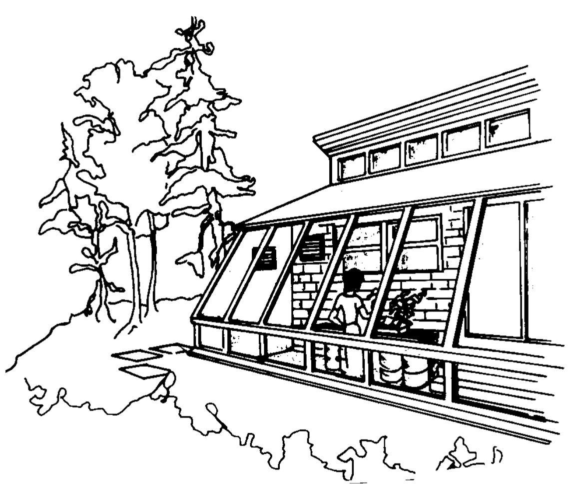
EEM-01259

Attached solar greenhouses have gained considerable popularity, as an addition to an existing house or as an integral part of a new home. The attraction of the solar greenhouse is its adaptability.

Design, construction, and use involve a wide range of options which can be combined to meet many tastes, needs and budgets. However, for good energy performance under Alaskan conditions, the following standards should be incorporated into the design of the greenhouse: the greenhouse should face south if the north side is not transparent; heavy insulation in the end walls and roof; no glass in the roof; no glass in the end walls unless you are prepared to leave movable insulation over the glass permanently during winter months; and heavy insulation at the slab (or other floor) perimeter.

How It Works

In the winter, sunlight passes through the windows and warms the darkened surfaces of the concrete floor, brick wall, water-filled drums, or other storage mass. Some heat is absorbed into the thick concrete and brick and the water, where it will remain stored until the indoor temperature begins to cool after the sun sets. The heat not absorbed by the storage elements can raise the air temperature inside the greenhouse, during the day, into the 90° to 100° F range. As long as the sun shines, this heat can be circulated into the house by natural convection or drawn by a low-power fan.



It is extremely difficult to design and build a greenhouse in Alaska that can be used as an efficient solar heater AND at the same time, an environment for growing plants and/or food. If a lot of mass is used in the greenhouse to reduce the temperature swings that destroy plant life, the vast majority of solar heat will be used in the greenhouse, and never enter the main house. If the intended purpose is to provide as much heat as possible to the house, mass should be MINIMIZED. This is because the heating load of a house is much greater than the heat available from the sun at any given hour of the day for about six months of the year. All the heat from the sun can be used immediately in the house. Storing heat in thermal mass in the greenhouse and then transferring it into the house at night is simply not very effective in Alaska for most of the year.

One alternative is to make the thermal mass portable (usually water), so that it can be removed during the winter, then put back into place in the summer. The mass helps prevent overheating and the need for continuous venting.

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Five Passive Solar Elements

Any solar greenhouse must include the following elements in order to be considered a passive solar heating system:

1. **A COLLECTOR**: such as the double layer of greenhouse window glazing (glass or plastic).

2. **AN ABSORBER**: usually the darkened surfaces of the walls, floors, and water-filled containers inside the greenhouse.

3. **A STORAGE MASS**: normally the concrete, rock, and/or water that retains the heat after it has been absorbed.

4. **A DISTRIBUTION SYSTEM**: which is the means of getting the heat into and around the house; i.e., natural convective flows through doors or windows or high and low openings into the house. Fans can supplement and greatly improve performance and are considered to be active components.

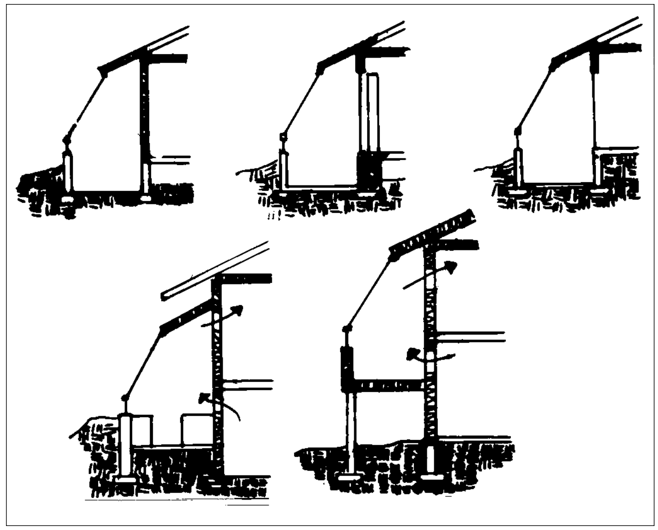
5. **A CONTROL SYSTEM** (or heat regulation device): such as the movable insulation used to prevent heat loss from the greenhouse at night, and roof overhangs that block the summer sun are passive controls. Some controls are operated by occupants, some are automatic, such as temperature sensitive motors, which are activated to open or close vents without the use of electricity. Fans and thermostats that activate fans are active control systems.

All five of these elements must work together.

The Attachment: Some Options

One of the more important questions to consider when designing a solar greenhouse is how it will be attached to the house. The following options demonstrate the adaptability of the greenhouse concept:

Option 1: The greenhouse is separated from the main structure by an uninsulated brick, block, or concrete wall. This wall will absorb and store solar heat that will–over a period of several hours–migrate through the wall, most of it reaching the main living space later in the day and after the sun has set.



Option 2: The greenhouse is separated from the main structure by sliding glass doors and stationary "door-size" windows. Behind the stationary windows, inside the living space, are tall water-filled tubes. Sunlight, passing through the greenhouse, then through the stationary windows, strikes the water tubes. These absorb and store heat for later use. (If the tubes are spaced apart, the room also receives direct sunlight for immediate warmth.)

Option 3: As in Option 2, the greenhouse is separated from the main house by oversized windows and sliding glass doors. The sunlight strikes the masonry floor of the living space. The floor should be at least four inches thick (typically, a concrete slab covered with ceramic tile or brick) and left uncarpeted (carpeting will prevent heat absorption).

Option 4: The greenhouse is attached below the roof line and covers a portion of two levels of the house. This option can, if properly designed, let the air circulate naturally between the house and the greenhouse and eliminate the need for fans for circulation.

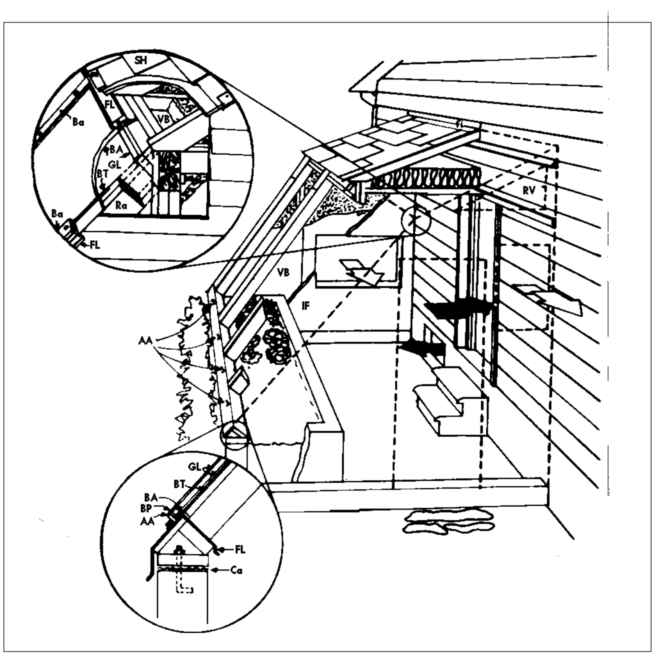
Option 5: The greenhouse is raised on pilings and insulated heavily in the floor, roof and other unglazed exterior areas. This option is suitable for permafrost areas and greenhouses that are attached to second story dwellings. Extreme care should be taken in permafrost areas to see that there is good air circulation around the pilings and that the pilings conduct as little heat as possible to the ground, or pilings and structure may settle.

A combination of these and other options may be the best overall approach. In any case, these are only a few of the things that ought to be considered when designing and building a solar greenhouse.

More Design Considerations

For Alaskan conditions, one recommended design consideration is the use of vertical glass instead of sloped. Sloped glazing is more difficult and expensive to install, has a much greater tendency to leak, and is more prone to breakage. In the winter, the sloped glazing actually gets LESS solar gain, because of our low sun angles (maximum solar gain occurs when the sun is perpendicular to the collector surface), and has to be cleared of snow. Also, sloped glazing is angled such that the reflection from the snow is less effective (snow reflection actually increases solar gain on vertical glass). Finally, because you can't easily shade the glass in summer, continuous venting is necessary. With vertical glazing, the overhang helps shade the glass, and overheating is minimized.

The illustration below shows some important design concepts, and many of the same details apply to a greenhouse with vertical glazing. The vertical glazed greenhouse is easier to build, because the glazing details are simpler.



(Above) Flashing and other details where the roof, end wall and glazing meet. (Below) The Flashing overlaps the sill both inside and out. In the large drawings, the dark arrows show winter airflow. The white arrows mark summer venting.

First, this solar greenhouse has an insulated roof. If the roof were glass, much more heat would be lost because warmer air rises and accumulates near the roof. Glass provides very little resistance to the conduction of heat back outdoors.

Another point about the design is its simple relationship to the main structure. Heat can be drawn from the top of the greenhouse by a fan, or heat can circulate naturally from greenhouse to house via an open window or door. Heat stored in the wall between the greenhouse and the house will radiate as the temperature falls.

Movable Night Insulation

When the sun sets, the window through which heat has been efficiently collected during the day, becomes a problem. The flow of heat back through the glass at night may result in losses greater than the daytime solar gain. It is important to block these night losses.

The traditional solution has been the use of movable night insulation. However, mechanical systems are expensive and manual systems don't get used with any regularity, as the thrill of the new structure dulls and the job of moving new shades becomes boring. But, they are essential if you intend to grow plants in the colder months. You can get by without shades if the greenhouse acts solely as a heater, and you allow that space to cool down at night. The greenhouse will buffer the wall it's attached to, reducing heat loss from the house. There is no question that there would be less heat loss with the movable insulation, but the economics are questionable because of the cost of shutters and shades.

Another alternative is the use of the new high R-value glazings that are now available. Low emissivity glass increases R-values as well as reduces summer heat build-up through selective filtering of the sun's rays. Though not as effective as movable insulation, they are better than a double pane window with unused shades because the homeowner forgot or wasn't around to close it!

How Much Heat Can Be Provided To The Home

The Alaska Department of Transportation and Public Facilities (DOTPF) Research section has studied the annual performance of a greenhouse attached to a building in Alaska. The study was conducted using computer simulation of the performance at wide-ranging locations throughout Alaska from Homer to Barrow. The conclusions are stern and conservative. The results show that it is not possible to justify the expense of an attached solar greenhouse in any climatic region of Alaska. It is important to consider this fact in the design, as there will be periods of the year when the greenhouse space will be a net loser of energy, regardless of the location.

Frequent problems have also been noted when a greenhouse, originally intended to be operated only in the warm months, is used year-round. The result is that condensation problems become rampant. The greenhouse acts as a large cold condenser for house air which finds its way into the greenhouse. Always assume that a pleasant and available space such as a greenhouse will in fact be used year-round because to do otherwise can cause condensation problems.

Air fans and air handling systems in a greenhouse are areas of special difficulty. These systems are especially difficult to seal and often exacerbate condensation problems.

Experience in Norway indicates that wood frames for greenhouses are subject to deformation, shrinkage, warping, and are difficult to protect from water damage, especially if they have roof joists where wood can become easily exposed to water penetration. These designs are popular in Alaska, but the consumer should be wary of these vulnerabilities.

Excess heat can be used to heat domestic hot water prior to the water going into the hot water tank. In Alaska, the ground temperature (and water) is often in the 35° to 40° F range. If the excess heat can be used to raise these low temperatures instead of dumping the excess heat, you will be conserving the energy source you are presently using to heat your domestic hot water. (Note: the average urban family of four can use up to 25% of the total energy used in the household just to heat domestic hot water.)

Solar greenhouses can be linked to a remote rock storage bin. Heat is ducted from the greenhouse to the rock bin with the help of fans and blowers. The rocks absorb and store the heat until it is needed. The bin is usually located in the basement or crawlspace of the house or underneath the greenhouse.

The introduction of active elements–the forced air duct to and from the rock bin and the rock bin itself–turns a greenhouse into a hybrid system, a combination of active and passive solar.

Construction

Some homeowners prefer to do it themselves, other prefer having it done for them. Some have their greenhouses custom-built, other buy packaged assemblies. The design presented in this factsheet is principally a tight solar heater; it can be adapted to both new and existing buildings. It can be built to whatever size and specifications are required. The cost of a greenhouse depends on the overall design, the materials used, and the need for and cost of professional labor.

Bibliography

The Solar Greenhouse Book, James McCullagh, Rodale, 1978.

The Passive Solar Energy Book, Edward Mazria, Rodale, 1979.

Passive Solar Energy, Bruce Anderson & Malcolm Wells, Brick House, 1981.

The Food & Heat Producing Solar Greenhouse: Design, Construction, & Operation, Fisher & Yanda, 1976.

Visit the Cooperative Extension Service Web site at: www.uaf.edu/ces/
and Rich Seifert's Homepage at: www.uaf.edu/ces/faculty/seifert

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BUILDING IN ALASKA

Woodstoves:

A Safety Checklist

EEM-01350

To protect your family and property, woodstoves must be properly installed and operated. This checklist was developed so that you can review the most important points before you start that first fire in your new woodstove.

CHECKLIST

Installation:

- Read your owner's manual and follow the recommendations and guidelines.
- Make sure the woodstove is not too large for the area it is heating.
- Make sure the stove does not have missing parts or large cracks that make it unsafe to use.
- Some kind of fire protection material must be used to cover the floor and walls that are close to the stove. Follow building codes and manufacturer's literature for safe installation. These sources will tell you what materials to use and how to install them.
- The stove should have legs at least 4 inches high or the unit should be placed on masonry blocks with the holes to the sides to allow air circulation under the stove. Securing the stove to the floor is advisable in seismic risk areas.
- Run a duct from the outside of the building to very near the woodstove to provide combustion air for the heating unit and minimize cold air infiltration to your home.
- For clearance requirements, refer to local building codes and manufacturer's literature. If none are provided in your area or with your stove, consider a 36-inch minimum distance to any wall from the stove.
- All open front woodstoves should have a screen.

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UNIVERSITY OF ALASKA FAIRBANKS

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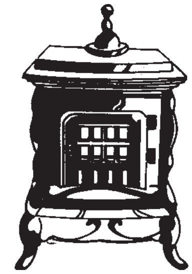
Chimney Installation:

- Do not reduce the stove pipe diameter between the stove and the chimney flue. Follow manufacturer's specifications.
- Avoid connecting more than one heating device to a single chimney flue because poisonous gases or sparks may pass from one appliance out the other.
- A single wall chimney pipe needs 18 inches of clearance to combustibles. Metalbestos or triple wall chimney pipes and masonry chimneys need 2-inches of clearance to combustible materials. If you insulate around the chimney, increase minimum recommended clearances and insulate with mineral wool (rock wool) or other non-combustible insulation. Fiber glass insulation is non-combustible but is held together with a resin that vaporizes at 250°F, so is not an approved material.
- Keep combustible forms of polyurethane, styro-foam, cellulose or other insulation away from chimney pipes.
- Install a damper on your chimney pipe, even if your stove is equipped with one, so that you can control a chimney fire.
- If using a single wall stove pipe, each joint should be secured with at least 3 metal screws. A severe chimney fire can blow unsecured joints apart.
- The chimney should extend at least 2 feet higher than any point of the roof within 10 feet of the chimney pipe. It is extremely important to maintain a minimum of a 2-inch clearance between the chimney and combustibles (i.e., support frames and insulation).

- Use an insulated metal chimney which is approved by Underwriter's Laboratories or the Alaska D.E.C., where a masonry chimney is not available or practical.

Operations and Maintenance:

- If using an airtight stove, open the intake damper fully before you open the door. Hot, unburned fuel gases can burn explosively if air is introduced too quickly.



- Never burn coal and wood in the same stove, unless it is designed to do so. Since coal generates a higher heat, coal stoves are constructed differently.
- Burn dry, well seasoned wood, which has dried at least one year. This will reduce creosote deposits, and provide more heat output. Two drying seasons are recommended for hardwoods, such as birch and aspen.
- If burning artificial logs, never poke or burn more than one at a time. They contain up to 60% wax or sterno and will burn extremely fast if broken up. This will damage your stove and may cause a house fire.
- Keep all wood, paper, matches or other combustibles away from the woodstove or chimney pipe.
- When you reload a woodstove or start a fire, let it burn with dampers wide open for five minutes. This will burn out creosote deposits in the chimney. Do not start a hot fire if there is an ⅛-inch or more thick layer of creosote in the chimney pipe.
- Never use flammable or combustible liquids to kindle or rekindle a fire!
- Use a metal container with tight fitting lid for ash disposal.
- The building or fire inspector should approve the installation.
- The company insuring the building should be notified of the installation.

WOOD STOVE SAFETY ISSUES

Stoves must be set up and used with great care to avoid serious fire hazards. Safe chimneys are absolutely essential. Flue walls must be sound as occasional chimney fires are almost inevitable when burning wood or soft coal. Safe placement of stoves and proper vent connection are also important.

Unlined single brick chimneys found in many older homes are especially hazardous. This type of chimney often was not very safe when it was built and certainly should be suspect now. Mortar in the joints probably has broken down and some bricks may be cracked. The combined action of weather and hot gases causes these conditions most often near the chimney top. However, cracks and openings commonly develop well below the roof in tinder-dry attics. Masonry chimneys also increase risk from collapse during earthquakes.

Fireplaces and older model stoves, when fired vigorously from day to day, are usually not as hazardous as the controlled burning stoves common today. Soot and creosote did not build up as small accumulations may have ignited and burned safely. Heavy chimney deposits, once ignited, burn intensely at dangerously high temperatures.

Present day building codes and insurance underwriters encourage safe chimney design. Masonry flues are lined with fireclay at least ⅝-inch thick or some other approved material. All wood beams, joists, and studs must be kept at least 2 inches away from masonry enclosing a flue. Approved, factory-built chimneys, when correctly installed, are also acceptable.

Chimney fires are possible in all but the cleanest chimneys. A safe installation and extra care will help prevent fire, abut accept the idea that there could be a fire and be prepared to handle it. Make certain everyone in the house is familiar with the warning signs of a chimney fire (sucking sounds, a loud roar, and shaking pipes). All adults should know how and when to use a fire extinguisher. Place the fire emergency phone stickers on every phone (available at your nearest fire station). If you think you have a chimney fire:

1. Call the fire Department immediately, before doing anything else.
2. Cut off the fire's air supply by closing all dampers on the woodstove and/or chimney pipe.
3. Get everyone out of the house and put them to work watching for sparks or signs of fire on the roof or nearby.
4. Keep a Class 1A:10BC dry chemical fire extinguisher handy. If the house catches on fire, try to extinguish it if it is safe to do so. Stand back 6 to 8 feet and direct the nozzle to the base of the flames.

Stoves, flues and chimneys should be kept clean. If a chimney has a build-up of ¼-inch of creosote, a chimney fire hazard exists. Chimneys serving airtight stoves should be checked frequently, as total blockage has occurred less than 72 hours after installation. Chimney cleaning should be accomplished by a mechanical means. Flue brushes with extendible poles are available for about $25 from most heating dealers. Do not use chemical cleaners, because they can cause corrosion on metal chimneys and sometimes start intense fires caused by accelerated oxidation.

Make sure all ashes are completely dead before you throw them out. Ashes make excellent sidewalk de-icers, and soil enhancement. This is **not** the case however, for coal ashes.

Most fire departments will inspect your stove and chimney. Many chimney sweep businesses provided free chimney inspection services as well. For more information on proper installation and maintenance of your wood burning stove, order a copy of the pamphlet entitled *Wood Stove Safety*, published by the Fairbanks Fire Department.

BACKDRAFTING

Research indicates that backdrafting problems are widespread and may pose a health hazard. In addition to backdrafting, many houses suffer spillage during the start-up of furnaces and water heaters.

Incidents of chimney spillage are becoming more frequent and hazardous. The spillage occurs when chimneys interact with other parts of the house.

Three factors are making houses more prone to pressure-induced spillage: tighter building envelopes; increased exhaust capacity; and, unusually weak chimney draft.

Before a house is occupied, a test should be conducted to see if the exhaust appliances are capable of depressurizing the house to unsafe levels. The simplest approach is to turn on all the fans and fireplaces. Then time the duration of spillage when the stove is started up. A smoke pencil or lighter flame can be used to detect spillage. If spillage continues for more than 30 seconds, you have a chimney venting problem. Try to avoid testing on windy days.

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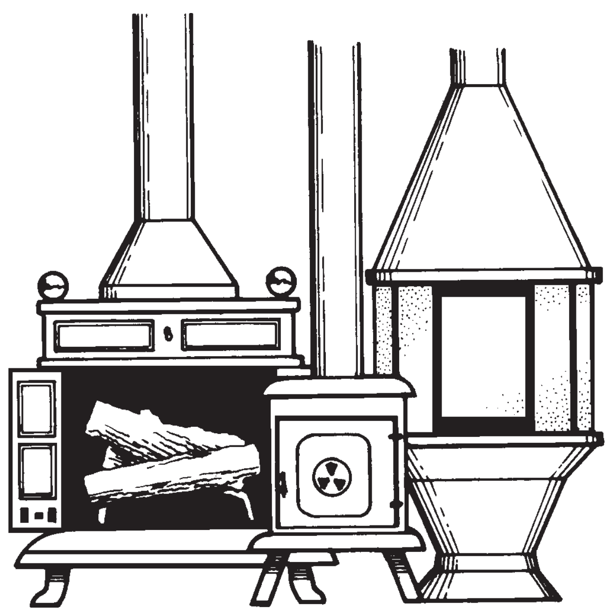


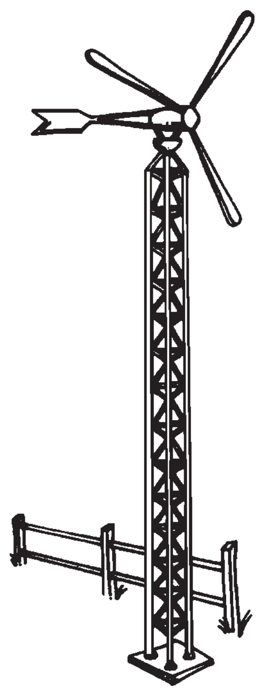
BUILDING IN ALASKA

EEM-01352

Windpower
Factsheet

Richard D. Seifert
Energy and Housing Specialist

Wind energy conversion systems (WECS) convert the kinetic energy of a renewable resource – wind – to mechanical energy. This energy can be used as electric power or for direct applications such as water pumping.



Several important considerations need to be applied to use successful wind energy for home power. These considerations include site evaluation, proper choice of equipment, and energy conservation.

Site Evaluation

Average wind speed is the critical factor used in determining the economic effectiveness of wind machines. For a WECS system that generates electricity to be practical, you will need an average monthly wind speed of 8 to 14 miles per hour (mph) at your site. The amount of power available in the wind is proportional to the cube of the wind speed, an important fact to consider when siting wind turbines. Underestimating the average wind speed 20% means that a site could actually produce 73% more energy. Overestimating a site's wind speed by 20% could produce about half the expected power.

An anemometer is used to measure wind speed. A basic anemometer measures the distance a column of air moves over a site in a given period of time and registers the count on a digital meter. Daily readings, totaled each month for at least four months (preferably a year) are advisable.

Government weather stations in your area can provide average monthly wind speed figures for a whole year. Contact at least three weather stations and compare your records to theirs. By

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comparing monthly averages you can find the ratio between your monthly wind speed and the average monthly wind speeds. This ratio helps you determine the average wind speed at your site during each month of the year.

You need to know the highest wind speed gusts that are likely at your site because the wind generator and tower must be built to withstand violent winds. Your local weather station can supply data on storm winds and gusts. Use the same ratio determined above to customize those figures to your site; multiply this new highest gust estimate by 1.33 (a "gust constant"). Your wind generator and tower support must be designed to handle this amount of gusting for safety and insurance purposes.

Equipment

Combine the efficiencies of both rotor and generator to determine system efficiency. Today's best turbines can convert about 40% of the wind's energy to mechanical energy. With a typical generator efficiency of about 85%, the WECS can achieve a maximum overall efficiency of about 35%. This conversion compares favorably with other energy technologies. Typical commercially available photovoltaic modules have efficiencies of less than 15%; conventional power plants have 30% to 40% thermal efficiency.

A wind generator's rated output is usually for sea level air density. Higher altitudes have lower air density and require higher wind speeds to achieve a given output. Temperatures also have some effect on output. The density ratio altitude (DRA) chart below shows the real output of a wind generator at your site's altitude. Find the DRA figure nearest your site's altitude and multiply it by the rated output of the wind generator you are considering to determine actual output.

Altitude Above Sea Level	DRA (60°F)
Sea Level	1.000
2,500 feet	1.000
5,000 feet	0.912
7,500 feet	0.756
10,000 feet	0.687

Any wind generator should be equipped with a blocking diode and proper voltage regulator to provide battery protection. The diode will prevent the generator from becoming a motor that would deplete the batteries when there is no wind.

AC or DC

The electricity generated by a wind turbine may be

1. Converted to alternating current (AC) and used without storage,
2. Stored in batteries and later used as direct current (DC) or alternating current, or
3. Tied into an existing utility grid through the use of an induction generator.

To use standard AC appliances you must either tie in to a utility or convert the DC produced by the generator to AC with an inverter.

System Sizing

The amount of electricity required is the basis for deciding the size wind generator you need. Power requirements may change during the year, so the demand estimate should be made on a monthly or seasonal basis. This estimate can be compared with wind speeds, which also vary seasonally, to determine the match between expected energy supply and demand. Electrical demand is usually greater during the winter than the summer for most Alaska users.

Decide what appliances will be used and how long they will be turned on to determine demand estimates. Also determine the maximum rate of electricity required, or how many electrical devices will be on at the same time.

Review your electrical needs and decide how much you can reduce them without giving up too much convenience. Using other energy sources to heat water, cook and refrigerate, will reduce your electrical needs and save money.

Proper Tower Placement

Wind turbine location is very important. Wind speeds can vary 30% or more between sites only 100 feet apart in areas of rolling hills or tree cover. Figures 1 and 2 show the effects of terrain and height on the percentage of maximum wind speed available.

The wind turbine should be mounted on a tower 30 to 80 feet high to take maximum advantage of the wind. Roof mounting is not recommended because blade vibrations can be felt through the entire house. The rule of thumb is to have the tower height at least 20 feet higher than any potential obstacle within a range of 500 feet. Remember that an increase of only 1 mph wind speed can give a 33% increase in power.

The wind tower should generally be located within 100 feet of the house or battery storage system because of the potential voltage drop in transmission lines.

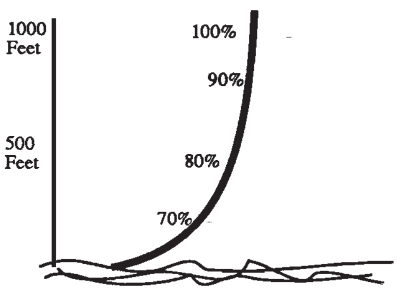


Figure 1. Height Over Smooth Terrain Vs. Percentage of Maximum Wind Speed

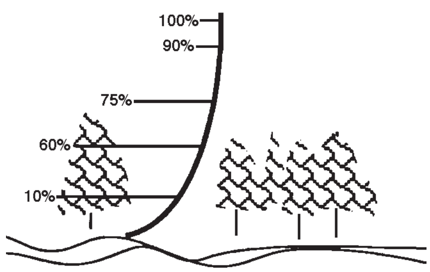


Figure 2. Height Over Rough Terrain Vs. Percentage of Maximum Wind Speed

Energy Conservation

1. Tower and foundation costs can be significant. It is often worthwhile to build 100-foot towers because of higher winds at higher elevations. A higher more expensive tower results in increased power output of the system and reduces backup power costs. This makes it possible to use a smaller and less expensive wind generator to get the same amount of power.
2. The model wind generator you choose will affect the cost of power generated. Larger, more expensive WECS cost more initially, but will provide lower cost per kWh. Alternatively, smaller units (less than 4 kW) are more proven and more likely to last longer.
3. A larger battery bank will allow for longer periods of low wind without the need of a back-up system.
4. An inverter allows you to convert wind power to AC and use more conventional appliances and wiring. Weigh the expense of the inverter versus efficiency, possibility of both AC and DC circuits, and the appliances involved.
5. Consider utility intertie. Determine rates at which your local utility is willing to buy and sell power. This rate will help figure the economics of tie-in versus using the utility as a back up source only – or not at all. Check with your local utility or the Alaska Public Utility Commission Tariff Section to establish pay back rates.

For more information contact:
Energy Resource & Information Center (ERIC)
520 E. 34th Avenue
Anchorage, AK 99503
(907) 564-9170 or 1-800-478-INFO (4636)

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
U.S. Department of Energy
P.O. Box 3048
Merrifield, VA 22116
800-523-2929

For a map of wind energy distribution in Alaska, see the publication Wind *Energy Resource Atlas, Volume 1, Alaska*, PNL-3195, in ERA-10, UC-60. Available from Environment and Natural Resources Data Center, University of Alaska, 707 A Street, Anchorage, AK 99501, or from N.T.I.S., U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22151.

Wind Power Related Webpages

http://www.windpower.dk
is the Danish turbine manufacturers page. It's the best wind site I've seen, has both technical and policy stuff.

http://www.dewi.de
is the German wind institute with links to most of the German companies.

http://www.uni-muenster.de/Energie/wind/markt/mkt-a-e.html
Try variations on this URL as there is quite a lot of interesting stuff at the site.

http://www.OrgVE.dk/
is the Danish renewable energy organization.

http://www.econet.org/awea/
http://www.bwea.com/
are the American and British Wind Energy Association home pages, respectively.

http://www.inforse.dk
is the international network for sustainable energy and should have some relevant information and interesting links.

http://www.dti.gov/NewReview/
has back issues of a UK government magazine on general UK renewable energy news.

http://www.wpm.co.nz
is the wind power monthly magazine electronic edition from New Zealand.

http://www.nationalwind.org/pubs/pubs.htm
At this site is the full text of "Wind Permitting Handbook" developed by the siting sub-committee of the National Wind Coordinating Committee. Useful if you want to go bigtime and provide utility power.

Reviewed by Virginia Moore, Energy Consultant and Educator, Anchorage, Alaska, and Richard Seifert, Extension Energy and Housing Specialist, Cooperative Extension Service, University of Alaska Fairbanks.

Visit the Cooperative Extension Service Web site at: www.uaf.edu/ces
and Rich Seifert’s homepage at: www.uaf.edu/ces/faculty/seifert

Chapter 3
Building Materials

"There are no wrong building materials—just materials used the wrong way." Joe Lstiburek

Key Points to Learn

- Building materials are key components of heat, air, and moisture control.
- Wood, the most common building material in Alaska, has many unique characteristics that must be considered by the builder.
- Building materials may affect indoor air quality.
- Some building materials are more environmentally friendly than others.
- There is no single best solution. Any combination of materials should be evaluated to choose the best compromise.

Introduction

Building science focuses on ways to con trol heat, air, and moisture flow in build ings. Building materials are key com ponents in that control, and choosing the right materials and installing them properly will ensure a successful finished product.

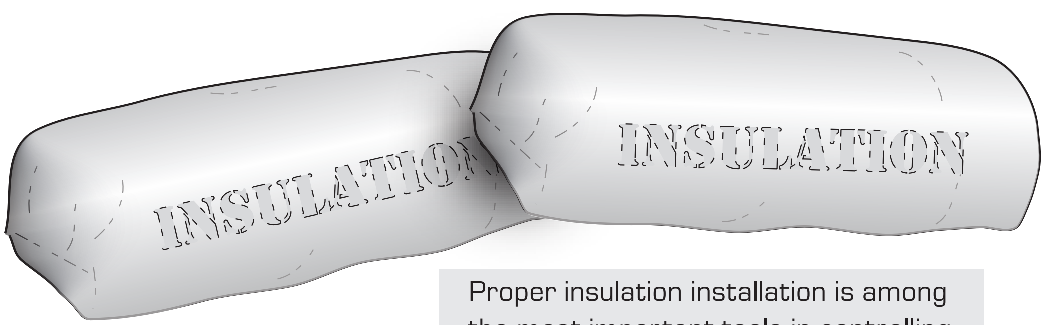
Choosing Building Materials

Materials selected during the design and construction phases need to be appro priate to the building location, climatic conditions, and building usage and must be compatible with each other.

When selecting individual compo nents of exterior building assemblies, use caution. Problems with incompat ible materials may take years to appear, so before relying on any new material, check first with the manufacturer to verify that the product is appropriate and compatible with all other materials used in the assembly. Or better yet, use a manufacturer that provides a complete system of compatible materials. Today there are many choices of materials available for building homes. Each ma terial has particular characteristics that make it more or less attractive than oth ers. There are obvious considerations such as cost, availability, and building constraints that will help you choose appropriate materials.

Also consider:

- Is it easy to install?
- If installed in a concealed location, will it last the life of the building or will it be accessible and easily repaired?
- Is it compatible with other materials?
- Is the material unhealthy for the in staller or the building occupant?



Proper insulation installation is among the most important tools in controlling home comfort and fuel costs.

Materials That Control Heat Flow

Insulation

Insulation is any material that restricts heat flow. It is installed continuously throughout the building envelope to reduce the conduction of heat through walls, ceilings and floors, keeping heat in during winter and out in summer. It comes in a wide variety of materials and in many forms, such as batts, blankets, loose fill, rigid and foam. Proper insu lation installation is among the most important tools in controlling home comfort and fuel costs.

When choosing insulation, there are several points to consider.

- Thermal performance: installed R value
- Lifetime performance: will it lose R value over time?
- Fire safety: If it is flammable, how should you protect it and the building?
- Moisture: What happens if it gets wet?
- Air infiltration: what happens if air gets into it? Does the insulation also work as an air barrier?
- Environmental issues: what does it do to the environment to manufacture it? Is it made of recycled material?
- Health issues: safety concerns of the installer and safety for the occupants

R-value measures how well a mate rial insulates; the higher the R value, the more effective the insulation. R-8 insula tion blocks heat movement twice as well as R 4 and half as well as R 16.

- To compare the effectiveness of different kinds of insulation, look at the R value per inch of insula tion. R value is proportional to the insulation's thickness, but it also depends on the type of material and its density. The more air pockets an insulating product has, the higher the R value.
- The R value assumes no air is leak ing through the insulation. Air leak age lowers the R value of insulation. It is important to seal air leaks. Standard density materials such as fiberglass batts and loose-fill mate rials do not seal effectively against air leaks. Some insulation materials, such as rigid foam and spray in place products, reduce or eliminate air leakage.
- Proper installation is as important as how much insulation is installed. Gaps and compressed areas can lower the R value over 30 .

The Impact of Voids

How big a problem are insulation voids? Large, as shown in Figure 3.1. Even a small area of missing insulation seriously impacts the effective R-value of the en tire component.

- Make sure the insulation boundary is complete. The insulated surfaces of the home define the insulation boundary. This should form a com plete envelope around the areas of the home that are heated and cooled. It is typically obvious where

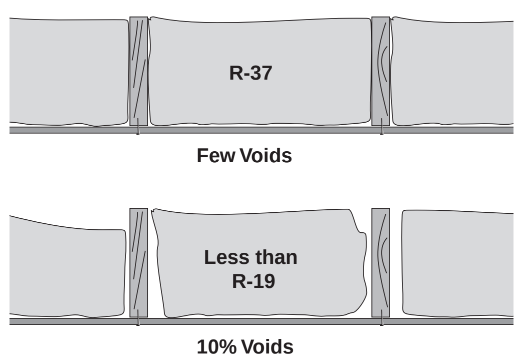


Figure 3.1: Effective R-values with and without voids in the insulation. The effective R-value of R-38 insulation, in- cluding the effects of framing, drywall, and air films, becomes less than R-19 with 10 percent air voids.

insulation should be placed. In cer tain areas, such as a crawl space or 1½ story home, you need to decide whether a space will be inside or outside the insulation boundary.
- Cost-effective wall and roof framing techniques use less lumber and more insulation.

Types of Insulation

Each type of insulation has pros and cons in terms of installation, cost, and effectiveness. Appendix 1 shows the R-values per inch of various buildng maeri als. The actual R-value for a specific type of insulation may vary between manu facturers and even between different products from the same manufacturer. Manufacturers must label their insula tion products according to strict regula tions of the Federal Trade Commission. The R value is always listed prominently either on the insulation material batts and rigid foam) or on the bag (loose-fill).

Building insulation materials can be loosely categorized as:
- batts and blankets
- loose-fill
- blown in
- sprayed in plastic foam
- rigid board plastic foam
- reflective insulation.

Fiberglass batts and blankets are the most commonly used insulation used in Alaska. The main insulating ma terial is mineral fiber—either fiberglass or rock wool fibers. Batts are sold as pre cut strips and blankets as continu ous rolls. Both are sold in widths that match conventional wall stud and ceil ing rafter spacings so they may be sim ply pressed or stapled into place. They are sold both with and without kraft or reflective foil/vapor-retarder facings. A vapor barrier is faced toward the warm in winter side . Types without a barrier are used when adding to existing insulation or with visqueen vapor barri er. Kraft paper is not an effective vapor barrier, particularly under our intense conditions in the subarctic. The advan tages of batts and blankets are that they are readily available at nearly all building supply centers, easy to install, and rela tively affordable.

Air can move through and around fiberglass batts that don't fill the entire cavity, or where the air barrier hasn't been properly installed. This reduces the effective R-value of the batts. To achieve rated performance, installers must spend enough time to get full loft and a good fit at edges, in nonstandard cavities, and around obstructions.

Unfaced and faced batts each have pros and cons. Unfaced, friction-fit batts are easier to install correctly be cause installers can more easily see the quality of their work. Kraft faced batts are more difficult to install because of the stiff facing material and because it is more difficult for installers to notice problems. Face stapling the paper to the studs is recommended to minimize air movement around the batts. A separate vapor barrier must be provided in both cases for subarctic regions typically polyethelene .

Unconditioned air can easily blow through batts on unsheathed walls border ing attics skylight wells, knee walls , rob bing R value. You should install some sort of wind barrier, typically wall sheathing or house wrap. As a side benefit, these mate rials also can help to permanently support the batt in place.

Loose-fill insulations, meant to be poured, stuffed, or blown in place, are made from several materials:
- Loose-fill fibers are made of the same spun minerals as batts and blankets   only they're left loose or made into pellets. They're used in attics and walls.
- Cellulose insulation is made from recycled paper mostly newspaper and wood fiber that has been treated

with a fire retardant. It is used in both attics and walls.
- Vermiculite is made from mica ore, and perlite comes from volcanic rock both are heated and expanded into a fluffy, noncombustible material that is used to insulate ceilings and some walls mostly concrete block .

Loose-fill insulation is sold in bags or bales and installed by professional in stallers or by homeowners who rent the special pneumatic equipment needed. The material is loaded into a machine that fluffs and blows it through a hose into the areas between ceiling joists or cavities between wall studs. Effective ness is a direct result of the application technique.

Foamed or sprayed-in-place insulation typically polyurethane is installed by professionals who have spe cial equipment for monitoring the mix and application. It provides very high R values, doesn't shrink or settle once in place, blocks drafts caused by air in filtration because it conforms to every nook and cranny, and offers a barrier to moisture. Sprayed in place types are designed for new construction and can be used in walls, beamed ceilings and around the foundation's perimeter. They are relatively expensive. NOTE: Urea formaldehyde foam in place insulation should not be used because of poten tially dangerous vapor emission.

Rigid foam board insulations are made from a number of different mate rials: asphalt-impregnated fiber board, polystyrene, polyurethane, and polyisocy anurate. These rigid panels are generally used in new construction or residing and reroofing) where they may be installed as wall or roof sheathing, insulation beneath interior walls or around foundations. Be cause they are classified as combustible, they cannot be left exposed indoors. The panels may have foil facings on one or both sides to reflect heat. This foil facing can serve as the air vapor retarder if the seams are taped.

Reflective insulations, made from aluminum foil, are most effective in hot climates for blocking radiant heat. Ef fectiveness depends on whether the foil is simply a flat sheet or a barrier that has multiple layers separated by air spaces.

What's on the Horizon?

The best available insulation products have a maximum R value of about R 11 per inch. Several new insulation tech nologies have an R value of 20 or more, but they have not been developed as building insulation products. They in clude gas-filled panels, vacuum insula tion panels, and aerogels.

- Gas-filled panels contain multiple pockets of sealed polymer film filled with low-conductivity argon, krypton, or xenon gas, which have R values per inch of 7.2, 12.4, and 20 respectively.
- Vacuum insulation panels use a vacuum held between two gas impermeable layers of metal to cre ate R values of 25 to 40 per inch.
- Aerogels are low density solids that resemble wisps of frozen smoke. They are made most commonly from silica and offer R-values of 15 to 35 per inch. One company is developing a granulated transparent aerogel used to create skylights and windows with R values of 8 to 20.

All three of these are currently used in appliances such as ovens and re frigerators, but they are too expensive to compete with traditional building insulations.

Materials That Control Air Flow

Air Barriers are Systems, Not Just Materials

The air barrier is not one material but a combination of materials used to block air movement through building cavi ties. Acting as a continuous system, they protect the building structure and the insulation from heat loss and moisture damage. To be effective, the air-barrier system must be:

- resistant to air movement;
- continuous, completely surround ing the envelope of the house and properly supported by rigid surfaces on both the interior and exterior to prevent movement in high winds ;
- strong and durable; and
- seam sealed with the appropriate tape, caulking, weather stripping or gasket.

In some cases, building components such as drywall, baseboards or structural members may become part of the air barrier when sealed to adjoining materi als. The combination of rigid air barrier materials forms the house's air barrier system as long as the joints are well sealed.

Figure 3.1.2: Rigid foam board insulation is also sold with foil facing that can be an effective vapor retarder.

Don't rely on the insulation. The most common insulation, fiberglass, does *not* stop air leakage. In older hous es, dirty fiberglass is a telltale sign of air movement (it simply acts as a filter).

Air-Barrier System Components

The most common components of an air barrier system are:

- sheet or rigid materials for large surfaces;
- caulking and gaskets for joints be tween materials that do not move;
- weather stripping for joints that do move.

Sheet materials. Sheet materials can bridge large gaps in the air barrier. Seal the edges. Provide blocking at the edges as needed to support the material and provide backing for sealants.

Polyethylene sheeting. Polyethylene sheeting "Visqueen" is not vapor per meable and should only be used on the warm side of an insulated surface. Rein forced products are recommended for longer life.

- Support seams and edges on both sides to maintain the seal.
- Use a durable product with a thick ness of 6 mil or more.
- Protect from exposure to sunlight or use a UV stabilized polyethylene.

House wraps. House wraps are perme able to water vapor but stop air move ment if taped at joints and the perime ter. They are used on the cold side of an insulated wall to provide a wind barrier.

- Seal all joints with housewrap tape
- Protect it from exposure to sunlight or use a UV stabilized product.
- Follow manufacturers' directions for use. In wet climates, some house wraps react poorly with some kinds of wood siding.

Rigid materials. Rigid building com ponents plywood, drywall, OSB, glass, and poured concrete but not concrete blocks will act as air barriers. They may be used to complete the air barrier behind soffits, chases, tub enclosures, dropped ceilings, and other cavities. Some insulating materials such as rigid foam boards also act as air barriers.

Sealants

Make sure that the caulking you use is compatible with the surfaces you are ap plying it to.

Caulks and foams. Caulkings are not permanent and will have to be main tained. They also vary in their durability, compatibility with other materials, suit ability for painting, and curing time. All sealants will require extra ventilation of the building after application to let the material cure.

Caulk. Use to seal gaps less than ½". Select grade interior, exterior, high tem perature based on application.

Spray foam. Expands to fill large cracks and small holes. It can be messy; consider new, water based foams. **Not** recommended near sources of heat such as flue vents etc. because it is flammable.

Siliconized acrylic latex caulk. This caulk has many uses; adheres well to clean, dry surfaces; and is paintable, inexpensive, easy to use, has a long life in interior applications, cleans up with water; has a low tolerance for joint movement, moderate shrinkage; fills a maximum ½" gap width; takes 30 to 60 minutes to dry to the touch and 14 to 30 days to final cure.

Polyurethane (one-part) caulk. Many uses, paintable, more tolerant of dirt and moisture, long life in both interior and exterior use, very elastic and flexible, high tolerance for joint movement, no shrinkage; however, it is harder to use requires solvent cleanup. It fills a maximum 1" gap width, takes 24 to 36 hours to dry to the touch and 14 to 30 days to final cure.

High-temperature silicone caulk. Used to seal flue or chimney penetra tions; long life, high tolerance for joint movement, no shrinkage; not paintable; takes 6 to 12 hours to dry and 14 to 30 days to final cure.

Nonexpanding urethane foam. Adheres well to clean and dry surface, long life, no shrinkage; does not tolerate joint movement, temperature sensitive; 30 to 60 minutes initial drying and 12 to 24 hours to final cure, solvent cleanup while wet. Caution: expanding foam may deform building materials.

Gaskets and adhesives. Used to seal between materials with large bearing surfaces. It is applied as materials are assembled. Gaskets maintain a seal even with joint movement while adhesives do not. Use mechanical fasteners to mini mize joint movement.

Polyethylene sill sealer. Closed cell gasket used to seal the foundation to mud sill joint.

Gasket materials (EPDM, saturated urethane, many others). Used to seal between drywall and framing and between framing members.

Polyethylene backer rod. Used to seal window and door frames to rough openings, and seal plastic plumbing stack penetrations.

Figure 3.2: Backer rod is a rope-like material made of polyethylene, normally used to seal the space between window and door frames and the rough opening.

Construction adhesive. Used to seal subfloor to rim joist and seal air barriers at cavities during framing.

Drywall adhesive. A continuous bead of adhesive can seal drywall to framing. Durability of the seal is unknown.

Mastic. Designed specifically for duct sealing.

Blocking. Use wood or rigid foam blocking to fill holes at key framing connections and cavities, such as split-level intersections, cantilevers, and floor joists in 1½ story homes. Seal the perimeter to the framing with caulk or foam. Code-required fire blocking can be part of the air barrier if properly located and sealed.

Inner tube rubber. This is flexible and works well for sealing plastic plumbing stacks to surrounding framing.

Sheet metal. Light-gauge material can be cut and stapled to seal large gaps around flues and other hot surfaces.

Insulation. Some insulation materials save time and money by insulating and providing an air sealing benefit in one step.

Cellulose insulation. Loose-fill cellulose slows air movement somewhat. When blown into a closed cavity at high density, it significantly reduces air leakage.

Closed cell foam insulation (such as urethane). impermeable to air movement, whether applied in a thin layer or used to fill a cavity.

Specialty air sealing products. Look for products designed to reduce air leakage or simplify sealing jobs: airtight recessed cans, direct vent or sealed combustion equipment (fireplace, water heater, furnace), gasketed electrical boxes, etc.

Weatherstripping

Weather-stripping is used to block air leakage around doors and the operable parts of windows. Weather-stripping comes in a variety of shapes; it can be a flat strip, tube, or V shape and can be designed to work under compression or by sliding along the joint. **To be effective, the product must close the gap and not allow air to pass.**

When choosing weather stripping, consider the size of the gap to be sealed and the durability, ease of installation, and appearance of the product. Look for products that are flexible and that spring back to their original shape quickly and easily. Avoid products that make it difficult to operate the window or door.

Materials That Control Moisture Flow

Moisture control is a balance of wetting and drying. The goal is to avoid wet ting as much as possible and to provide the capability for drying when wetting does occur. We want to keep water out of the building shell as much as pos sible but provide a way for it to get out when it does get in. Water moisture is in two forms, liquid and vapor, and proper moisture control deals with both.

Controlling Liquid Water

Other sections of this manual deal with construction techniques such as proper foundation drainage, rain screens, and overhangs. Flashing, gutters, and rain spouts provide a last line of defense against liquid water penetration.

Flashing

The main job of a roof is to maintain a barrier between the interior and the weather. The most difficult weather ele ment to control is water. Some parts of roofs and exterior walls are particularly prone to leaks and water damage. Nearly anywhere runoff is heavy or where two different surfaces meet requires the extra protection that flashing provides. Roof flashing is usually the last line of defense in the battle against water penetration. The most common loca tions for roof flashing are at valleys, chimneys, roof penetrations, eaves, rakes, skylights, ridges, and at roof to wall intersections.

To be effective, flashing must re sist gravity, surface tension, and wind pressure. Flashing materials must be durable, low maintenance, weather re sistant, able to handle movement, and compatible with bordering materials. Common reasons for failure include exposure to salt air, excessive heat, acid rain, heavy snows, and scouring winds.

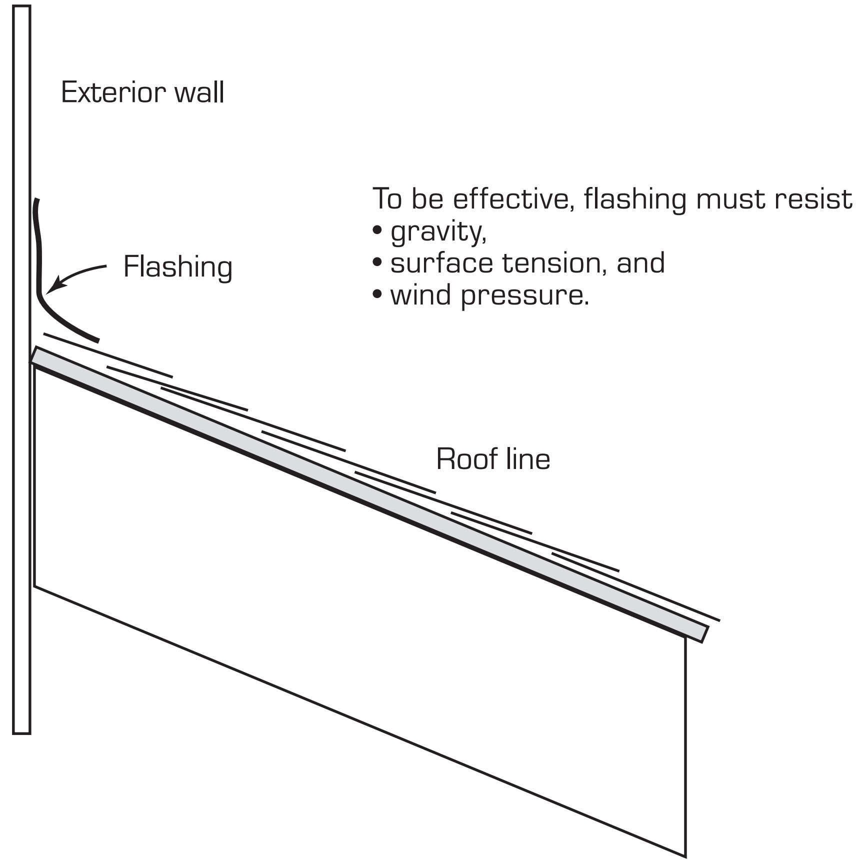


Figure 3.3: Flashing is applied where a wall meets a roof line, such as above a bay window.

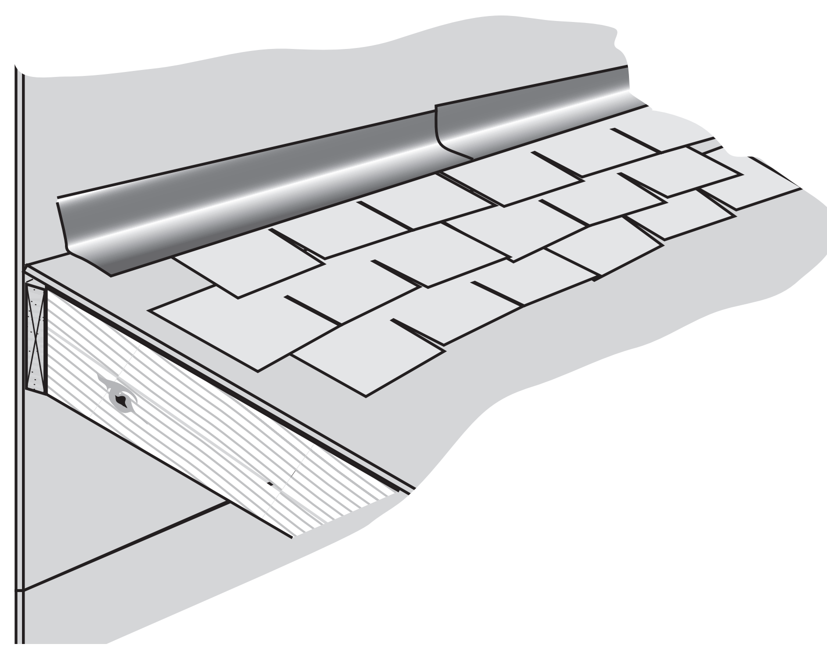


Figure 3.4: Flashing at the intersection of a wall and roof.

Roof flashing materials can be clas sified into membrane and sheet metal. Ice and water barriers and roll roofing are membranes. The most typical sheet metal flashing materials are aluminum, copper, lead coated copper, lead, stain less steel, galvanized steel, zinc, and Galvalume.

Continuous flashing protects the joint between a vertical wall and a sloped roof.

Vent pipe flashings fit over flues and pipes that protrude through the roof. Made of sheet metal, they're cone shaped with a flange at the base; this flange is worked into the shingles as roofing is applied (see Figure 3.5).

Chimney flashing is applied around the base of a chimney in several parts: continuous flashing along the bottom, step flashing up the sides and a saddle flashing at the top. Cap flashing, mortared or caulked into the chimney, laps over the top edges of the other flashings to prevent water from running in behind them (see Figure 3.5).

Z-flashing seals the horizontal seams between plywood or hardboard siding panels.

Valley flashing protects the valleys between two meeting roof planes. On most roofs, this W shaped channel is placed over the top of building felt be fore the finished roof is installed.

Drip caps are L or Z shaped metal flashings that flash frames above win dows and doors.

Drip edges prevent water from seeping under roofing along the edges at rakes and eaves. They're applied under roofing felt along eaves and over roofing felt along rakes.

Skylights often have their own, integral flashing. Otherwise, their curbs are flashed with continuous flashing along the base, step flashing up the sides, and saddle flashing across the top.

Step flashing is fitted into each course of shingles to provide protection along the side walls of dormers, sky lights and chimneys.

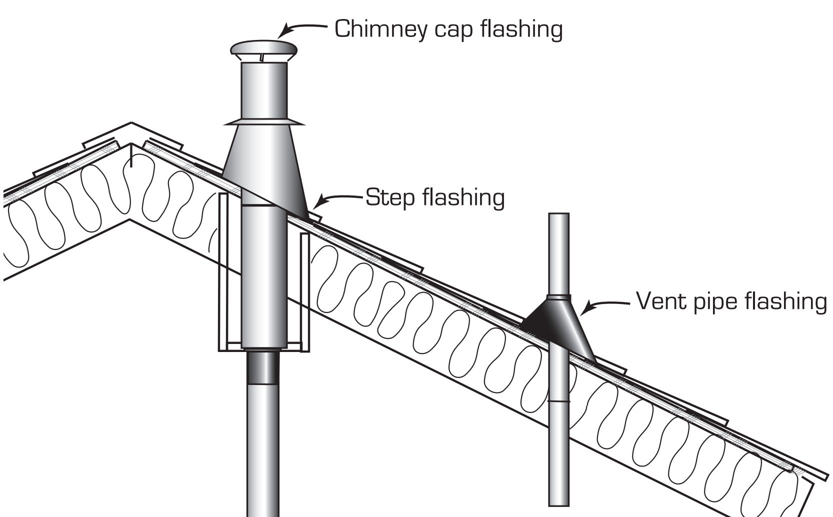


Figure 3.5: Flashing for chimneys and plumbing vent stacks.

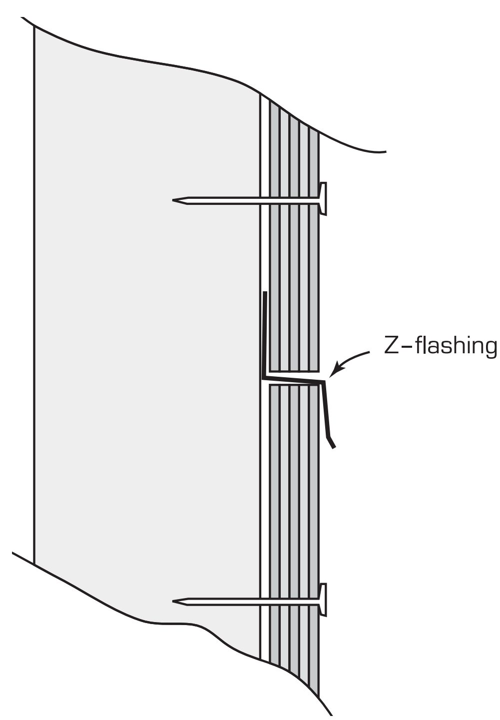


Figure 3.6: Z-flashing.

Gutters and Hangers

A heavy rain flowing down house walls to the ground below, can cause a great deal of damage. At the very least, it tax es paint and wriggles into cracks, con tributing to eventual long term decay. At its worst, it foils windows, invades walls and undermines foundations. Gutters and drainage systems handle rainwater removal to keep these things from hap pening.

Gutters are long troughs that catch water at the eaves. They slope slightly toward downspouts that pipe the water to the ground. Water is then diverted away from the foundation.

To catch both runoff and ground water, perforated drain pipe, run in a gravel-filled trench, provides the path of least resistance for water. Pipe drops at a minimum slope of ½ inch per foot.

Gutters on new homes are usually aluminum or vinyl. Do it yourself metal and vinyl types are fitted together from 10 foot long gutter sections and a variety of corner connectors, end caps, and oth er components. Lightweight and simply snapped or glued together, vinyl gutter systems are favored by do it yourselfers. Professionally installed seamless gutters are extruded from precoated aluminum in very long single runs at the site.

Depending on the type of system, gutters are either hung from the sheath ing along the eaves before the roof is shingled or nailed to the fascia with a clip hanger or spike and ferrule hanger rooftop hangers are more secure and less visible .

Controlling Water Vapor

Water vapor is an invisible gas that can travel through air at a great speed. Wa ter vapor can move from warm living spaces to cooler spaces inside the build ing cavities in two different ways:

Convection: the motion of air, which includes water vapor. Materi

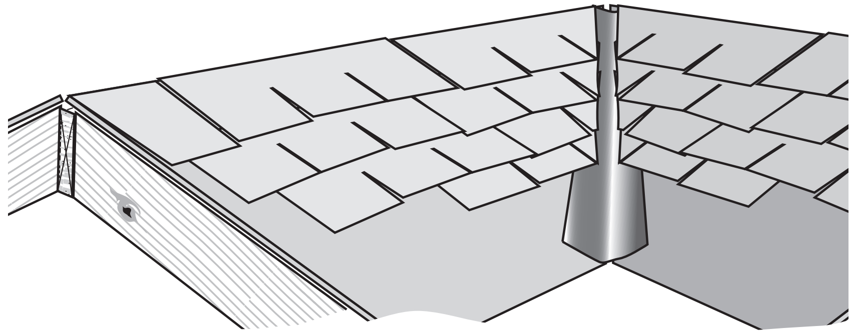


Figure 3.7: Valley flashing.

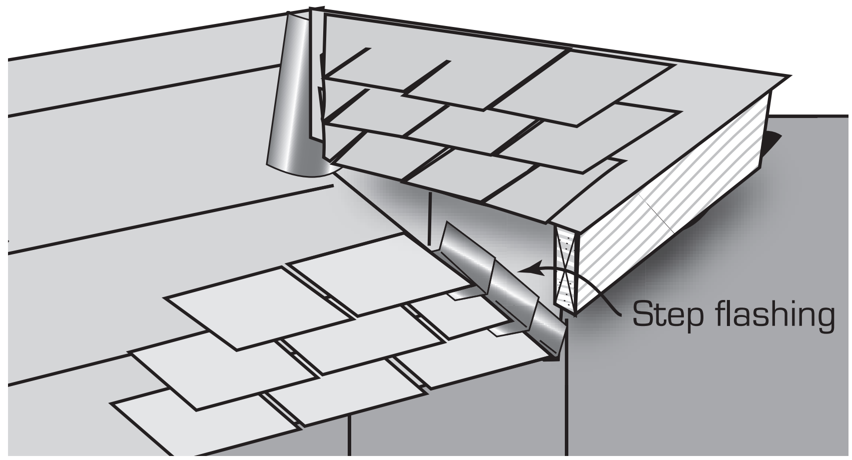


Figure 3.8: Step flashing.

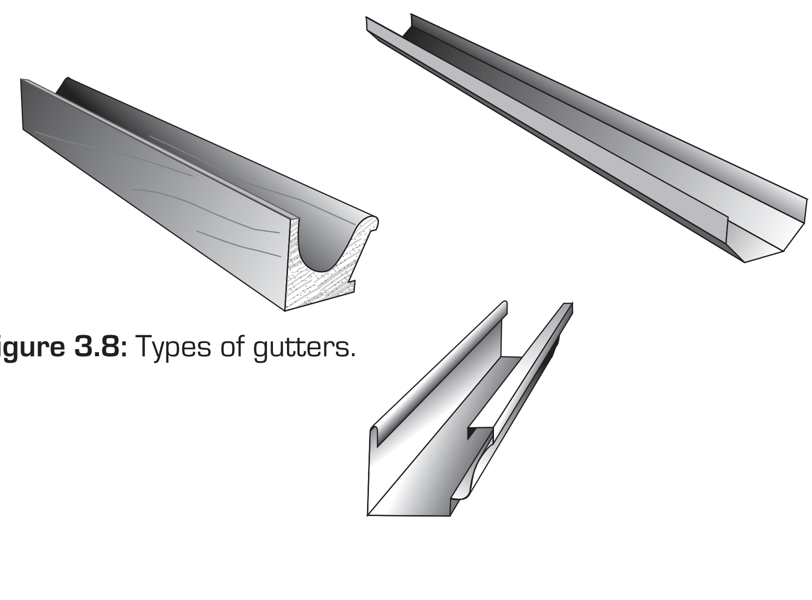


Figure 3.8: Types of gutters.

als intended to retard convection are part of the air barrier system described earlier.

Diffusion: movement of water vapor molecules alone as they spread by random motion from an area of higher concentration inside to an area of lower concentration the cavity or outdoors .

More than 95 of all water vapor in building cavities is transferred by air movement convection . That is why it is so important that all unintentional air leaks be carefully and permanently sealed. Diffusion is a much slower process and most common building materials slow moisture diffusion to a large degree, although they never stop it completely.

Requirements for Vapor Retarders

Vapor retarders are materials that slow moisture movement by diffusion. To be effective, the vapor retarder must be:

- resistant to the flow of water vapor;
- durable; and
- located on the warm side of the insulation.

The vapor barrier does not need to be perfectly continuous like an air bar rier, but it should cover as much of the building envelope as possible. Although it needs to be located on the warm side of the insulation, the vapor barrier can be installed partway into the wall, pro vided that no more than one third of the insulating value of the wall is on the warm side of the vapor barrier. See the discussion of the one third, two thirds rule in Chapter 2, Building Science. This should be reduced to one quarter or less of the insulating value in very cold cli mates or in buildings with high moisture sources such as swimming pools.

Like an air barrier, the vapor barrier can be made up of different materials; even some existing building components such as plywood, paint, or vinyl wallpa per may form part of the vapor barrier.

Classes of Vapor Barriers and Vapor Retarders

Vapor retarder effectiveness is measured in "perms," which stands for the *perme ance* of the materials; one perm equals one grain of water per square foot per hour per unit vapor pressure difference. The lower the perm rating of a mate rial, the better the material is at slow ing moisture transfer. Appendix 2 lists the perm ratings of common building materials.

Knowing the perm rating of a mate rial is critical when choosing materials for walls. To allow any moisture that does pass through the vapor retarder to escape, the outer skin of the wall should be at least five times more permeable than the vapor retarder. This 1:5 ratio should be applied when choosing a va por retarder and also when choosing sheathing materials for the outer skin of the building.

All building materials can be sepa rated into three general classes based on their permeability:

- **Vapor impermeable:** referred to as vapor barriers: 0.1 perm
- **Vapor semi-impermeable:** 1 perm or less, but greater than 0.1 perm
- **Vapor semipermeable:** More than 1 perm and 10 perms or less
- **Vapor permeable:** referred to as breathable: more than 10 perms

Materials that are generally classed as impermeable to water vapor are:

- rubber membranes
- polyethylene film
- glass
- aluminum foil
- sheet metal
- oil based paints
- vinyl wall coverings
- foil faced insulating sheathings

Materials that are semipermeable are:

- plywood
- OSB
- unfaced expanded polystyrene EPS
- fiberfaced isocyanurate
- heavy asphalt impregnated building papers
- the paper and bitumen facing on most fiberglass batt insulation and most latex based paints

Materials that are permeable are:

- unpainted gypsum board and plaster
- unfaced fiberglass insulation
- cellulose insulation
- unpainted stucco
- lightweight asphalt impregnated building papers
- asphalt-impregnated fiberboard
- exterior gypsum sheathings
- cement sheathings
- house wraps

Vapor Retarder Design Concerns

Vapor retarders are intended to prevent building cavities from getting wet, but they often prevent those cavities from drying. When installed on the interior of building assemblies, they prevent assemblies from drying inward. This can be a problem in any air conditioned space, in any below grade space, or when a vapor barrier is also on the exterior.

Mistakes to Avoid

- Installing vapor retarders on both sides of assemblies; i.e., double vapor barriers.
- Placing a layer of sand between polyethylene vapor barriers and concrete slabs on grade.
- Installing polyethylene vapor barriers on the interior of internally insulated basements.

Cold Climate Concerns

These materials can be an effective but unwanted vapor barrier if they are not placed or added carefully to the exterior of a wall.

- The use of insulating sheathings.
- The use of damp spray insulations with insulating sheathings.

What's New?

"Smart" vapor retarder materials now on the market have the ability to change their permeance when the humidity changes. Under high relative humidity conditions the vapor retarder becomes more permeable, allowing moisture to pass through. When humidity is low, the material blocks the passage of moisture so that it will not condense on cold surfaces within the building cavity. These materials are similar to those used in the food packaging industry for casing sausages and other edibles. Both these materials can be effective vapor barriers if placed or added to the exterior of a wall.

NOTE: Like R-values, perm ratings are dependent on the thickness of the material. But unlike R-values, perm ratings are not additive. The water vapor permeability of a material is roughly inversely proportional to its thickness: doubling the thickness halves the permeability. It's more complicated for films and coatings, however, and this rule should not be applied to these materials.

Framing Materials

Wood

Many types of building materials are needed to construct a house, but ask most people what materials they would need and their first answer is likely to be "wood." Of course, that's no surprise: Wood has been the choice of homeown ers and builders for centuries. It is both available and renewable; it is relatively inexpensive; and when manufactured into pre engineered construction com ponents, wood is very strong. Wood is durable and can be shaped, sanded, painted, or stained. Wood is easily re paired or replaced. Dings, nicks, and dents can be sanded and refinished. Even the house itself is easily expanded or altered when wood framing is used.

Things to Know When Building With Wood

Wood is **biodegradable**. That's a char acteristic sometimes considered a ben efit of choosing natural materials. Molds are wood rotting fungi that can break down wood into its basic chemicals so that fallen logs in the forest can contrib ute to the growth of the next generation of life. This process essential in the forest must be prevented when we use wood in buildings. Molds require four things for growth: food, suitable temperature, oxygen, and moisture. In certain situations, wood can provide the necessary elements to allow mold to grow. Wood is organic, consisting of biological materials such as cellulose and lignin. Since wood fiber comes from a living tree, it also contains sugars, starches, and proteins that can serve as a food source for mold. Molds grow best between 70 and 85 degrees F. Oxygen is readily available in most areas where wood is used, as are favorable tempera tures. Water is normally the only one of these factors that we can easily manage. Wood and wood composites are hygro scopic, or water absorbing, materials. Always containing water, wood con stantly exchanges water vapor with the air, picking it up when relative humidity in the air is high and giving it off when relative humidity is low.

Wood will shrink and swell as the result of moisture content change in the surrounding environment. In high humidity, wood absorbs moisture and swells: in low humidity wood releases moisture and shrinks. You can predict shrinkage of wood, and to eliminate fu ture trouble in buildings you must plan for it. To avoid problems, it is recom mended that relative humidity be main tained within the range of 25 to 55 .

Wood is an anisotropic material; that is, its dimensions change differently in three directions: tangentially, radially, and longitudinally. Virtually all of wood's physical properties vary greatly, depend ing on whether they are measured paral

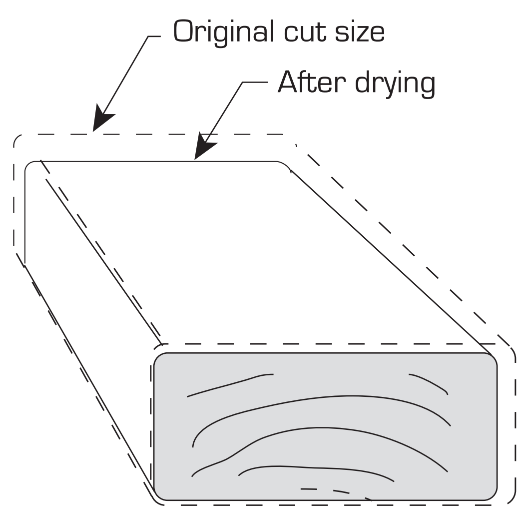


Figure 3.9: Wood is an anisotropic material; its dimensions change differently in three directions: tangentially, radially, and longitudinally.

lel to the direction of the grain or across it. The direction of the grain in a piece of wood affects every aspect of how we can use it, including its production, shaping, fastening, structural capacity, its durability, and beauty.

Because wood's straw like cells are laid down in concentric circles the growth rings , with their length parallel to the trunk of the tree, green lumber shrinks by different percentages in length, width, and thickness during dry ing. Shortening along the grain, or longi tudinal shrinkage, is so small that it usu ally can be ignored. But shrinkage across the grain, whether around the growth rings tangential shrinkage or across them radial shrinkage , is substantial and has to be accounted for in the de sign of just about anything made from wood. Though shrinkage values vary widely among woods, tangential shrink age averages about 8 ; radial shrinkage, about 4 .

Unequal shrinkage and swelling in the longitudinal, tangential, and radial directions can cause the bowing, twist ing, and other warpage often seen in lumber. It is also responsible for the wide checks and splits that open in large timbers and logs.

The first rule of shrinkage is that all woods shrink across the grain. The sec ond rule is that all wood will continue to shrink to some degree after being used in construction. The third rule is that all wood will continue to expand and contract with changes in humidity no matter what you do to it.

Things to Know When Buying Wood

Grade Stamps

Structural lumber has a grade stamp on its face so everyone can be sure it meets the specified strength requirements. Be cause nonstructural lumber is used for finishing, it may have a grade stamp on the end instead of the face, or bundles might have a grade-stamp certificate.

A typical grade stamp usu ally provides five important pieces of information:

Grading Agency: There are many grading agencies in the U.S. and Canada. Grading agencies make spot checks of manufacturing facilities to ensure the grading done by a given manufacturer falls within acceptable limits of quality.

Grade: The grade stamp will indi cate the individual species or species combination of the stamped lumber.

Moisture: The grade stamp will usually indicate S DRY or KD 19 lum ber at 19   moisture content or less at the time of final finishing) or S-GREEN lumber at more than 19   moisture content at the time of final finishing).

Mill Identification Number: This is a number assigned by the inspection agency to a given mill. All the lumber manufactured in a given mill will carry the same mill number.

Figure 3.10: Example of a grade stamp

Lumber Size

The actual size of dimension lumber is always smaller than the size it was when rough sawn. First, as the lumber is dried during the manufacturing process, shrinkage occurs across the board. Sec ond, to prepare lumber for handling and use, it is planed or sanded dressed on all four sides. Dressing can remove a few sixteenths of an inch from the width.

Nominal Size is the size of a piece of lumber before dressing and drying. The nominal size 2 x 4, 2 x 6, etc. de scribes the dimensions at the time of rough sawing.

Actual Size is the minimum accept able size after dressing and seasoning as defined by North American lumber standards. A nominal 2 x 4 will have a minimum actual size of 1.5 inches x 3.5 inches see Table 4.1 .

Table 4.1: Nominal and actual sizes of lumber

Framing Lumber

Nominal Size (in.)	Actual Size (in.)
2 x 2	1½ x 1½
2 x 3	1½ x 2½
2 x 4	1½ x 3½
2 x 6	1½ x 5½
2 x 8	1½ x 7¼
2 x 10	1½ x 9¼
2 x 12	1½ x 11¼
4 x 4	3½ x 3½
4 x 6	3½ x 5½
4 x 10	3½ x 9¼
6 x 6	5½ x 5½

Finish Lumber (boards)

Nominal Size (in.)	Actual Size (in.)
1 x 2	3/4 x 1½
1 x 3	3/4 x 2½
1 x 4	3/4 x 3½
1 x 5	3/4 x 4½
1 x 6	3/4 x 5½
1 x 8	3/4 x 7¼
1 x 10	3/4 x 9¼
1 x 12	3/4 x 11¼

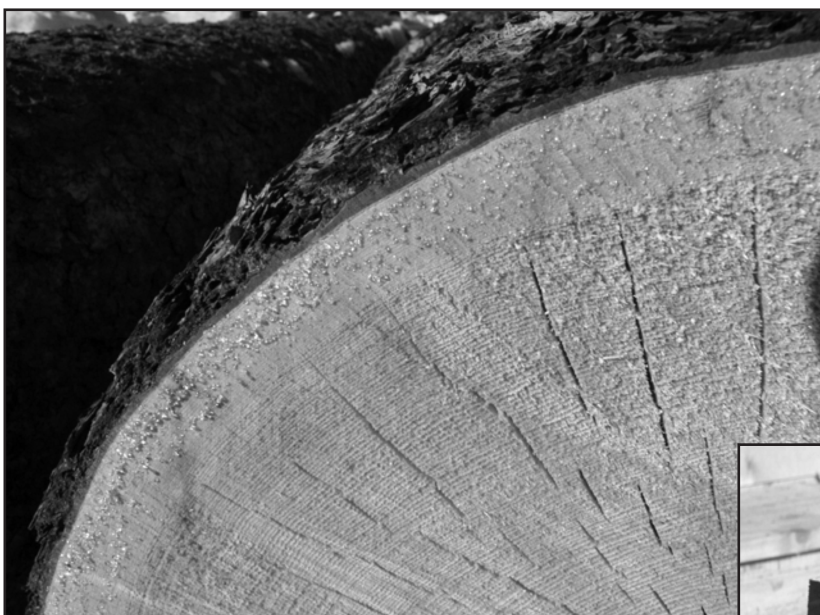


Figure 3.11: A raw log

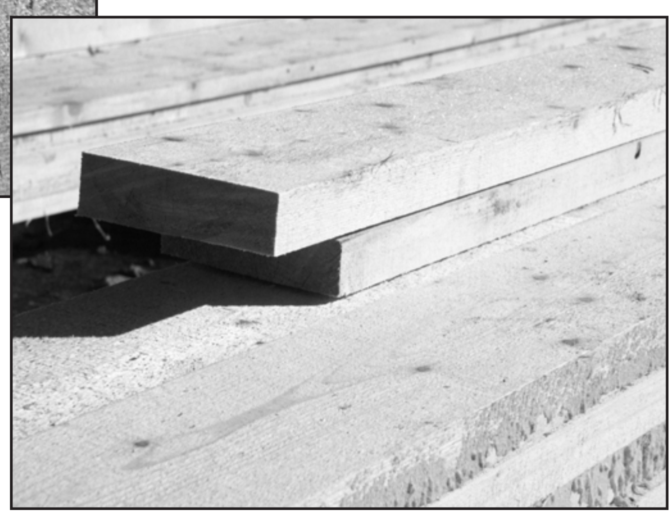


Figure 3.12: Dimensional lumber

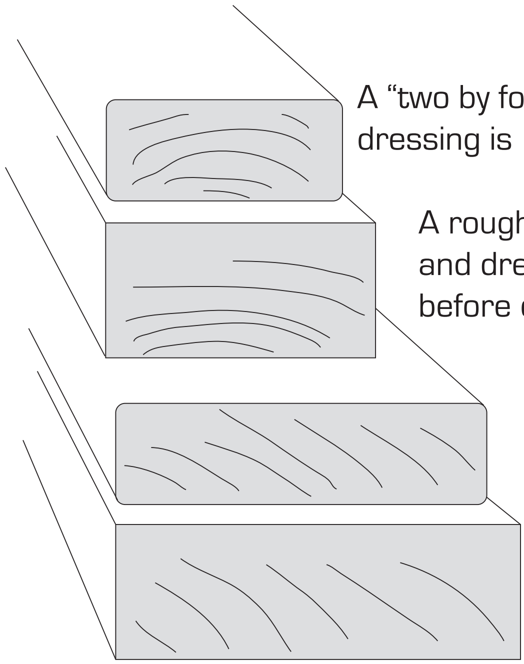


Figure 3.13: Sizes of common dimensional lumber

Alternatives to Solid Wood

The average single family home con sumes 11,000 board feet of lumber. Recently, conventional lumber has been questioned as the preferred framing ma terial because of its gradually increasing prices as well as concerns about decreas ing quality and future availability.

The two most common alternative forms of residential framing are engi neered lumber and light gauge steel.

Engineered Wood

For hundreds of years, the wood used to build houses was simply identified by species. Today, high tech wood products are just as likely to be identified by the highly specialized functions they serve.

Engineered wood products are made from strands of wood stripped from low grade trees such as poplar and as pen trees grown in 25 year rotations in plantations .

A key advantage to engineered wood products is that they are very stable and offer greater structural strength than typical wood building materials. This means that engineered joists and beams can be used in place of steel in many building projects.

Application

Engineered wood products are con sidered a combustible construction product, which places restrictions on building design. For example, building size may be restricted and there may be additional requirements for sprinklers and fire truck access.

Although engineered wood products are considerably more expensive than standard wood products, there is much less construction site loss due to warp ing or shrinkage. The greater strength of engineered wood products means that buildings can be designed to use fewer structural components. In addition, engineered wood products may produce less construction site waste because they can be ordered to specification.

Types of Engineered Wood

Plywood is an engineered panel prod uct consisting of thin sheets, or veneers, laid and glued one on top of the other so the grains run in opposite directions. This gives plywood equal strength in its length and width (Figure 3.14).

Structural plywood, used for con struction and industrial applications, is made with waterproof glue to maintain strength in exterior applications.

Decorative plywood is used for wall paneling, cabinet construction, or furniture. It uses softwood veneers or for the substrate, onto which high quality hardwood veneer is glued.

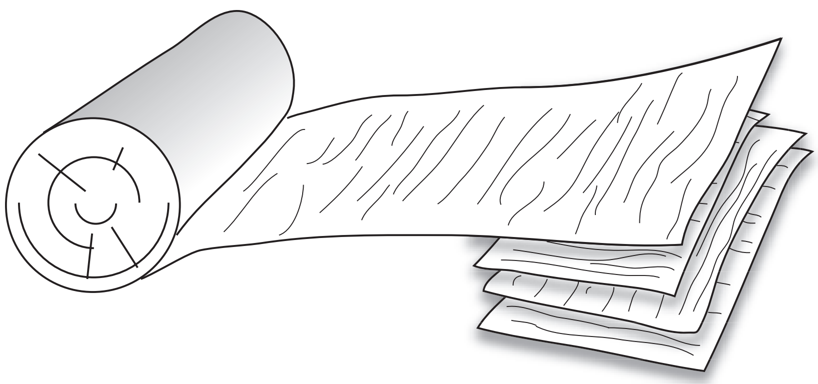


Figure 3.14: Plywood is an engineered panel product consisting of thin sheets, or veneers, laid and glued one on top of the other so the grains run in opposite directions.

Oriented Strand Board (OSB) is a wood panel used as a sheathing mate rial for floors, walls and roofs. OSB is popular because it is economical and has excellent racking resistance, which strengthen a building against horizon tal loads such as extreme winds or the forces of earthquakes (Figure 3.15).

OSB is manufactured from "strands" of wood 6 inches long and 1 inch wide that would otherwise be wasted wood.

During the manufacturing process, OSB strands are oriented in one direc tion as they are placed on a mat for pressing. Like plywood, OSB layers are also placed perpendicular to each other. Surface layer strands are aligned in the long panel direction; inner layers consist of cross aligned or randomly aligned strands. This means the completed panel, like plywood, has good strength across its length and width.

Like structural plywood, OSB is manufactured using waterproof glues to ensure that strength is maintained even if the panels become wet during the construction phase or later.

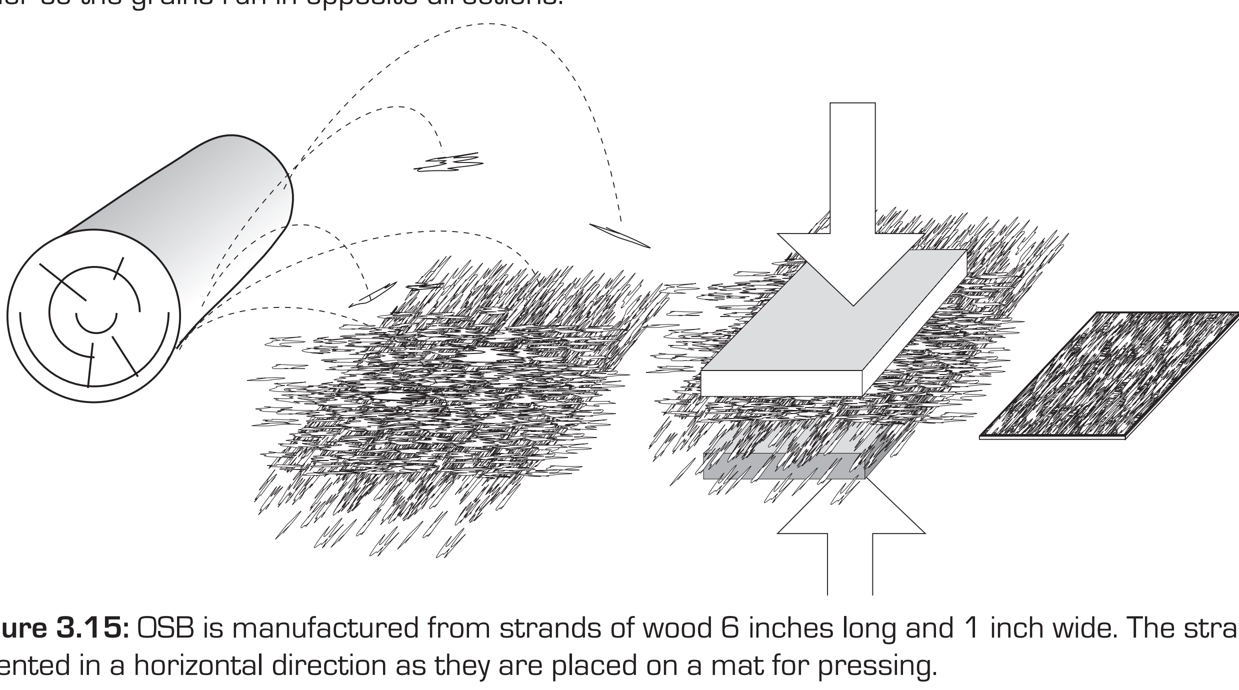


Figure 3.15: OSB is manufactured from strands of wood 6 inches long and 1 inch wide. The strands are oriented in a horizontal direction as they are placed on a mat for pressing.

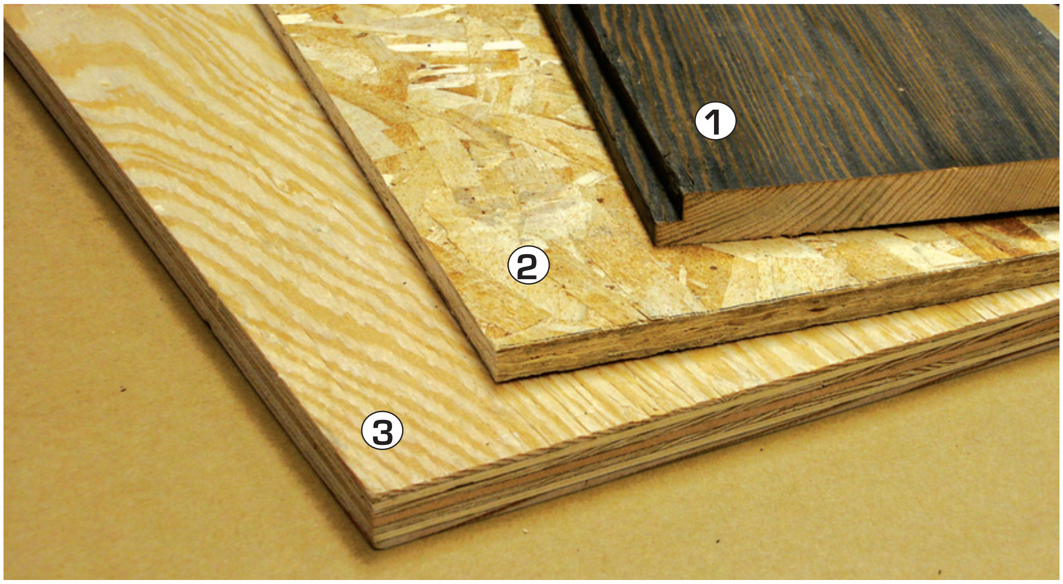


Figure 3.16: (1) Plain-sawn douglas fir ship lap sheathing board, (2) oriented strand board (OSB), (3) plywood.

Glulam or glue laminated timber (Figure 3.17) refers to large, structural members made by gluing together piec es of dimension lumber. It is a unique structural material because it can be formed into many curved shapes and the sizes are limited only by transporta tion restrictions. It is generally used for columns and beams.

I-Joists. Wood I-joists (Figure 3.18 are a structural engineered wood product often used for joists and raf ters in residential and commercial construction.

I joists are made by gluing solid sawn lumber or laminated veneer lumber (LVL) flanges to a web made of plywood or OSB. I-joists have uniform stiffness, and are strong and lightweight.

Some wood I joists are manufactured with knockouts in their webs for instal lation of wires. The knockout holes also provide ventilation when the joists are used in cathedral type ceilings.

Holes for plumbing and mechanical ductwork are drilled easily through the web, but must be located according to the manufacturer's recommendations.

Several different wood I-joists are available and feature different designs and materials.

Figure 3.17: Glulam or glue-laminated timber refers to large, structural members made by gluing together pieces of dimension lumber.

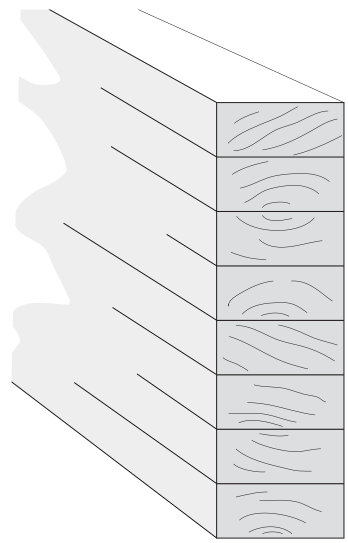
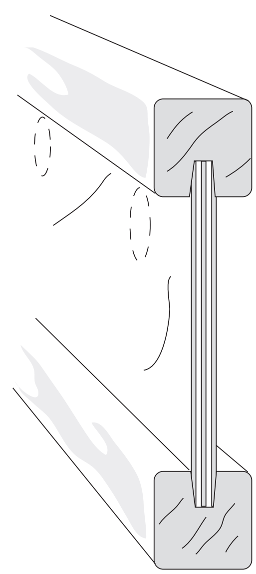


Figure 3.18: I-joists are made by gluing solid sawn lumber or laminated veneer lumber (LVL) flanges to a web made of plywood or oriented strand board (OSB)



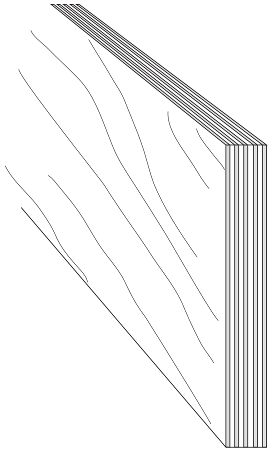


Figure 3.19: Laminated veneer lumber (LVL) has several layers of wood veneers and adhesive.

Laminated Veneer Lumber (LVL) (Figure 3.19) has several layers of wood veneers and adhesive. First used during World War II to make airplane propellers, it has been used since the mid 1970's to build beams and headers for buildings where high strength, sta bility and reliability are required.

Parallel Strand Lumber (PSL) is a high strength structural composite marketed under the trade name Paral lam (Figure 3.20, 3.21). PSL is compara ble in strength to laminated veneer lum ber. Both products are often grouped under the heading structural composite lumber SCL . PSL is made from long strands of wood chopped from wood veneer. This process allows the removal of growth defects from the raw material. PSL is then made into large billets and sawn into stock and custom sizes.

Because it is a glued manufactured product, PSL can be made in long lengths but is usually limited to 66 ft. 20 m. because of transportation con straints. Manufactured at a moisture content of 11 percent, which is approxi mately the equilibrium moisture con

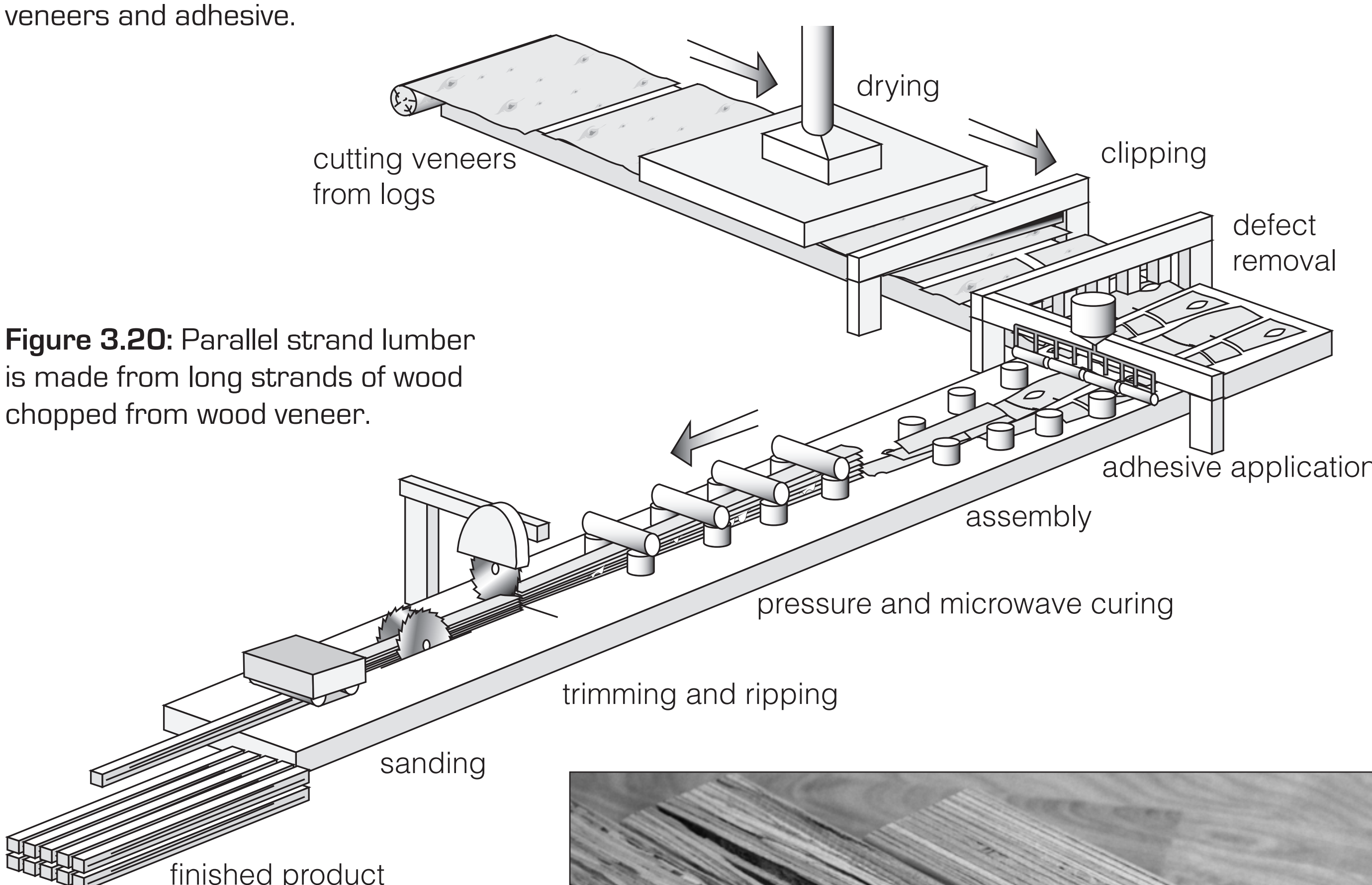


Figure 3.20: Parallel strand lumber is made from long strands of wood chopped from wood veneer.

Figure 3.21: These samples of Parralam, Timberstrand, and Microlam engineered lumber from Trus Joist MacMillan show different styles of laminate orientation for different applications.

tent of wood in most service conditions, PSL is less prone to shrinking, warping, cupping, bowing, or splitting. PSL is manufactured in the U.S. from southern pine as well as other species and from Douglas fir in Canada. PSL has consis tent properties and a high load carrying ability.

Particleboard is a panel product made from sawdust and other residue left over from the manufacture of lum ber and other wood products. Since it is made from waste products, particle board is an environmentally friendly choice.

Particleboard has many uses. The manufacturing process, particle types and sizes, and resin content can be varied to produce panels with differ ent densities and characteristics to suit specific end uses. Although it is used in some structural applications such as floor sheathing, the types of glues used in most particleboard also make it well suited for furniture and cabinetry ap plications. It is also used in the manu facture of laminate flooring, stair treads, shelving, and many other products.

Particleboard is often used as a sub strate. Substrate means that other finish materials are laminated over the top of the particleboard core to produce a fin ished panel. Melamine, plastic laminate, and hardwood veneer are a few of the typical finish surfaces. In the home, fin ished panels are typically used for coun tertops, tabletops and desktops.

Medium Density Fiberboard *(MDF)* is a wood based panel made from fine cellulose fibers combined with a synthetic resin or other suitable bond ing system, which is then joined to gether under heat and pressure. Because of the fineness of the fibers, it forms and machines smoothly and precisely, making it an ideal substrate for thin laminates.

Steel Framing

Steel framing is becoming more com mon in residential construction. There are three residential steel framing methods:

Stick-built. Layout and assembly of steel framing is the same as for lum ber, except components are screwed together rather than nailed. Replacing wood framing with steel, stud for stud, requires skilled labor to field engineer the material. Raw materials may cost less than wood, but labor may be higher.

Panelized systems use prefabri cated walls, floors, and roof components. Exterior sheathing is applied to the panel before it is erected. Panels can be made in the shop or field. A panelized system can be framed in about one fourth of the time required to stick build.

Pre-engineered systems use steel efficiently and allow design flexibility unavailable with other systems. Most of the fabrication labor is done by the sup plier of the system, and framing crews must be trained by the supplier. The materials in a pre engineered system may cost 10 to 15 more than conven tional 2 x 6 wood framing.

The thickness, or "gauge" of sheet steel ranges from 10 to 25. By

Figure 3.22: Steel construction requires some new tools and techniques.

convention the higher the gauge num ber the thinner the steel. The more lightweight non load bearing interior walls of residential structures are usually made of 25 gauge steel, while the exte rior load bearing steel studs are usually built from stronger 18 or 20 gauge steel.

Using steel for framing residential construction has both advantages and disadvantages. Carefully consider both when choosing construction techniques.

Advantages of Steel Framing

- Steel framing weighs 60 less than wood. A 2000 square foot home re quires only 6 tons of steel compared to 20 tons of lumber.
- No other standard construction material can match steel's superior strength and durability.
- Steel construction components can be premeasured and precut to exact specifications. On-site adjust ments are generally not required. Steel framing members also have prepunched holes that allow for easy installation of electrical wiring and plumbing.
- Steel is resistant to termites and other damage causing pests.
- Steel stays straight and true, while wood may warp or crack.
- Steel components generate little waste and all light gauge steel construction materials are 100 recyclable.
- Health: Steel is inert and emits no toxic chemicals so is safe for workers and occupants.

Disadvantages of Steel Framing

- Steel studs generally don't perform as well as wood studs when it comes to insulating capability. Steel con ducts heat more readily than wood. Adding rigid foam insulation on the outside of the wall helps some, and building engineers are working on new ways to improve the insula tion capabilities of steel framed buildings.
- Steel construction requires some new tools not presently used by car penters. The combination of addi tional training and tools translates to increased costs of construction for a short period of time.
- To protect steel from rusting, steel is zinc galvanized. This protection is necessary during storage, con struction, and while in use to avoid damage and loss of strength due to rusting.

Recommendations

- Use steel studs for interior walls. This starts the learning process with a small, manageable step that doesn't affect heat loss at all.
- Use full width insulation. Batt in sulation cut to fit between wood framing is 15 or 23 in. wide. Steel studs are often C shaped, so batt in sulation should be the full width 16 or 24 in. . Unfortunately, most high density batts, such as the R 21 wall batt, aren't available in full widths. Blown in insulation gets around the problem.
- Build 4 inch thick walls and hang as much rigid insulation on them as you can. With solid steel framing extra cavity thickness is a waste of money.
- Consider foam core panels over a steel frame. By putting all the insula tion outside the frame, you'll detour around the thermal bridge.
- Avoid the "stick for stick" approach, where you replace each wooden member with a steel one. If you're serious about steel, investigate vari ous engineered framing systems.

Combined Wood and Steel Framing

Now there is a framing system that combines the best of steel and wood. The combination steel and wood fram ing system uses recycled steel studs and joists that attach directly to wood plates and bands using the same tools and methods as conventional fram ing techniques. The steel members are lightweight, quality consistent, and ap plicable for load bearing and nonload bearing construction. They conserve lumber, speed up construction, and add structural flexibility. The new system is being used in the U.S. by manufactured housing industries, site builders, panel ized builders, and structural insulated panel manufacturers.

Figure 3.23: All steel framing

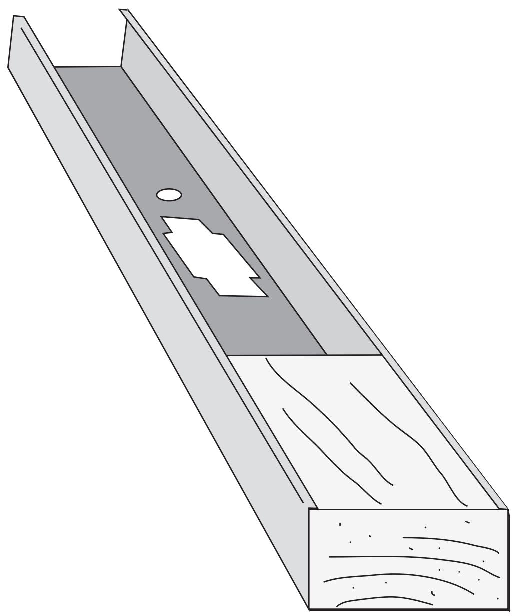


Figure 3.23: Steel and wood framing

Concrete Structures

Concrete has been used in construction for over 2,000 years, perhaps first by the Romans in their aqueducts and road ways. The making of concrete is a very complex process involving both chemi cal and physical changes.

Concrete is made by the combina tion of cement, water, and aggregate of various sizes sand and gravel or crushed stone to make a workable slurry that has the consistency of a thick milk shake. It is the inclusion of cement in the recipe that causes concrete to set, stiffen, and become hard. The amount of water determines a lot of concrete's properties: its workability, its strength, the amount of shrinkage, and its perme ability and porosity.

A chemical reaction between the cement and water, called hydration, forces the paste to bind the aggregate into a rocklike mass. The strength of the concrete keeps growing as long as the chemical reactions continue. During the first week to 10 days of curing it is important that the concrete not be per mitted to freeze or dry out before it has the proper strength. Once set, concrete continues to harden cure and become stronger for a long period of time, often up to several years, but about 90   of its strength is gained in the first 28 days.

Too much water can result in low strength concrete and can cause too much shrinkage and undesirable cracks. Most concrete is made with a water to cement mass ratio from 0.35 to 0.6.

Admixtures

Sometimes other materials are incorpo rated into the batch of concrete to cre ate specific characteristics. These addi tives are called admixtures. Admixtures are used to alter the fluidity (plasticity) of the cement paste, increase acceler ate or decrease retard the setting time, increase strength both bending and compression , or to extend the life of a structure see Table 4.2 .

Properties of Concrete

Concrete has many properties that make it a popular construction material. Its properties are determined by the type of cement used; the additives; and the

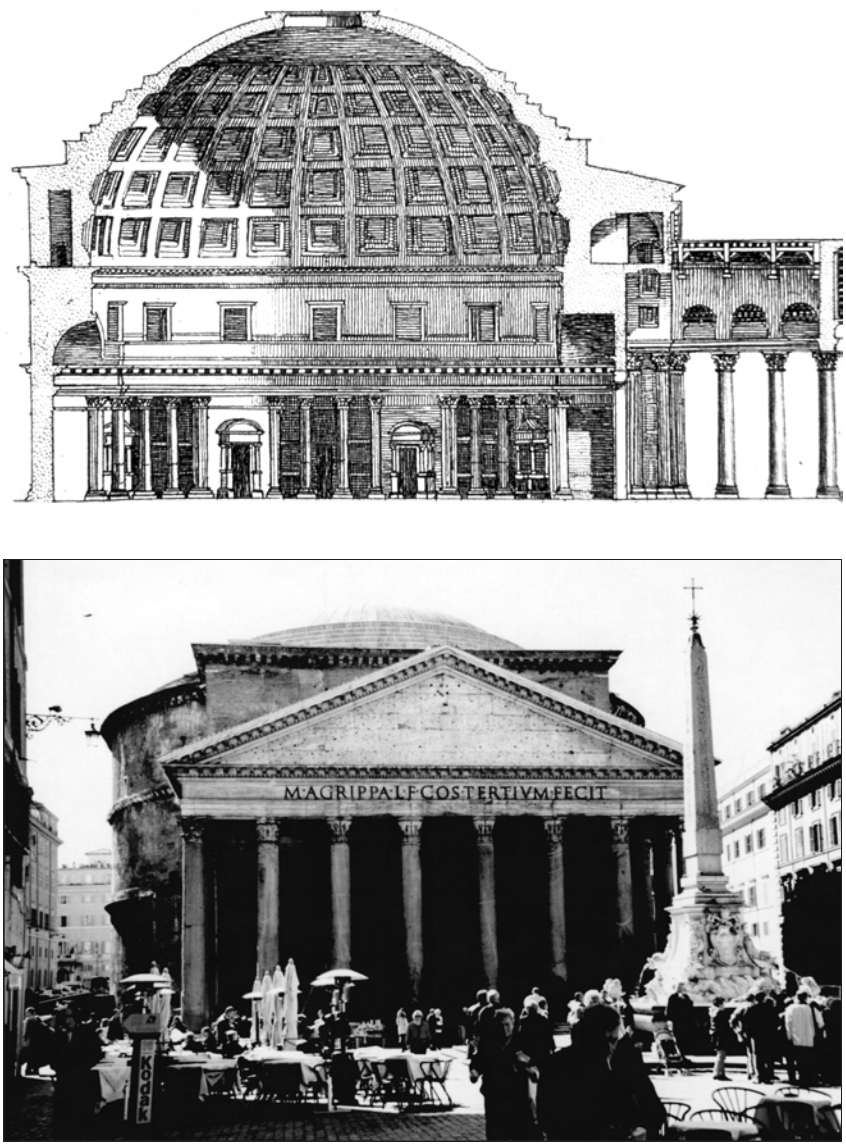


Figure 3.24: At just over 43 meters in diameter, the Roman Pan theon is the largest unreinforced solid concrete dome in the world. The Roman emperor Hadrian ordered it built almost 2,000 years ago. It is still in use today

overall proportions of cement, aggre gate, and water; placement; and curing.

First, it is economical when ingre dients are readily available. Concrete's long life and relatively low maintenance requirements increase its economic benefits. Concrete is not as likely to rot, corrode, or decay as other building materials. Concrete has the ability to be molded or cast into almost any desired shape, and building the molds and cast ing can be done on the work site.

Concrete is a noncombustible mate rial which makes it fire-safe and able to withstand high temperatures. It is resis tant to wind, water, rodents, and insects. Hence, concrete is often used for storm shelters.

Concrete does have some limita tions despite its numerous advantages. It shrinks, creeps, and moves. Shrinkage causes cracks that must be planned for by using rebar and control joints.

The **capillary action** in concrete can draw up water to a height of 6 miles. Concrete foundations require damp proofing to protect them from absorb ing ground moisture by capillary action. Dampproofing is typically provided by sealing the exterior with a tar or bitumi nous coating or by using polyethylene sheeting. The top of the footings must also be damp proofed to break the cap illary path between them and the foun dation wall.

Concrete remains a material of choice for many applications regardless of these limitations.

Types of Concrete in Building Construction

Unreinforced concrete does not have any iron or steel reinforcing bars. It was the earliest form of concrete. The ingredients become a plastic mass that hardens as the concrete hydrates or cures. However, unreinforced concrete is relatively weak, and since the turn of the century it has largely been replaced by reinforced concrete.

Reinforced concrete is concrete strengthened by the inclusion of metal bars that increase the tensile strength of concrete. Both unreinforced and re inforced concrete can be either cast in place or precast.

Cast-in-place concrete is poured onsite into a previously erected form work that is removed after the concrete has set. Precast concrete is molded offsite into building components. More recent developments in concrete tech nology include post tensioned concrete and prestressed concrete, which feature greater strength and reduced cracking in reinforced structural elements.

Table 4.2: Concrete admixtures and their uses

Type	Function
Air Entraining	improves durability, workability, reduces bleeding, reduces freezing and thawing problems (for example, special detergents)
Superplasticizers	increase strength by decreasing water needed for workable concrete (special polymers)
Retarding	delays setting time, more long term strength, offsets adverse high temp. weather (sugar)
Accelerating	speeds setting time, more early strength, offsets adverse low temp. weather (calcium chloride)
Mineral Admixtures	improves workability, plasticity, strength (fly ash)
Pigment	adds color (metal oxides)

Insulating Concrete Forms are rigid plastic foam forms that are filled with reinforced concrete to create structural walls. They hold concrete in place during curing and remain in place afterwards to provide thermal insula tion. ICFs are used to make structural concrete walls and can be used to make either foundation or above grade walls. The forms are typically made from pure foam plastic insulation but may also be made from a composite of cement and foam insulation or a composite of ce ment and processed wood. The foam is typically either expanded polystyrene EPS or extruded polystyrene XPS and occasionally polyurethane. Forms come in three basic types: blocks, planks, and panels. Blocks are molded, hollow foam blocks that are stacked, much like Legos. Plank and panel types use flat sheets (typically) of foam held together with plastic or metal ties, with panels using larger sheets of foam, similar to metal or plywood formwork. The resulting shape of the concrete, ex plained in more detail later, will be one of several shapes: flat, waffle- or screen-grid, or post and beam.

As with any product, ICFs have their advantages and disadvantages. Although they can be more expensive than other residential wall types, and there is much debate over their use below grade be cause of termites, ICFs appeal to build ers and homeowners because of their strength, thermal efficiency, reduction in through the wall sound transmission, and the ease of construction.

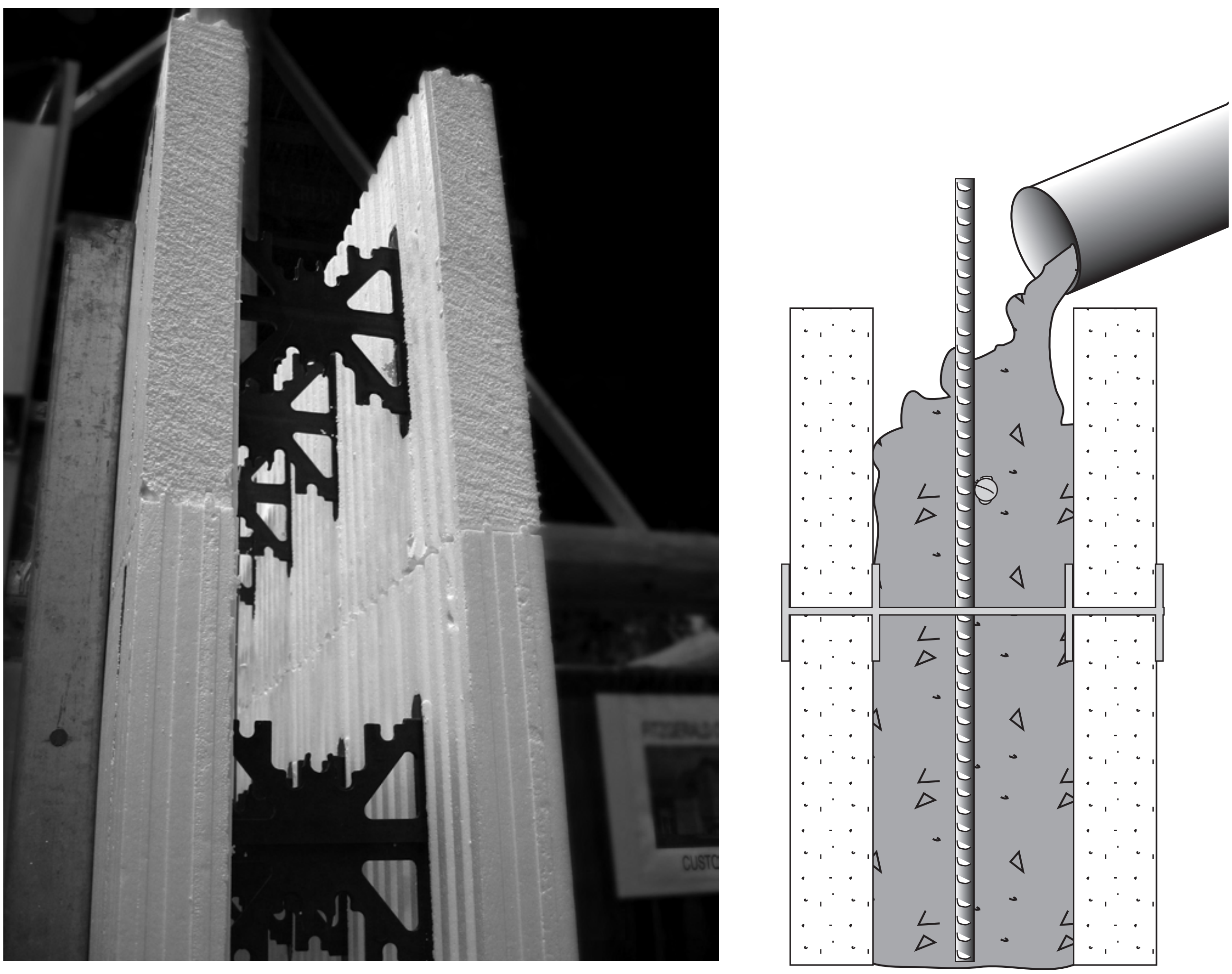


Figure 3. 25: ICFs are rigid plastic foam forms that are filled with reinforced concrete.

Healthy Building Materials

Materials for a Healthier Indoor Environment

In a healthy home, construction and finishing materials can be selected that produce little or no air pollutants. How ever, this is a relatively new area and only in recent years have researchers begun to understand the causes and ef fects of air pollutants in a house. Their research has led to the development and manufacture of more environmentally friendly products that can be used in building homes.

As you consider the options avail able, remember the steps towards better indoor air quality: First, eliminate as many polluting sources as possible. Sub stitute with something less polluting. If you can't eliminate the source, isolate it from the living space. This could be as simple as covering the material with nontoxic paint or sealant. Then you can use mechanical ventilation and filters to provide fresh, clean air.

Paint

Choose nontoxic and low VOC products. All paints release gasses after application, some for several months. These gasses can cause upper respiratory irritation, headaches, skin irritation, and other health symptoms to you and your family. It is best to paint during the spring and summer months when you can comfort ably open windows and doors while oper ating a fan for increased ventilation.

Stains, Sealants, and Varnishes

These products typically contain high levels of VOCs that are released during application. Even after drying, they will off-gas with increased relative humidity. Many of these products are also capable of off-gassing during storage. Com mon chemicals found in these products include acetone, benzene, methanol, toluene, and phenol, just to name a few. Look for natural or low VOC alterna tives and minimize or eliminate your use of these high VOC products.

Wall Coverings

Some wallpapers and wallpaper adhesives are treated with fungicides to prevent mold growth. Ask for more information about the paper or adhesive from your supplier or from the wallpaper manufac turer. Vinyl wall coverings and any wall paper products that are petroleum based in particular can off-gas vapors that may cause headaches or respiratory irritation. It is best to avoid these petroleum prod ucts when possible.

Flooring

Flooring covers a large surface area within a home, so choices can have con sequences for both price and indoor air quality. Flooring products are made from a variety of materials, ranging from natu ral to synthetic. Some types of flooring, as well as the glues and sealers used in their installation, release chemical emis sions that may be harmful for those who have allergies, asthma, or sensitivities to chemical products. It can take weeks or months for these chemicals to off-gas or dry out. Consider choosing flooring with the lowest emissions possible.

When using adhesives and sealers for the flooring, choose a water-based product. If possible, obtain the Mate rial Safety Data Sheets MSDS for the product. These are available at most supply outlets. Ask the supplier what the offgasing or dry-out time is, after which there should be no discernible odor. This is an important consideration for allergy or asthma sufferers.

Keep in mind that the ideal floor ing material for a healthy home is a smooth, easy to clean surface such as tile or wood. If you choose carpet, keep it to a minimum.

Hardwood Floors

Solid hardwood floors are recommended because of their smooth, easy to clean surface. Because of the VOCs found in many finishes it is important to consider the type of finishing material you use on the wood floor. Most finishes are either oil or water based. Oil-based finishes are often considered to be more durable and long-lasting under foot traffic; however, they off-gas more slowly than water-based finishes. Oil-based finishes can also contain petroleum based solvents that may be particularly irritating to many individuals. If you select an oil based finish, make sure there is adequate ventilation during the finishing.

To reduce odors and mess, consider selecting prefinished wood flooring. Pre finished flooring eliminates the need for additional stain, sealer, and varnish.

Ceramic Tile

Most ceramic tile is inert and consid ered a good material selection. Tile that has been glazed make sure it is not a glaze containing lead is recommended because it has been sealed and has less chance of sheltering bacteria or other microorganisms. Using a sealer on the grout seams can help prevent molds from growing there.

Vinyl

Vinyl is one of the most readily available flooring materials and comes in sheet goods or individual squares. It is durable and easy to clean. To avoid potential respiratory irritations, ask for low toxic adhesive for installation. It is a good idea to unroll the vinyl in another location to allow off-gassing before installation.

Linoleum

Linoleum is made from linseed oil, pine resins, and wood flour on a jute backing. It contains no harmful toxins and can easily be cleaned. Some people are sensi tive to the pine resins and should avoid linoleum materials.

Carpet

Carpet contains a variety of synthetic chemical compounds that are used to improve certain characteristics, such as stain resistance in fibers. Other carpet chemical treatments include fire retar dants, fungicides, and pesticides. Once installed carpet can harbor dust mites, bacteria, mold, and other harmful pol lutants. These compounds may cause upper respiratory irritations, flu-like symptoms, and in some cases cause per manent illness. Carpet pads, whether natural, rubber, or plastic may also cause irritations.

Cabinetry

A good selection for cabinets is solid hardwood, sealed with a low VOC seal er. Many cabinets are made from par ticleboard that has a wood veneer glued to the exterior side. The particleboard and the bonding agent contain formal dehyde as well as other VOCs, and they can be irritants to many people until the vapors completely off-gas in a few years. If using plastic laminate on the cabinet exterior, try to use a medium density fiberboard (MDF) as an underlayment to the laminate. MDF has a lower level of formaldehyde than other wood compos ite materials. It off-gasses very low levels of VOCs and can be sealed completely with a plastic laminate. Another option for cabinetry is metal.

Countertops

Inert materials such as glazed ceramic tile, stone, stainless steel, and some types of synthetic solid surface materi als are good choices for countertops. Many countertops, like cabinets, are made with a particleboard or fiberboard core, covered with plastic laminate. If you choose this type of countertop, pay attention to the type of under board and laminate adhesive used for assembly of the materials. Both may contain form aldehyde as well as other chemicals that can cause irritation during the off-gas sing process. Ask for formaldehyde free types of board and a low toxic adhesive to reduce chemical emissions.

Interior Fabrics

For people who are very sensitive to biological agents such as dust mites, pet dander, and molds, it is recommended to keep upholstery, furnishings, drapery, and other window treatments to a mini mum. Many of the fabrics used to make these items contain stain repellants, fun gicides, and formaldehyde, all of which emit chemicals into the indoor environ ment. They can also become collectors of biological contaminants that cause upper respiratory irritation.

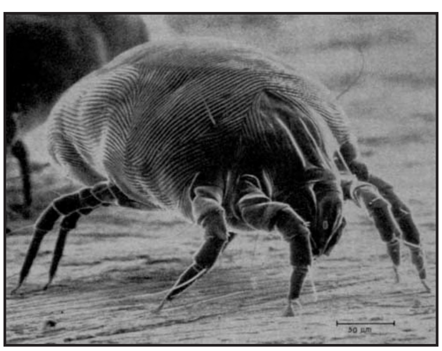


Figure 3.26: Dust mite magnified many times its actual size. House dust mites, due to their very small size (250 to 300 microns in length) and translucent bodies, are not visible to the unaided eye.

Working With Building Materials

Many materials used in building con struction could pose a health risk to construction workers. You can learn about the hazards and how to avoid them by consulting the material safety data sheet MSDS associated with the material. The MSDS contains informa tion about the ingredients, health and safety hazards, cautions about use and storage, recommended protective equip ment and first aid.

Insulation and Other Particulate Materials

Fibrous insulation materials such as fi berglass can easily irritate the skin, eyes, and respiratory system. Long sleeves, tight cuffs, and loose, thick clothing will help minimize any skin irritations. Spe cial barrier creams that protect the skin when working with fibrous materials are available.

Wear goggles whenever there is any possibility of insulation dust coming in contact with the eyes. Eyes can easily become irritated or inflamed by brittle glass or mineral fibers, and **permanent damage** can result.

Wear a mask for nontoxic particles if there is a possibility of breathing airborne particles of insulation mate rial. Fiberglass, rock wool, cellulose and vermiculite all require a face mask and safety glasses for normal handling. The tiny fibers from glass and mineral in sulations can cause respiratory tract ir ritation and lung inflammation. **Avoid breathing insulation dusts.** Well designed, snug-fitting face masks are available through safety supply houses. Buy a supply of filters rated for the material you are using and change the filters frequently.

Plastic Insulations

Rigid polystyrene insulation is essentially an inert material, but it can shed particles when cut. Use a face mask when cutting board stock.

Polyurethane and polyisocyanurate insulations give off harmful vapors when the rigid boards are being manufactured and when the material is being sprayed in place on the job site. The vapor causes skin and eye irritation and breathing difficulties, even at low levels of exposure. Residual amounts of vapor may be present with the rigid board material.

Make sure the work area is well ventilated. These types of rigid boards will also shed particles when cut; use a mask as for polystyrene.

When applying the spray in place material, contractors take special safety precautions and use respirators. If you plan to have foam insulation installed inside your home, provide additional ventilation until the material has cured.

Paints, sealants and caulking materials have many different chemical compositions but they share some common characteristics:

- They all use solvents to keep the material pliable until it is installed.
- Once applied, the solvents will evaporate and fumes will be given off as the material sets or cures.

Fumes from these materials can cause respiratory irritation or other allergic reactions. Make sure the work area is well ventilated and provide additional ventilation during the curing period. The curing time can vary from days to weeks.

Green Building Materials

Today people are more concerned about taking care of the environment and finding ways to make our buildings as friendly to the environment as possible. This includes the selection of building materials used in "green" buildings.

Types of Green Building Materials

For the most part, green building materials are materials that are reusable or renewable or all natural or contribute to energy savings or are created in ways that are friendly to the environment. One of the oldest forms of green materials are stones that are used to build homes and other buildings. Some would consider trees grown specifically for construction with new trees being planted each time others are harvested to be acceptable as long as the area is not stripped bare and left alone.

Recycled materials such as paper, wood, and plastic can make good green building materials. Many construction materials, such as cellulose and some mineral fiber insulation, steel stud framing, manufactured and structural wood products, and sheathing for building exteriors, are now made from 25 to 100 recycled, renewable, and reused material. Recycled materials can be used to build decks, siding, flooring, and a number of other parts of a building. One example is the use of plastic soda bottles to make carpet that is stain resistant, long lasting, and comfortable.

Green building designers and builders also become familiar with local sources of construction materials, such as wood, insulation, windows, concrete block, brick, gravel, etc. Using local materials whenever possible reduces excess energy use from transporting materials long distances and helps local economies by increasing jobs and keeping cash-flows and tax revenues in your community.

When performance, durability, energy efficiency, and cost trade-offs appear reasonable, using "green" materials boosts overall energy efficiency, can greatly benefit the environment, and also creates jobs and markets for such materials.

Material Incompatibilities

Today, residential construction has become much more complex. In addition to providing shelter, residential builders need to consider energy efficiency, using materials that minimize the effect on the environment, waste reduction and stringent code requirements for fire, durability, indoor air quality, sound transmission, and moisture and mold control.

Many new products are now available to help builders and renovators meet these increasing requirements, and more are becoming available every day. The wide range of possible combinations for building materials, finishes, furnishings, and accessories increases the likelihood that some of these materials might not be compatible with others. The use of incompatible materials can result in deterioration of one or both materials, reduced life, discoloration, or poor adhesion between materials. In some cases, product literature may identify incompatibility issues, but it is not always noted or may be overlooked when different trades are involved. In other cases, the products have not been field tested long enough to understand their long-term effect on other building materials.

Some incompatibilities are well documented. For example, it has long been known that the combination of two different metals will result in corrosion of one. This does not mean that one metal is better than the other, simply that precautions are necessary in cases where the use of two different metals cannot be avoided. These types of incompatibilities can usually be identified and substantiated by literature research.

Other instances of incompatibility involve new products or applications of products that were not expected during product development and testing. Often, these incompatibilities are reported by building professionals.

Compatibility between the exterior building materials, flashing, caulks, and windows is essential for proper moisture deflection. Material compatibility is also essential for roofing materials to eliminate moisture infiltration. Cracks or separations between dissimilar materials indicate incompatible materials.

Physical incompatibilities can occur when materials react differently to temperature or moisture.

Chemical incompatibilities occur when adjacent materials react chemi

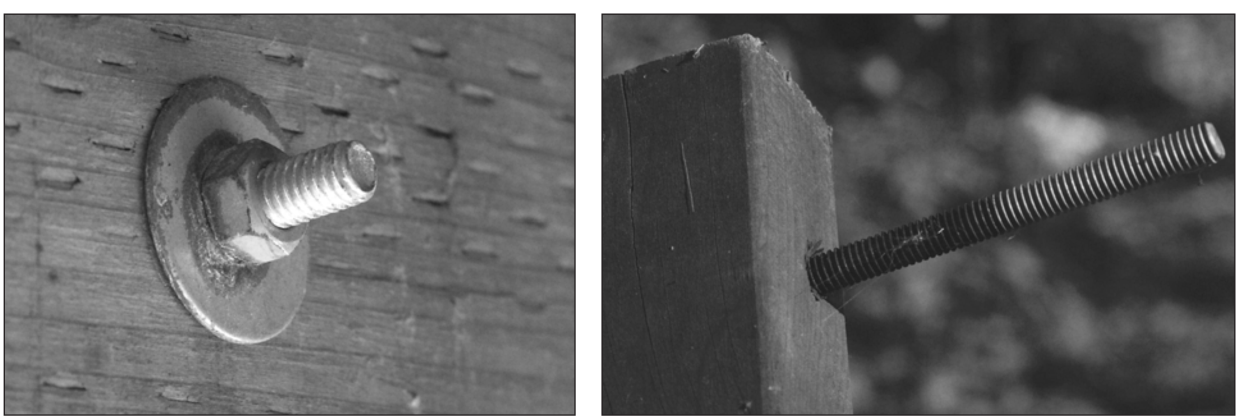


Figure 3.27: The corrosion on these galvanized bolts was mostly hidden in the joint. Corrosion of the fastener is probably due to galvanic reaction between the fastener, the moisture in the wood, and the copper in the treated wood. Stainless steel would be a better choice here.

cally. For example, metal fasteners used with wood products made of redwood or cedar or treated with preservatives may corrode when subjected to moisture (Fig ure 3.27 . Hot dipped galvanized, coated fasteners recommended by the preserva tive manufacturer or stainless steel fas teners should be used instead.

Special Considerations

Direct contact of aluminum products with certain dissimilar materials, or con tact with water runoff from dissimilar materials, is likely to result in corrosion. Care should be taken during installation to avoid such contact of aluminum with dissimilar materials including dissimilar metals for example, copper, zinc, steel, etc. , concrete, stucco, asbestos siding, pressure treated or pretreated lumber, masonry, roofing materials or roofing systems containing metallic granules or strips or corrosive nonmetallic materials.

Prevent direct contact between alu minum surfaces and ferrous or other incompatible metals by one of the fol lowing methods:

- Paint the incompatible metal with an appropriate protective coating
- Provide an approved nonabsorptive gasket.
- Apply an approved caulking between the aluminum and the incompatible metal.

Avoid Corrosion When Using Steel and Concrete

If you are building a house using con crete masonry for the foundation and cold-formed steel framing for the floor, you need to be concerned with possible corrosion problems due to the direct contact between steel and concrete.

Connecting conventional and in novative floor systems to concrete ma sonry walls requires techniques that may be unfamiliar to most home builders. In order to prevent corrosion, cold formed steel that is in direct contact with con crete masonry requires a moisture bar rier between the steel and the masonry. You can create the moisture barrier with polyethylene sheet, sill sealer, felt, or galvanized sheet metal flashing.

Sealants

A sealant is a material intended to seal the building joints from air and moisture leakage. It is important that it be able to handle movement. It also must be able to adhere to the surfaces it is sealing. Because there are so many types of seal ants and because their use has become commonplace with so many different materials, a basic understanding of seal ants will help avoid compatibility prob lems. Each manufacturer has different formulations so check compatibility for your most common applications. Then, select a group of sealants that suit your applications and stay with them.

House Wraps

The primary function of a house wrap or sheathing membrane is moisture con trol. Therefore, any breakdown of the moisture penetration control barrier of fers the possibility of water getting into the building. Certain chemicals, called surfactants, can cause the loss of water repellency of spun-bonded polyolefin housewraps. The tannins that make species such as cedar and redwood du rable can act as surfactants that cause house wrap to become more permeable to water. In addition, certain additives that improve the workability of stucco can also act as surfactants and lower the effectiveness of house wrap moisture barriers.

Back priming or back coating wood clapboards and trim helps to isolate the surfactants in the wood from the house wrap or building paper surface. Similarly, providing an air space between wood trim and clapboards using furring or some other spacer reduces the quantity and time water is trapped in the exterior of the wall assembly, thereby reducing the potential of surfactant movement.

Stucco should never be installed in direct contact with any of the plastic based house wraps. In addition to the problem of surfactants, stucco can "bond" or adhere to the house wrap surface, altering its surface energy and allowing house wrap pores to become "wetted" and subsequently establish capillary flow.

A drainage space between stucco and building papers or house wraps is essential to control water penetration. Bonding typically does not happen between stucco and building papers. However, most stucco applications over building papers don't allow enough drainage. Use at least two layers of building paper under stucco in order to allow some drainage between the two layers (Figure 3.28). Even better is to provide a spacer between the two layers of building paper by using a textured building paper or a building paper with granules or cork adhered to its surface, creating a space.

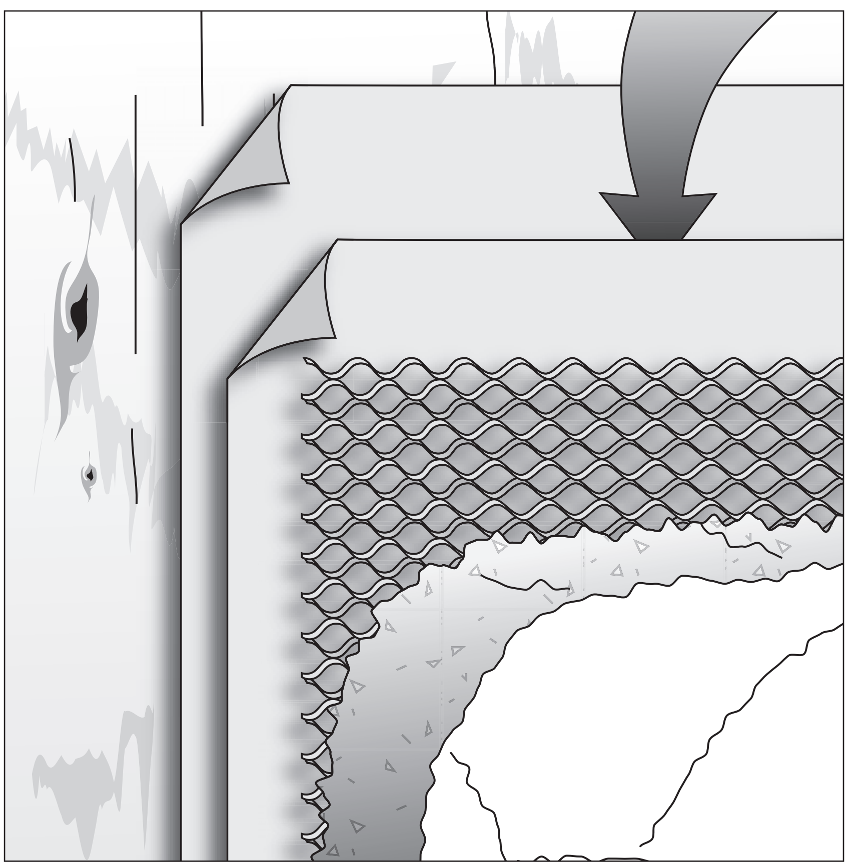


Figure 3.28: How to construct a drainage space for stucco

R-Value of Building Materials

Material	R/ Inch	R/ Thick-ness
Insulation Materials		
Fiberglass Batt	3.14	
Fiberglass Blown (attic)	2.20	
Fiberglass Blown (wall)	3.20	
Rock Wool Batt	3.14	
Rock Wool Blown attic	3.10	
Rock Wool Blown wall	3.03	
Cellulose Blown attic	3.13	
Cellulose Blown wall	3.70	
Vermiculite	2.13	
Air entrained Concrete	3.90	
Urea terpolymer foam	4.48	
Rigid fiberglass (> 4 lb/ft³	4.00	
Expanded Polystyrene bead board	4.00	
Extruded Polystyrene	5.00	
Polyurethane foamed in place	6.25	
Polyisocyanurate foil faced	7.20	
Construction Materials		
Concrete Block 4 inch		0.80
Concrete Block 8 inch		1.11
Concrete Block 12 inch		1.28
Brick 4 inch common		0.80
Brick 4 inch face		0.44
Poured Concrete	0.08	
Soft Wood Lumber	1.25	
2 inch nominal 1 ½ inch		1.88
2 x 4 3 ½ inch		4.38
2 x 6 5 ½ inch		6.88
Cedar Logs and Lumber	1.33	
Sheathing Materials		
Plywood	1.25	
¼ inch		0.31
⅜ inch		0.47
½ inch		0.63
⅝ inch		0.77
¾ inch		0.94
Fiberboard	2.64	
½ inch		1.32
25/32 inch		2.06

Material	R/ Inch	R/ Thick-ness
Fiberglass (¾ inch		3.00
1 inch		4.00
1 ½ inch		6.00
Extruded Polystyrene ¾ inch		3.75
1 inch		5.00
1 ½ inch		7.50
Foil-faced Polyisocyanurate ¾ inch		5.40
1 inch		7.20
1 ½ inch		10.80
Siding Materials		
Hardboard ½ inch		0.34
Plywood ⅝ inch		0.77
¾ inch		0.93
Wood Bevel Lapped		0.80
Aluminum, Steel, Vinyl hollow backed		0.61
w/ ½ inch Insulating board		1.80
Brick 4 inch		0.44

Interior Finish Materials		
Gypsum Board drywall ½ inch		0.45
⅝ inch		0.56
Paneling ⅜ inch		0.47
Flooring Materials		
Plywood	1.25	
¾ inch		0.93
Particle Board underlayment	1.31	
⅝ inch		0.82
Hardwood Flooring	0.91	
¾ inch		0.68
Tile, Linoleum		0.05
Carpet (fibrous pad)		2.08
rubber pad		1.23
Roofing Materials		
Asphalt Shingles		0.44
Wood Shingles		0.97
Windows		
Single Glass		0.91
w/storm		2.00
Double insulating glass 3/16 inch air space		1.61
¼ inch air space		1.69

½ inch air space		2.04
¾ inch air space		2.38
½ inch w/ low E 0.20		3.13
(w/ suspended film)		2.77
(w/ 2 suspended films)		3.85
(w/ suspended film and low-E)		4.05
Triple insulating glass ¼ inch air spaces		2.56
½ inch air spaces		3.23
Addition for tight fitting drapes or shades, or closed blinds		0.29

Doors		
Wood Hollow Core Flush 1 ¾ inch		2.17
Solid Core Flush (1 ¾ inch		3.03
Solid Core Flush (2 ¼ inch		3.70
Panel Door w/ 7/16 inch Panels 1 ¾ inch		1.85
Storm Door wood 50 glass		1.25
metal		1.00
Metal Insulating 2 inch w/ urethane		15.00
Air Films		
Interior Ceiling		0.61
Interior Wall		0.68
Exterior		0.17
Air Spaces		
½ inch to 4 inch approximately		1.00

BUILDING IN ALASKA

Caulks and Sealants Factsheet

An Energy Factsheet

EEM-01252

Infiltration heat loss can be up to 40% of winter home heat loss. Most of this occurs through leaky windows and door casings, those intentional openings in our buildings, which are not well weather stripped or caulked. Good sealants and caulks can reduce this easily, effectively and inexpensively. Good air sealing also increases the comfort level in homes.

The word "caulk" is an old boat building term: sealant originated in the homebuilding industry. Today some manufacturers use caulk as an all purpose term and sealant to describe their high performance specialty products. Most often these terms are used interchangeably and all the products serve the same purpose, to fill the gaps or pores in building materials and to keep water and air from penetrating or leaking out.

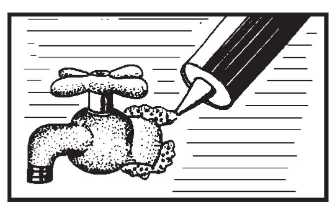
Much of what we will cover in this caulks and sealants factsheet will relate to new construction, but also it is important to consider sealants if you are retrofitting or rehabilitating an older structure. And it doesn't require an experienced handyman to do the work. But, some of the information, and the diversity of caulks on the market can be confusing and daunting to the novice.

Another important factor is to understand how caulks can fail. By installing them with the best application techniques and with good anticipation of success, you can prevent these failures. The bond between the caulk and the substrate (whatever it's being attached or adhered to) can fail. The caulk itself can tear or the substrate can break. However problems with caulk joints are commonly due to one of two errors. Either the substrate, typically wood or some other building material, was not properly and effectively prepared or the wrong product was chosen.

Another important consideration for caulking in Alaska is always caulk when the temperature is above 40°F or higher. Although some caulks can set up at cold temperatures and if you have an emergency they can be used, it is always better to have the caulk set up at a warm temperature. Polyurethane caulks can "set" at cold temperatures, but it is still better to apply them when it's above 40°F.

WHERE TO CAULK

NOTE: Weatherstripping, NOT caulking, is applied between moving surfaces such as window sashes and frames. Also, use foam gaskets around electrical outlets. Caulking should be used only as recommended by the manufacturer and in places where movement is untypical except for expansion and contraction.

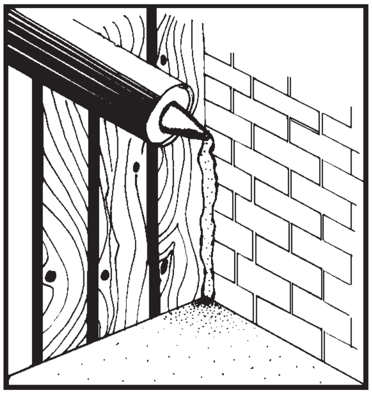


Caulking should be applied wherever two different materials or parts of the house meet but don't move and are not intended to move. These include:

- At the sill where wood structures meet the foundation.
- Where storm windows meet the window frames, leaving weepholes on bottom of outside pane.
- Baseboards, duct outlets, and any penetrations to a home for electrical plumbing or other utilities.

CAULKING MATERIALS

First invest in a good caulking gun. Caulk typically comes in cartridges and it's often easiest to apply it with a caulking gun. But there are other means, including small tanks, boxes with expanding foam fillers and caulks, and some caulking materials even come in spray cans or can be applied with a brush. In order to work or form the joint, a putty knife, even a plastic spoon can be used to make a very good tooled surface to the caulk bead. Expect that a 10 to 11 oz. tube of caulking will fill 20 to 30 linear feet of joint space.



There are many types of caulks, however the following types can meet most of your needs:

First we'll consider **Silicone.** Silicones are the best sealants for glass, metal, and cold weather. So these should be highly considered for many applications in Alaska. However a major caution in silicones is don't use the "acid cure" type. Experienced contractors and builders in Alaska have a phrase that gives a clue to how to judge whether to use a certain silicone. That is, if it smells like vinegar don't use it on bare wood.

There are silicones that are neutral cure and these are the ones to use. Neutral cure silicones absorb oxygen from the air to stimulate the curing process. Although many products have come into the market since silicones were first sold, and other chemistries are outperforming silicones and may even be easier to work with, silicones are still the best product available for many applications. This complicates the decision, but you can rarely go wrong using an appropriate silicone for a caulk application.

Silicone products have been formulated for just about every substrate. Silicone is a bit tricky to work with. It's more difficult to gun and tool than some other caulks and requires solvents to clean it up. And an important note: most silicones cannot be painted. Once silicone is damaged it tears easily and silicone products cannot be repaired by reapplications because ironically, silicones do not adhere to cured silicones.

Silicone also adheres poorly to one of the most common building materials, wood. On the other hand, its advantages are that it stands up to extreme weather, cures soft and remains flexible. Because silicone is inorganic it's unaffected by ultraviolet radiation and resists mold and mildew. It can be applied at virtually any temperature and can stand up to adverse weather conditions shortly after application.

Again, there are formulations for every substrate, but most importantly silicone adheres to nonporous substrates better than any other sealant, making it the best choice for surfaces such as, glass, metal, ceramic tile, and porcelain. And keep in mind again, that for silicone, clean and dry substrate surfaces are imperative.

Another relative newcomer on the market is **Synthetic-rubber** caulk. These include products like **Sashco Lexel** (www.sashco.com) and **OSI's Quad**. Although they are synthetic rubber, they are not labeled as a particular chemistry like silicone or polyurethane. However they represent some of the most flexible and clearest-curing products on the market. These qualities make them ideal for exterior joints likely to expand and contract.

These solvent-based synthetic-rubber products adhere well to most substrates and can be applied in wet and cold weather, and also resist mildew. The qualities however that set these caulks and sealants apart from the rest are the ease with which they stretch, their ability to stretch without breaking, and their ability to recover. Because they stretch so easily, there's less chance that the bond or substrate will break during joint movement.

Synthetic rubber is also said to have memory. When it is stretched even to extreme length it returns to its original cured size and shape. These qualities make solid based rubber caulks and sealants the best products for use in log homes, on wood siding and roofs, and other joints that encounter frequent movement.

Synthetic-rubber caulks and sealants are paintable with water-base paints and come in clear formulas that cure more transparent than any other caulk. Be careful because they are also flammable until they cure, shrink significantly, and have a high percentage of volatile organic compounds (VOCs) in them. In fact, in some parts of the country synthetic-rubber caulks don't meet current VOC regulations. Therefore they should not be used indoors without very ample ventilation, if at all.

Next we want to talk about **Polyurethane** caulks. Polyurethane frankly can be dangerous. Polyurethane is stringy and odorous and is also toxic and potentially hazardous to your health. So why would you bother with polyurethane? Well because polyurethanes are the only sealants that can stand up to abrasion. So there is almost nowhere in residential construction that a safer product cannot be substituted except for very high-traffic areas.

Polyurethanes are also curious because they actually cure better if slightly moistened. If you need to seal joints on a floor, on a driveway, or in a garage with frequent foot or vehicular traffic, break out the rubber gloves, the respirator, and the polyurethane sealant.

There are also polyurethane spray foams to fill large gaps and they end up with an R-value of about 4 ½ per inch. But these foams are tricky to use because they expand as they cure. Polyurethane foams come in low, moderate, and highly expanding formulas, but even minimally expanding polyurethanes can grow up to 300% before they cure.

Spray polyurethane may not be the best choice for a sealant but it is well suited for insulating in narrow spaces such as around windows. It is difficult to apply foam as uniform and complete as necessary for the tight seal required for the building envelope. Some polyurethane foams become solid and even brittle as they cure and age. If there is any relative movement such as the expansion and contraction of vinyl windows, these brittle foams turn into "saw-dust-like" dust. Other foam products cure into a resilient, sponge like media that will last indefinitely and will bond to wood and PVC fairly well. Hilti makes one product that is very well suited for this application.

Several foam manufacturers provide a foam applicator that greatly enhances the technician's ability to apply a uniform amount of foam where desired, as well as reducing the waste of partly used cans with the valve on the can. The applicators have a flow control and shut off valve as well as an easy to operate trigger to start and stop the flow of foam. When a partial container of foam is left the shut off valve is closed and the rest may be used even months later. It is advisable to test the polyurethane foams available locally or discuss with contractors just what product works best. Even with applicator use it is not possible to make an airtight seal around the corners of vinyl windows. Relying on the foam to expand to fill small voids and openings is wishful thinking and a poor practice. The external seal on windows should be made with a single part urethane caulk (i.e., Bostik Chemcaulk 900 or Tremco 830).

There are also **water-base** caulks now available and they are the easiest to work with. They have a smooth, thin consistency and are basically latex products, but also include vinyl and acrylic caulks. They clean up with water, have little odor, and are nontoxic. Water-base caulks adhere well to most common building materials and these cured water-base caulks are paintable.

Performance of water-base caulks however can vary dramatically from one product to the next. There is a wide range of water-base caulk from painter's caulk to elastomeric sealants. Latex caulks can be used for just about any application as well.

Some water-base products are flexible and weather resistant for exterior joints, others are intended to hide only interior seams that are to be painted. These water-base caulks perform best in warm, dry weather. Be careful in rainy situations because although water-base caulks can be applied to moist surfaces, rain can wash them away before they cure fully.

Butyl caulks are exceptionally messy and they stretch like chewing gum and have little or no ability to recover. They have an unattractive tarlike appearance. But as far as caulk technology has come, butyl is still the most water-resistant product available. For this reason, butyls remain viable for specific applications. Gutters are a good example of the right place to use butyl caulk. Butyl resists water and because it never hardens completely, butyl can stand up to random movement of a shear joint.

A shear joint is where two substrates overlap. Roof flashing is an example of a shear joint, and another place where butyl is the best choice. Butyl's resistance to moisture also makes it the best caulk to use on foundations or anywhere a sealant may be needed below grade.

Butyl caulk is a controversial option. Some information sources recommend it as a best choice for applications such as rain gutters and roof flashing, such as we quote here. Other users and reports indicate butyl is a *poor*(!) choice for such applications. As indicated on the Canadian Wood Products table included later in this publication, it is reputed to have "low moisture resistance." These claims are diametrically opposed to each other.

While claims that butyl caulks are messy and leave an unattrative tarlike appearance are clearly true, the author's personal experience with butyl caulk is that it has worked well on storm gutters, and for many years. Reports from readers' experiences with butyl caulks are welcome, so that we can get some Alaskan experience into the mix. Please contact the author at ffrds@uaf.edu with your experiences at using butyl caulks, or any of these other options, for that matter.

Modified-silicone polymers like **DAP's Side Winder** and **OSI's Advantage** represent the newest type of sealant available. They are difficult to classify because they combine the chemistry and benefits of water-base, silicone, and polyurethane products into one sealant. They are expensive but worth the money for sealing important outdoor areas like windows, doors, and vents. Like latex and acrylic products, modified-silicone polymers are easy to gun.

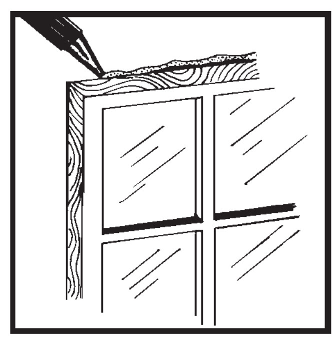
Like silicones they can be applied in extreme temperatures and can withstand a rain almost immediately and like polyurethanes, they are incredibly durable and adhere well to almost any substrate material. They are flexible, paintable with water-base paints, but you should use a latex primer before coating with oil-base paints. These hybrids also have a lower VOC content than solvent-based synthetic-rubber products. They cure quickly and don't shrink.

At this point the only uncertainty about the modified-silicone polymers is that they are expensive and new. Although manufacturers put all their products through rigorous testing, modified-silicone polymers have been on the market for only a few years and not long enough to prove their worth to demanding builders and homeowners, so be careful when choosing these.

Finally, let's talk about **Acoustical Sealants** those materials that are recommended for sealing polyethylene air/vapor retarders, TYVEK® air retarders and other materials to these plastic air/vapor retarders and their substrates. Tremco acoustical sealant, Teno sealant and some other new materials including LePage's Bulldog Grip PL Acousti-seal are all designed to be used to seal polyethylene and other plastic air/vapor retarders to substrates in building situations. The properties of these materials are generally recognized as the best choice for sealing air/vapor retarders of all types. Because of the sticky, tenacious adhesion, and properties of not hardening, fluidity at cold temperatures, and very good adhesive quality it is an ideal sealant for plastics. Solvents for it (an important consideration!) are acetone, petroleum distillate, kerosene and other solvents.

CAULKING APPLICATION

1. Thoroughly clean and dry area to be caulked with a solvent and putty knife. Solvent for latex is water; other caulking compounds require mineral spirits, acrylic or naphtha.



2. Don’t caulk a joint that is larger than the tip of the nozzle of the caulking gun. If the cracks are deep or wide, fill them with a filler material. As a rule, cracks measuring more than ½ inch wide or ½ inch deep require special preparation with backer rod or expanding foam. Backer rod is a foam rubber rope used to fill larger gaps, e.g., in a log cabin. It comes in ¼ inch to 1¼ inch diameters. Expanding foam is a sealer, not a filler.

3. Cut the spout of the caulking gun at an angle that will give you the proper size bead for the job.

4. Hold the gun at a 45° angle. Make sure the bead covers both sides of the crack. DON’T SKIMP. Most people caulk from top to bottom, but you

TABLE 1 - CAULKS AND SEALANTS FOR INTERIOR USE

Sealant type (CGSB spec. #)	Typical uses & materials	Joint width and % movement	Advantages	Disadvantages
Oil or resin based (11-GP-6M)	Interior rigid joints	10mm (3/8") 1%	Lowest cost	Low performance, may dry hard, may bleed oils, cannot be painted, lower life span
Acoustical (19-GP-21M)	Interior unexposed joints, polyethylene sheeting	16mm (5/8") 10%	Good workability, good sealing properties, adheres to polyethylene, long life span	Cannot be painted, difficult to clean, non-hardening, needs support
Acrylic latex (19-GP-21M)	Interior finishes and low-movement joints, except metal	9mm (3/8") 2%	Good general purpose caulk, low movement, fast curing, paintable	Apply above 4.4°C (40°F) only, low moisture resistance, moderate flexibility
Vinyl acrylic latex	Interior finishes, porous surfaces such as wood or concrete	9mm (3/8") 2%	Low cost, paintable, (Lower performance than acrylic latex.)	Apply above 4.4°C (40°F) only, poor flexibility, shrinks, low moisture, sun resistance
Thermoplastic elastromer	Interior air seal and finishes, adheres well to most interior surfaces	12mm (1/2") 4%	Good moisture resistance, paintable, minimal odor, clear, long life span	Low elasticity, low resistance to water, sun

Source: Technical Bulletin No. 1, Windows, The National Energy Conservation Association (NECA), Winnipeg, MB

can get better results by caulking from bottom to top and pushing the gun up versus pulling the gun down.

5. Smooth out the compound with the nozzle as you apply it and with a putty knife after application. If the caulking material shrinks after drying, reapply. Make sure the caulking bridges the gap. Trowel and tool the bead with a putty knife, plastic spoon or other surface finish tool.

6. Start at the back of your house and work towards the front. Your skill level will improve when you caulk in places that are visible!

NOTE: Caulking windows on the inside is preferable at all times, due to moisture migration and in-cavity condensation.

REFERENCES

1. http://www.taunton.com/finehomebuilding/pages/h00146.asp Article from "Fine Homebuilding" Magazine, Making Sense of Caulks and Sealants. 6p.

2. http://www.lepageproducts.com

3. http://www.cwc.ca/design/building_science/internal_barriers/caulks.php

4. http://www.factsfacts.com/MyHomeRepair/caulk.htm
   This is a private/personal website with a good archive of personal experiences rating caulks and sealants for various uses. It includes all sorts of tips for clean-up, storing caulk, testing before use, and problems as well.

TABLE 2 - CAULKS AND SEALANTS FOR EXTERIOR USE

Sealant type (CGSB spec. #)	Typical uses & materials	Joint width and % movement	Advantages	Disadvantages
Solvent-based acrylic (19-GP-5M)	Widely used, general purpose exterior sealant	19mm (3/4") 7.5%	Excellent adhesion, good resistance to chemicals (cannot be painted)	Should be applied above 4.4°C (40°F), subject to stains cracks before service life
One-part polysulfide	Large joints, masonry and concrete	19 to 24mm (3/4" to 7/8") 12 to 25%	Excellent flexibility and durability, resistance to moisture, paintable, long life span	Requires surface priming, strong odor during application, toxic to skin
Hypalon	Concrete, metals, wood, masonry	15mm (1/2") 12.5%	Good elasticity, cures to consistency of rubber, paintable	Should be applied above 10°C (50°F), slow curing, unsuitable for most surfaces
Butyl-based (19-GP-14M)	Exterior metal or masonry sealant non-exposed interior	12mm (1/2") 5 to 10%	Very flexible	High shrinkage, must cure 1 week before painting, low moisture resistance*
Silicone (19-GM-18M)	Exterior finishes, some interior uses	25mm (1") 12 to 25%	Excellent performance, good temperature and flexure resistance, long life span	Cannot be painted, high cost, may require surface priming, gives off odor when curing (acid cure)
Thermoplastic rubber	Exterior finishes, interior finishes	13mm (1/2") 50%+	Exceptional flexibility, available in range of colors, minimal odor, long life span	Lowest service temperature specified as -30°C (-23°F), should be applied above 5°C (16°F)
Polyurethane and pre-polymer Type (CAN2 19.13-M82)	Small exterior and interior joints (walls, floors)	12mm (1/2") 25 to 50%	Excellent flexibility and resistance, minimal odor, paintable, long life span	High cost, primer may be required, low adhesive to plastics
Two-part polysulphide	Joint filler, high traffic areas, wet areas	20mm (3/4") 25%	Excellent adhesion, flexibility and durability, long life span	Difficult application from bulk loader, may require surface primer
Transparent removable	Small crack air-sealing, usually interior windows	10mm (3/8") 10%	Low cost, easy application and removal, suitable for most materials	Must reapply each winter, gives off odor while curing, 24 hours to harden, shorter life span

Source: Technical Bulletin No. 1, Windows, The National Energy Conservation Association (NECA), Winnipeg, MB

* The validity of this claim is in question.

BUILDING IN ALASKA

EEM-00259

Permeability of Common Building Material to Water Vapor

WHAT IS A PERM RATING?

If a material has a perm rating of 1.0, we know that in 1 hour, when the vapor pressure difference between the cold side and the warm side of the material is equal to 1 inch of mercury (1" Hg), 1 grain of water vapor will pass through 1 square foot of the material. One grain of water is equal to 1/7000 of a pound.

Vapor pressures depend on the temperature and relative humidity (RH) of the air — as temperature and RH go up, vapor pressure gets higher. The greater the vapor pressure differential across or through a material, the greater the tendency for water vapor to migrate from the high pressure side to the low pressure side.

EFFECT OF MATERIAL THICKNESS

The perm ratings given are for stated thicknesses of materials. Generally, doubling material thickness halves water vapor transmission: if 1 inch of a material has a perm rating of 2.0, then for 2 inches, the perm rating would be 1.0. With paints, however, adding a second coat more than halves the water vapor transmission.

ALASKAN VAPOR BARRIERS

Because of Alaska's wintertime vapor pressure differentials, and the lengths of the cold spells, the ideal vapor barrier has a perm rating approaching 0.0. The most widely used vapor barrier is 6 mil polyethylene, which has a perm rating of 0.06. Given the combination of high RH indoors, and very cold weather outside, measurable amounts of water vapor will pass through 6 mil polyethylene. For high moisture buildings, such as those housing swimming pools or Jacuzzis, 10 mil polyethylene is often specified. In practice, however, it is not usually the perm rating of the water vapor barrier which determines how much water will pass into the insulation, but the quality of the vapor barrier installation. A carefully installed, well sealed 4 mil polyethylene vapor barrier is much to be preferred to a 6 mil VB with unsealed seams, gaps, tears at electrical boxes and unsealed attic scuttle openings.

QUALITY OF DATA

Perm ratings are established by testing, but several different test methods are used, and different tests on the same materials yield different results. For this reason, published perm ratings are not to be regarded as the truth, but as a design guide. When the vapor barrier performance of a material is critical to an installation, it is best to rely on manufacturer's specifications, or conduct an independent test. For an enlightening discussion of this issue, see The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE's) *1985 Handbook of Fundamentals*.

A SAMPLE CALCULATION

For demonstration purposes, we shall now assume a set of conditions and make a calculation concerning the amount of water vapor which will migrate through a vapor barrier. The relevant formula is:

WVT = A x T x delta P x perms

WVT stands for **"water vapor transmission."** Unit of measurement: grains. One pound equals 7000 grains.

A means **"area."** Unit of measurement: square feet (ft^2). We will assume that this is a two story house, 24' wide by 40' long by 17' high. Area of the vapor barrier, then, is about **3900** ft^2, allowing 10% of floor area for doors and windows.

T means **"time."** Unit of measurement: hours. We will perform this calculation for the month of January, which has **744** hours.

Delta P means **"difference in vapor pressure between inside and outside."** Unit of measurement: inches of mercury (" Hg). In order to derive this number, we must assume a temperature and a relative humidity (RH) for both inside and out. Let the inside temperature be 70°, and the outside -10°, which is about average for January in Fairbanks. Let the inside RH be 40%, and the outside be 70%. The Table of Vapor Pressures gives figures for saturated air (100% RH); to get the vapor pressure at an RH less than 100%, you multiply by the percent RH. In this case, (.7392 x 40%) - (.022 x 70%) = **.2803** " Hg.

Perms means **"perm rating."** Unit of measurement: grains of water vapor per hour per square foot per inch of mercury vapor pressure differential (gr/ft^2/hr/" Hg). We will assume that the average perm rating of the installation (including unpatched tears, nailholes, etc.) is 0.1 perms.

With these assumptions, then:

WVT = A x T x Delta P x Perms
3900 x 744 x .2803 x 0.1 = 81332

grains of water. This is 11.6 pounds, or about 1.4 gallons.

Table 1 ***Vapor Pressures For Saturated Air***

°F	in Hg	°F	in Hg	°F	in Hg	°F	in Hg
-65	.0007	15	.0806	43	.2782	71	.7648
-60	.0010	16	.0847	44	.2891	72	.7912
-55	.0014	17	.0889	45	.3004	73	.8183
-50	.0020	18	.0933	46	.3120	74	.8462
-45	.0028	19	.0979	47	.3240	75	.8750
-40	.0039	20	.1028	48	.3364	76	.9046
-35	.0052	21	.1078	49	.3493	77	.9352
-30	.0070	22	.1131	50	.3626	78	.9666
-25	.0094	23	.1186	51	.3764	79	.9989
-20	.0126	24	.1243	52	.3906	80	1.032
-15	.0167	25	.1303	53	.4052	81	1.066
-10	.0220	26	.1366	54	.4203	82	1.102
-5	.0289	27	.1432	55	.4359	83	1.138
0	.0377	28	.1500	56	.4520	84	1.175
1	.0397	29	.1571	57	.4686	85	1.213
2	.0419	30	.1645	58	.4858	86	1.253
3	.0441	31	.1723	59	.5035	87	1.293
4	.0464	32	.1803	60	.5218	88	1.335
5	.0488	33	.1878	61	.5407	89	1.378
6	.0514	34	.1955	62	.5601	90	1.422
7	.0542	35	.2035	63	.5802	91	1.467
8	.0570	36	.2118	64	.6009	92	1.513
9	.0599	37	.2203	65	.6222	93	1.561
10	.0629	38	.2292	66	.6442	94	1.610
11	.0661	39	.2383	67	.6669	95	1.660
12	.0695	40	.2478	68	.6903	96	1.712
13	.0730	41	.2576	69	.7144	97	1.765
14	.0767	42	.2677	70	.7392	98	1.819

TABLE 2 *PROPERTIES OF WEATHER BARRIERS AND BUILDING PAPERS*

Product Name	Tyvek homewrap, Dupont Company	Airtight-Wrap Presec, Inc.	Typar BBA Fiberweb building felt	R-Wrap Ludlow Coated Products	Barricade Building Wrap-Simplex	Conventional 15-lb asphalt-impregnated
Type Product	Single bonded Polyethylene	Micro-perforated cross-laminated high-density polyethylene film	Non-woven polyethylene	Spun-Bonded polyethylene with microporous coating	Spun-Bonded polyester	
	(1)		(2,3,4)		(5)	(6)
Permeance (**perms**) ASTM E-96 Method A	[48]	{15.2}	11.7	59	25.4	[5.6]
Thickness (**mils**)	6.1	3	12.9	9	6	37.4
Weight (**lb/1,000 ft²**)	8.81	12.7	21	17.3	136.1	150
Available dimensions (**ft**)	9x195 3x160	9x195 4.5x195	3x100 10x100 10x200 9x50 & 9x100 9x111 & 9x150 9x195 & 4.5x200	9x100 9x150 4.5x100 4.5x150 1.5x150	3x195 4.5x195	3 rolls (3x100)
Tensile strength, (**lbs**) ASTM D-1882						
Length	43.2	57.2	80	32	N.A.	N.A.
Width	64	60.4	87	32		
Tear resistance (**lbs**) ASTM D-827						
Length	[6]	[36.0]	[36.0]	[36.0]	[5.2]	[24.8]
Width	[6]	[36.0]	[36.0]	[36.0]	[14.6]	[20.7]
Air porosity (**seconds**) Gurley porosity TAPPI-T460	[300sec/100cc]	[8.7]	2500sec/100cc	[8.7]	10.5	[14.3]
Water resistance (**cm**) AATCC Method 127	[210]	11	865	>186	[35.8]	[41.8]

NOTES:
1. Extrapolated from, "Wrap Wars," Alex Wilson, New England Builder, August 1987.
2. Values in brackets, [ ], obtained from DuPont literature on Tyvek.
3. Values in brackets, { }, low because film installed backwards (worst-case situation).
4. All other values obtained from company literature or personal communication with company.
5. Perm: Vapor transmission rate of 1 grain of water vapor/ft²/hr/in. of mercury pressure difference.
6. The data are provided to permit comparison of material and selection of air-vapor barrier or weather barrier materials.
7. Exact values should be obtained from the manufacturer of material.
8. A continuous air-vapor barrier is usually placed on the warm side of the shell before the gypsum board (drywall) is placed.
9. The air-vapor barrier should have a permeance of less than 1 perm.
10. The weather barrier should have a high permeance, a low water resistance, a high air porosity, high tensile strength, and high tear resistance.
11. The compilation is from a number of sources; values from dry-cup and wet-cup methods were usually obtained from investigations using ASTM E96 and C355. Other values were obtained using techniques such as two-temperature, special cell, and air velocity.

Source: Axel R. Carlson, Professor Emeritus, University of Alaska Fairbanks, Fairbanks, Alaska, 9/3/87.

TABLE 3 WATER VAPOR PERMEANCE OF CONSTRUCTION MATERIALS

Material	Thickness (in.)	Permeance (perm)	Permeability (perm/in.)
MATERIALS USED IN CONSTRUCTION			
Concrete, 1:2:4 mix	4	1.25	3.2
Brick masonry	4	0.8	
Concrete block, cored limestone aggregate	8	2.4	
Tile masonry, glazed	4	0.12	
Asbestos cement board	0.12	4-8	
with oil base finish	0.12	0.3-0.5	
Plaster on metal lath	0.75	15	
Plaster on wood lath	0.75	11	
Plaster on plain gypsum lath, with studs	0.75	20	
Gypsum wall board, plain	0.375	50	
Gypsum sheathing, asphalt impregnated	0.5		20
Structural insulating board, sheathing quality	0.5		20-50
Structural insulating board, interior uncoated	0.5	50-90	
Hardboard, standard	0.125	11	
Hardboard, tempered	0.125	5	
Roofing, built up, hot mopped		0	
Wood, sugar pine			0.4-5.4
Plywood, Douglas Fir, exterior glue	0.25	0.7	
Plywood, Douglas Fir, interior glue	0.25	1.9	
Acrylic, glass fiber reinforced sheet	0.056	0.12	
Polyester, glass fiber reinforced sheet	0.048	0.05	
THERMAL INSULATIONS			
Air still			120
Cellular glass			0
Mineral wool, unprotected			116
Expanded polyurethane, R-ll, board stock			0.4-1.6
Expanded polystyrene, extruded			1.2
Expanded polystyrene, bead			2.0-5.8
Phenolic foam, covering removed			26
Unicellular synthetic flexible rubber foam			0.02-0.15
PLASTIC AND METAL FOILS AND FILMS			
Aluminum foil	0.001	0	
Aluminum foil	0.00035	0.05	
Polyethylene	0.002	0.16	
Polyethylene	0.004	0.08	
Polyethylene	0.006	0.06	
Polyethylene	0.008	0.04	
Polyethylene	0.010	0.03	
Polyvinyl chloride, unplasticized	0.002	0.68	
Polyvinyl chloride, plasticized	0.004	0.8-1.4	
Polyester	0.001	0.73	
Polyester	0.0032	0.23	
Polyester	0.0076	0.08	
Cellulose acetate	0.01	4.6	
Cellulose acetate	0.0125	0.32	

TABLE 3 *(CONTINUED)*

Material		Permeance, (perms)		
		Dry-cup	Wet-cup	Other
BUILDING PAPERS, FELTS, ROOFING PAPERS:	**Weight (lb/100 ft²)**			
Duplex sheet, asphalt laminated, aluminum foil, one side	8.6	0.002	0.176	
Saturated and coated roll roofing	65	0.05	0.24	
Kraft paper and asphalt laminated, reinforced 30-120-30	6.8	0.3	1.8	
Blanket thermal insulation back up paper, asphalt coated	6.2	0.4	0.06-4.2	
Asphalt-saturated but not coated sheathing paper	4.4	3.3	20.2	
Asphalt-saturated and coated vapor barrier paper	8.6	0.2-0.3	0.6	
15-lb asphalt felt	14	1	5.6	
15-lb tar felt	14	4	18.2	
Single-kraft, double	3.2	31	42	
LIQUID-APPLIED COATING MATERIALS	**Thickness (in.)**			
Commercial latex paints, dry film thickness				
Vapor retardant paint	0.0031			0.45
Primer sealer	0.0012			6.28
Vinyl acetate/acrylic primer	0.002			7.42
Vinyl-acrylic primer	0.0016			8.62
Semi-gloss vinyl-acrylic enamel	0.0024			6.61
Exterior acrylic house and trim	0.0017			5.47
Paint, 2-coats				
Asphalt paint on plywood			0.4	
Aluminum varnish on wood		0.3-0.5		
Enamels on smooth plaster			0.5-1.5	
Primers and sealers on interior insulation board			0.9-2.1	
Various primers plus 1-coat flat oil paint on plaster			1.6-3.0	
Flat paint on interior insulation board			4	
Water emulsion on interior insulation board			30.0-85.0	
Exterior paint 3-coats, on wood siding	**(oz/ft²)**			
White lead and oil		0.3-1.0		
White lead-zinc oxide		0.9		
Styrene-butadiene latex coating	2	11		
Polyvinyl acetate latex coating	4	5.5		
Chloro-sulfonated polyethylene mastic	3.5	1.7		
Chloro-sulfonated polyethylene mastic	7	0.06		
Asphalt cut-back mastic, 1/16 in., dry		0.14		
Asphalt cut-back mastic, 3/16 in., dry		0		
Hot melt asphalt	2	0.5		
Hot melt asphalt	3.5	0.1		

Notes:
1. Extrapolated from "Moisture in Building Construction," ASHRAE, 1985.
2. Tables give water transmission rates of representative materials.
3. Perm: Vapor transmission rate of 1 grain of water vapor/ft2/hr/in. of mercury pressure difference.
4. Exact values should be obtained from the manufacturer of material.
5. The air-vapor barrier should have a permeance of less than 1 perm.
6. The air barrier should have high permeance, low water resistance, high air porosity, high tensile strength, and high tear resistance.
7. The compilation is from a number of sources; values from dry-cup and wet-cup methods were usually obtained from investigations using ASTM E96 and C355. Other values were obtained using techniques such as two-temperature, special cell, and air velocity.

Source: Axel R. Carlson, Professor Emeritus, University of Alaska Fairbanks, Fairbanks, Alaska, 9/3/87

TABLE 4 *PERMEANCE OF INTERIOR WALL COVERINGS*

Treatment	Outside Tempera-ture, °F	Relative Humidity %	Water Passing ml/h	Permeance perm	Variance
Control	-8.0	60	1.32	7.02	0.783
Control	-10.5	41	1.04	7.68	0.456
Cotton cloth	12.3	61	0.66	3.61	0.347
Sealer, 1-coat	-16.2	62	0.91	4.29	0.498
Sealer, 1-coat	5.8	63	0.78	4.03	0.145
Sealer, 2-coat	-17.3	61	0.54	2.78	0.082
Wall paper, conventional	-17.8	38	0.82	7.03	0.366
Vinyl paper	-24.0	66	0.15	0.73	0.189
Mean	-9.46	56	0.78	4.65	0.358

NOTES:
1. Extrapolated from, "Interior Wall Coverings For Moisture Control," James A. Lindley and Helen A. Lunde, Agricultural Engineering and Home Economics Departments, North Dakota State University, Fargo, North Dakota, 1987.

Source: Axel R. Carlson, Professor Emeritus, Cooperative Extension Service, University of Alaska Fairbanks, Fairbanks, Alaska, 9/21/87.

Mention of a brand name does not constitute an endorsement of the product mentioned.

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Insulation Factsheet

EEM-01454

Materials	Advantages	Disadvantages	Applications*: Roof, cathedral ceiling	Applications*: Attic floor, flat ceiling	Applications*: Walls: between framing	Applications*: Walls: sheathing	Applications*: Floors over unheated spaces	Applications*: Masonry walls (interior surface)	Applications*: Masonry walls (exterior surface above ground)	Applications*: Masonry walls (exterior surface below ground)	Thermal Properties: R-Value	Thermal Properties	Density (lb.ft.^{3})	Effectiveness as a Vapor Barrier*	Resistance To:* Water Absorption	Resistance To:* Moisture Damage	Resistance To:* Direct Sunlight	Resistance To:* Fire	Maximum Service Temperature (°F)	Packaging
ROLLS BATTS & BLANKETS																				
Fiberglass (many brands)	Easy to install in many locations, especially standard frame construction. Fairly inexpensive per R-value point. Good fire resistance. Widely available.	Hard to install properly in tight or cramped spaces. Cannot be installed in enclosed cavities. “Vapor barrier” facings hard to install effectively; additional vapor/infiltration barriers usually required. Moisture and infiltration degrade R-value of insulation. Insulation “dust” during installation can irritate eyes, skin, and lungs;: Installer should wear eye protection, respirator, gloves, and full-coverage clothing. Most facings are flammable; some nonflammable facings may be available. Multiple layering of batts/blankets in horizontal space (attic floors) can degrade R-value of lower layer because of compression.	1	1	1	4	2	3	4	4	3.14 (3.0-3.8)	C	0.3-2.0	Unfaced: not a vapor/ infiltration barrier. Faced: poor vapor barrier, which requires sealed polyethylene vapor barrier in Alaska’s climate.	B	A	A	B	180°	Batts up to 8’ long Rolls up to 70’ long Widths: 11” to 48”. Thicknesses: 1” to 13” Available with kraft- paper or aluminized-paper facings, or unfaced.
Rock Wool (slag wool) (Many brands)	Same as fiberglass except has excellent fire resistance.	Same as fiberglass.	1	1	1	4	2	3	4	4	3.14 (3.0-3.7)	C	0.3-2.0	Unfaced: Not a vapor/ infiltration barrier. Faced: same as above.	B	A	A	A	Over 500°	Batts and rolls Widths: 11” to 24” Thickness: 3” to 8”

*Rating System: 1 = recommended, 4 = not recommended *A = Excellent B = Good C = Fair D = Poor †Includes cost of installation by a contractor. ‡NA = information not available.

Materials	Advantages	Disadvantages	Applications*								Thermal Properties				Resistance To:*					
			Roof, cathedral ceiling	Attic floor, flat ceiling	Walls: between framing	Walls: sheathing	Floors over unheated spaces	Masonry walls (interior surface)	Masonry walls (exterior surface above ground)	Masonry walls (exterior surface below ground)	R-Value		Density (lb.ft.^{3})	Effectiveness as a Vapor Barrier*	Water Absorption	Moisture Damage	Direct Sunlight	Fire	Maximum Service Temperature (°F)	Packaging
LOOSE FILL (FOR POURING/BLOWING)																				
Fibeglass (e.g., Fiberglas, Insulsafe, Retrofil, and others)	Can be poured or blown into enclosed, inaccessible, and oddly shaped cavities. In horizontal spaces like attic floors, pour-in is faster to install than batts/blankets. Blown insulation is often the only retrofit option for woodframe walls. Widely available. Good fire-resistance. Does not absorb water.	Does not provide a vapor/infiltration barrier. Moisture and infiltration in cavity can degrade R-values. Blow-in installation not usually practical for do-it yourself applications; contractor or experienced help usually needed. Generates more dust during installation than batts/blankets. Installer should wear eye protection, respirator, gloves, and full-coverage clothing. Blown fiberglass has lowest R-value per inch of all loose-fill materials. Blown fiberglass can get hung up on wires and nails. Settling and voids can occur if blown at too low density.	1	1	3	4	1	4	4	4	2.8 (2.2-4.0)	C	0.61-2.5	Not a vapor/ infiltration barrier.	B	A	A	B	180°	Bags: 15-30 lb.
Rock wool (Many brands)	Same as fiberglass except has about 25% higher R-value per inch than loose-fill fiberglass.	Same as fiberglass, except has lower R-value per inch than batt/blanket rock wool.	2	1	2	4	2	4	4	4	3.1 (2.8-3.7)	C	1.5-2.5	Not a vapor/ infiltration barrier.	B	A	A	A	Over 500°	Bags: 25-35 lb.
Cellulose (Many brands)	Highest R-value per inch of all loose-fill materials. Can be blown through smaller holes than fiberglass. More impervious to air infiltration than fiber-glass or rock wool. Can be blown or poured. Widely available.	Requires careful chemical treatment to avoid fire hazards. (Look for class "A" fire rating.) Absorbs water, dries very slowly. Can deteriorate under prolonged exposure to moisture. Settling and voids can occur if blown at too low density.	2	1	2	4	3	4	4	4	3.2 (2.8-3.7)	C	2.2-3.0	Not a vapor/ infiltration barrier.	D	D	B	C	180°	Bags: 15-30 lb.
Perlite (Many brands)	Very good fire resistance. Widely available.	Must be poured; not suitable for blow-in installation.	4	1	3	4	1	4	4	4	2.7 (2.5-4.0)	C	2-11	Not a vapor/ infiltration barrier.	C	B	A	B	200°	Bags
Treated Perlite and "Ceramics" (e.g., Fire-Guard Lite Ceramic Products)	Very good fire resistance.	Same as perlite, except more expensive.	4	1	3	4	1	4	4	4	3.4 (NA)‡	B	4-6.8	Not a vapor/ infiltration barrier.	B	B	A	B	200°	Bags: 26 lb.
Vermiculite	Exceptionally good fire resistance. Widely available.	Absorbs water, dries slowly. Seldom used to insulate houses because of relatively low R-value and heavy weight.	4	2	4	4	1	4	4	4	2.13		7.0-8.2	Use polyethylene vapor barrier	B	C	N/A	A	Over 500°	?
Expanded Polystyrene (beads or shredded)	High R-value per inch. Can be blown or poured. Settling not a serious problem.	Potentially combustible, cannot be used near chimneys or flues. Must be covered with fire-resistant sheathing. Not widely available.	4	2	2	4	4	4	4	4	4.0		1.8	with these insulations	B	C	D	D	165°	Various

*Rating System: 1 = recommended, 4 = not recommended *A = Excellent B = Good C = Fair D = Poor †Includes cost of installation by a contractor. ‡NA = information not available.

			Applications*								Thermal Properties				Resistance To:*					
Materials	Advantages	Disadvantages	Roof, cathedral ceiling	Attic floor, flat ceiling	Walls: between framing	Walls: sheathing	Floors over unheated spaces	Masonry walls (interior surface)	Masonry walls (exterior surface above ground)	Masonry walls (exterior surface below ground)	R-Value		Density (lb.ft.^{3})	Effectiveness as a Vapor Barrier*	Water Absorption	Moisture Damage	Direct Sunlight	Fire	Maximum Service Temperature (°F)	Packaging
RIGID BOARD																				
Extruded Polystyrene (e.g., styrfoam, foamular)	Same as expanded polystyrene except: Good for exterior insulation of foundations and basement walls because of high moisture resistance and compressive strength. Closed-cell structure provides excellent moisture resistance.	Same as expanded polystyrene except: Some products contain fluorocarbons, which may damage the environment. Higher cost.	2	3	3	1	2	1	1	1	5.0 (5.0)	A	1.6-2.0	B	A	A	D	D	165°	Lengths: 8', 9' Widths: 16", 24", 48" Thicknesses: 3/4' to 2' Tongue-and-groove edges, special mastics and fasteners available.
Expanded Polystyrene (e.g., Cellulite, R-Wall, Insulfoam, Zonolite, many others)	High R-value per inch. Sometimes sold pre-bonded to various facing materials to provide heat-reflective surface, vapor/infiltration barrier, fire resistance finished wall surface, etc. Air infiltration does not degrade R-value as much as loose fills or batts/blankets. Lowest cost per R-value of all board insulations. Available in several density grades; higher density provides better thermal resistance & moisture resistance. Widely available.	Hard to install in corners and odd-shaped spaces. Combustible; must be covered with fire-resistant sheathing. Less mechanical strength and rigidity than extruded polystyrene.	2	3	2	1	2	1	1	3	4.0 (3.6-4.4)	A	0.9-1.6	D	D	B	D	D	165°	Panels: 2' x 8', 4' x 8', many other sizes. Thicknesses: 3/4" to 6" Tongue-and-groove edges, foil facings, composite panels, and many other special treatments available.
Urethane, Isocyanurate e.g., Thermax, Trymer, Thermatite, Plus High-R, many others)	Same as expanded polystyrene, except urethane has highest R-value per inch of all insulation materials.	Same as extruded polystyrene.	2	3	3	1	2	1	1	3	7.2 (7.1-7.7)	A	1.6-2.0	B Foil face is perfect vapor barrier but edge must sealed.	B	C	D	D	200°	Lengths: 8', 9' others available Widths: 4', others available Thicknesses: 1/2" to 3" Tongue-and-groove edges, foil facings, composite panels, and many other special treatments available.
High-density Fiberglass (e.g., Insulquick, many others)	Highest R-value per inch of all forms of fiberglass. Good fire-resistance. Conforms to slight irregularities in the framing better than plastic foam boards, which are more rigid.	Hard to fit in complex corners or odd-shaped spaces.	2	3	3	1	1	1	3	4	4.4 (3.85-4.76)	C	4-9	C	B	A	A	B	180°	Panels: 4' x 8' Thicknesses: 1" to 3" Available with facings of paper, plastics, metals, and unfaced.

*Rating System: 1 = recommended, 4 = not recommended *A = Excellent B = Good C = Fair D = Poor †Includes cost of installation by a contractor. ‡NA = information not available.

Materials	Advantages	Disadvantages	Applications*								Thermal Properties		Density (lb.ft.^{3})	Effectiveness as a Vapor Barrier*	Resistance To:*				Maximum Service Temperature (°F)	Packaging
			Roof, cathedral ceiling	Attic floor, flat ceiling	Walls: between framing	Walls: sheathing	Floors over unheated spaces	Masonry walls (interior surface)	Masonry walls (exterior surface above ground)	Masonry walls (exterior surface below ground)	R-Value				Water Absorption	Moisture Damage	Direct Sunlight	Fire		
SPRAYED IN PLACE																				
CELLULOSE (Many brands)	Can be used as a fire-resistant covering for sprayed urethane. Provides a continuous, air-tight seal around penetrations, gaps in framing, etc. Ideally suited for rough, irregular surfaces.	Must be installed by qualified contractor with special equipment. Requires careful chemical treatment to avoid fire hazards. (Look for Class "A" fire rating.)	4	4	4	4	4	1	1	4	3.5 (3.0-4.0)	B	varies	B	D	D	B	C	180°	Many different formulations available for specific applications.
FOAMED IN PLACE																				
Urethane (Many brands)	High R-value per inch. Provides a continuous, air-tight seal around penetration, gaps in framing, etc. Ideally suited for rough, irregular surfaces. Very useful in specialty designs (e.g., earth-bermed walls, underground construction, etc.)	Must be installed by qualified contractor with special equipment. Combustible; must be covered with fire-resistant sheathing, cannot be used near chimneys or flues. Ultimately will be phased out because it contains CFC's.	1	3	1	4	3	1	1	3	6.2 (5.8-6.8)	B	2	A	A	C	D	D	165°	Many different formulations available for specific applications
Polyicynene	Not restricted because air is used as inflation gas. Small inflation pressure water based foam provides continuous fill for wide range of applications, par-ticularly: •fireproof •good air retarder properties •contains no formaldehyde or CFC's.	Because water-based, should be used when and where drying can take place. Low expansion pressure doesn't guarantee complete filling of cavity. Effectiveness as vapor barrier/retarder.	2	2	1	4	1	n/a	n/a	4	3.6	B	varies	?	C	A	N/A	A	No information	Sprayed in place

*Rating System: 1 = recommended, 4 = not recommended *A = Excellent B = Good C = Fair D = Poor †Includes cost of installation by a contractor. ‡NA = information not available.

New insulation materials are constantly being developed. This Factsheet can be a guide to help you determine the advantages and disadvantages of new products. Always check independent test results to confirm product claims.

Major reference: ASHRAE Handbook of Fundamentals, 1985, Chapter 23.

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6/5/RDS/1000 Reprinted February 2007

WEATHER-RESISTIVE BARRIERS

How to select and install housewrap and other types of weather-resistive barriers

Buildings for the 21st Century

Buildings that are more energy efficient, comfortable, and affordable… that's the goal of DOE's Office of Building Technology, State and Community Programs (BTS). To accelerate the development and wide application of energy efficiency measures, BTS:

- Conducts R&D on technologies and concepts for energy efficiency, working closely with the building industry and with manufacturers of materials, equipment, and appliances
- Promotes energy/money saving opportunities to both builders and buyers of homes and commercial buildings
- Works with state and local regulatory groups to improve building codes, appliance standards, and guidelines for efficient energy use
- Provides support and grants to states and communities for deployment of energy-efficient technologies and practices

INTRODUCTION

Weather-resistive barriers are a part of exterior wall systems that protect building materials from exterior water penetration. They perform like a shell for buildings—liquid water that has penetrated the exterior finish does not pass through, yet water vapor can escape. By keeping building materials dry, a weather-resistive barrier improves building durability, decreases maintenance costs, and reduces the risk of moisture-related problems such as bugs, mold, mildew, and rot. Some weather-resistive barriers also reduce air infiltration, cutting utility costs and increasing comfort.

TYPES AND COSTS OF WEATHER-RESISTIVE BARRIERS

Building paper is a traditional paper sheet or felt material that is asphalt coated or impregnated to increase its strength and resistance to water penetration. It is primarily employed to protect against moisture as a drainage layer. Housewrap refers to spun-plastic sheet materials that are wrapped around a house to protect against moisture penetration. If properly sealed, housewrap can also serve as an air retarder to reduce infiltration. In some wall systems, sealed water-resistive sheathing such as rigid foam board can serve as the weather-resistive barrier, eliminating any need for building paper or housewrap.

Building paper typically costs about $300, material and labor, to cover a 2,500-square-foot home. It usually comes in a 3-foot roll that one person can install. Housewrap costs about $450, materials and labor, for the same size house. While it is available in 3-foot rolls, rolls are usually 9-feet wide and require two people for installation.

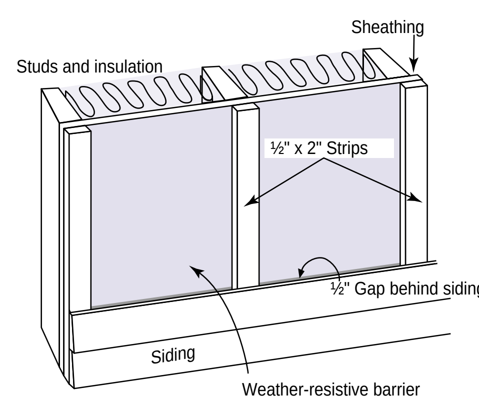
WHEN AND HOW TO USE WEATHER-RESISTIVE BARRIERS

As part of a whole-wall design, weather-resistive barriers need to be integrated with other wall system components, including structure, insulation, vapor retarder, air retarder (if separate), and flashing systems.

A comprehensive approach to water management prevents water from reaching the sheathing or framing. Primary water management strategies include water-shedding characteristics that include overhangs and exterior claddings. Secondary (redundant) water management usually employs a weather-resistive barrier to protect the sheathing and framing from moisture damage.

A weather-resistive barrier is a drainage plane. It allows water that has penetrated past the siding to drain away from the wall system. Building paper or housewrap is usually used to form the barrier. Attaching siding to furring strips provides an air gap between the siding and weather-resistive barrier that improves drainage and addresses related moisture issues.

FURRED-OUT SIDING



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ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

INSTALLATION

Weather-resistive barriers require thorough, comprehensive integration with other building envelope elements to retain system integrity. Flashing and other components, including windows, doors, attached decks, and band joists, usually present the most difficulty. Expert supervision by a knowledgeable person can foster proper field installation. While some general installation guidelines are outlined here, it is essential to accommodate regulatory and product manufacturer procedures.

The approach used to install an appropriate weather-resistive barrier is dependent on why it is being used. If intended only to resist water entry, a weather-resistive barrier must be properly lapped and integrated with other flashing—taping of all seams is not critical. If it is used to reduce air infiltration, all seams and edges must be sealed with compatible tape or sealant.

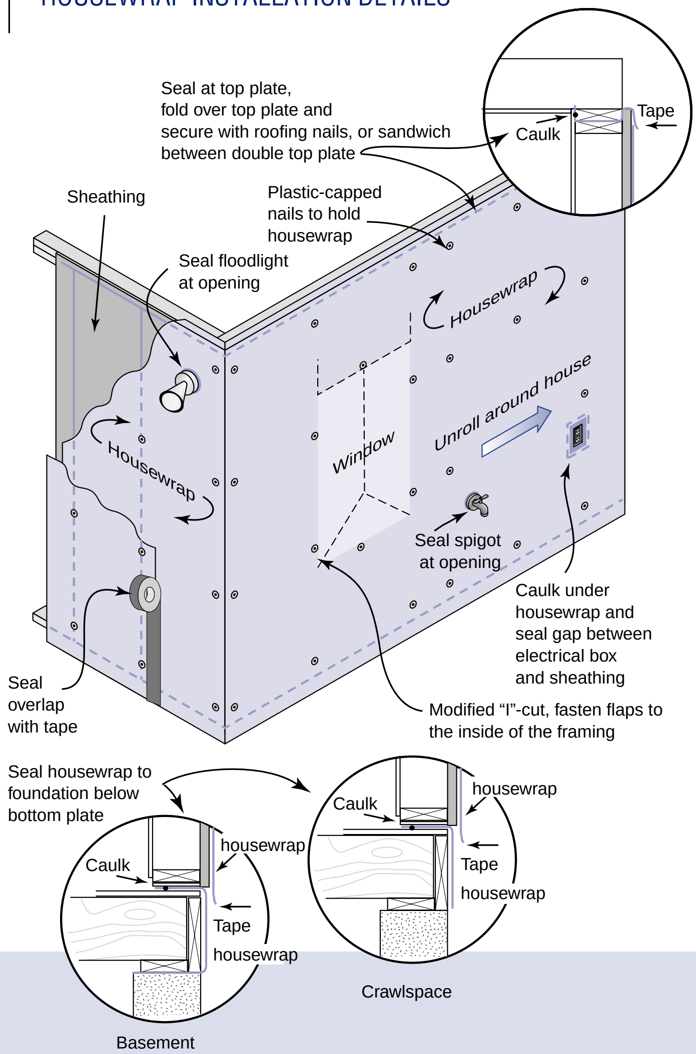
Suitable attachment of the weather-resistive barrier to the sheathing is important. Wide-crown staples, nails with a large head, or nails with a large plastic washer are recommended for wood-frame construction. Distance between fasteners is specified by the manufacturer or by codes, but 12 to 18 inches is typical.

When installing a weather-resistive barrier, especially building paper, remember that materials higher on a wall should overlap materials lower on the wall—consider the path that a drop of water would take if impacting the top of the wall and running downward. Water may also be driven sideways or even upward for a distance by wind pressure. Therefore, laps must be of sufficient length to prevent water entry—4 to 12 inches of overlap is typically recommended. Material should also extend around corners by 6 to 36 inches.

Housewrap installation may be eased by attaching the material to walls before standing the walls up—just leave sufficient additional length at all sides for later overlaps. This approach improves speed and safety, and results in a more wrinkle-free application (wrinkles can impede drainage and hinder cladding application).

To maintain a continuous air retarder around the building envelope, housewrap should cover the seams between framing members (e.g., between bottom plate and foundation). This may be accomplished by incorporating housewrap into the framing or by adhering housewrap continuously across the assembly. Overlap and seal all seams, and seal penetrations in the housewrap. Tape is usually used to cover seams, while sealant is used where tape may not provide sufficient adhesion, such as sealing to wood or concrete. Use manufacturer-approved tapes and sealants, not generic tape such as duct tape.

HOUSEWRAP INSTALLATION DETAILS



DETAILS FOR WINDOWS AND DOORS

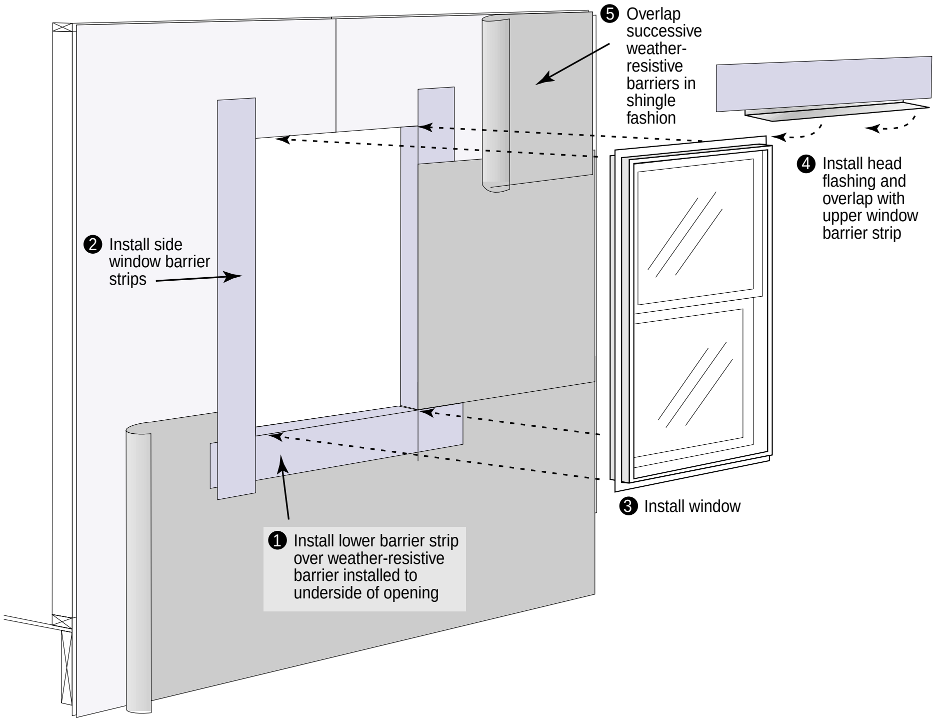
Some windows leak through their frames or at the junction where two or more windows are joined (mulled). Without a weather-resistive barrier, water leaking behind the plane of the nailing flange or on the back of the brick mould can damage the sheathing.

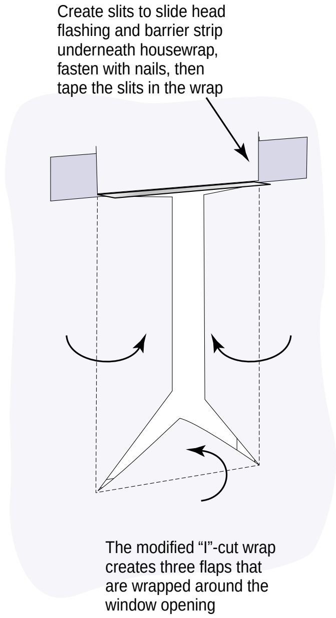
The figures illustrate a procedure for flashing window openings with building paper or housewrap so that any potential leaks do not cause damage. Details may vary with siding and window type and the installation sequence for the window, trim, and weather-resistive barrier. It is advisable to install window head and sill flashing, whether it is metal, plastic, or a self-sticking elastomeric membrane. Avoid relying on tapes or sealants to provide waterproofing, as these products may fail over time. Some building paper may not be suitable for wrapping window openings or corners because of material cracking.

It is common practice and recommended by some manufacturers to cut an "X" in housewrap placed over window and door openings, pull the material inside, and secure it by stapling. Other manufacturers require alternative methods, such as the modified "I"-cut, depending on the overall flashing approach. The "I"-cut allows the vertical leg of head flashing to be placed under the weather-resistive barrier and then taped or sealed.

It is best to divert drainage onto the face of the weather-resistive barrier. Do not tape down or seal behind the bottom nailing flange of windows, as doing so could accidentally trap in water.

FLASHING WINDOW OPENINGS





- Barrier strips are attached with nails and overlapped with successive barrier strips and weather-resistive barriers in shingle fashion. Do not depend on tapes or glues, as they may fail over time.

  Housewrap technique utilizes a modified "I"-cut in the material, which is then wrapped to the inside of the window frame and fastened. The head flashing and barrier strip are fastened and "shingled" under a flap that is cut in the wrap. These seams are then taped.

WEATHER-RESISTIVE BARRIERS

PROPERTIES OF WEATHER-RESISTIVE BARRIERS

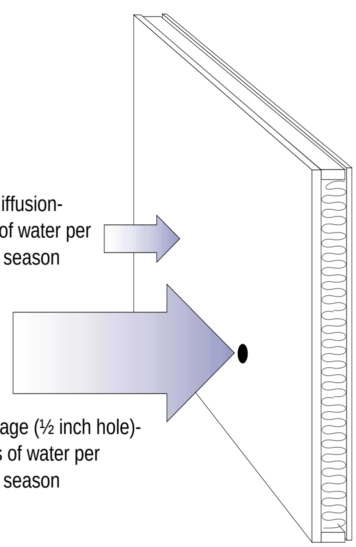
Building paper is made with or without perforations (tiny pinholes) in common weights of 15 and 30 pounds (per 100 square feet). Housewrap comes in a variety of materials and can be perforated or non-perforated. Perforations can hasten moisture vapor outflow while curtailing liquid transfer.

✓ Resistance to Water Penetration

Building paper temporarily resists water penetration, while housewrap is designed to eliminate penetration and absorption. Moisture moving through wood extracts chemicals (surfactants), however, that can in time help water soak through housewrap. Coating all sides of wood siding with clear, water-repellent wood preservative and priming and finish painting with two finish coats helps inhibit this migration.

MOISTURE MIGRATION PRIORITIES

Significantly more water vapor travels through a wall by air leakage than by diffusion



✓ Vapor Permeability

Vapor permeance refers to the amount of water vapor that can pass through a material—the higher the rate, the greater the vapor flow. By code, weather-resistive barriers must be rated at five perms or higher. Higher-perm materials can be desirable to speed the escape of trapped moisture vapor.

✓ Air Resistance

Weather-resistive barriers make an effective air retarder when all seams and penetrations are fully sealed with an appropriate sealant or tape. Common, unsealed building paper is not a true air retarder. Most housewrap air leakage rates (at 0.1 inches mercury pressure differential) fall between 0.03 and 0.08 CFM/ft^2—the higher the rate, the greater the airflow.

✓ Durability

Weather-resistive barriers vary in their resistance to ripping, ultraviolet (UV) radiation, and moisture tolerance.

Tear Resistance—This is important in resisting rips during installation or under wind loading. Housewraps are highly resistant to tearing, unlike building paper.

UV Resistance—UV rays within sunlight will attack many building materials during the construction installation process. Most building paper is non-UV-resistant, whereas recommended housewrap exposure limits vary widely (check with the manufacturer).

Moisture Tolerance—Housewrap tolerates repeated wetting because plastic does not absorb moisture. Building paper absorbs moisture and thus can help dry out water otherwise trapped behind it.

For more information, contact:

Energy Efficiency and Renewable Energy Clearinghouse (EREC)
1-800-DOE-3732
www.eren.doe.gov

Or visit the BTS Web site at
www.eren.doe.gov/buildings

Or refer to the Builder's Guide
Energy Efficient Building Association, Inc.
651-268-7585
www.eeba.org

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Chapter 4

Foundations, Floors, Basements, and Crawlspaces

Key Points to Learn

- Foundations provide all the basic structural support for the building.
- Foundations often must be customized to match the site conditions, which are extremely variable throughout Alaska.
- Heat loss through foundations can be controlled with appropriate insulation materials, applied either inside or outside the walls
- Air leakage control is very important as in all of the structure.
- Moisture control is through the use of appropriate materials and condensation prevention.
- Foundation types appropriate to Alaska include (subject to site conditions) full basement, crawl space, frost-protected shallow foundation, piling, post and pad, and various permafrost foundation options.
- Appropriate materials for foundations include poured concrete, including ICF (concrete poured into stryrofoam forms to provide a preformed wall system); concrete block; treated wood; steel or wood piling; and newer trussed foundations for permafrost or poor soil conditions.
- Designing building elements to prevent earthquake damage is very important in most of the highly populated areas of Alaska. Alaska is one of the most seismically active areas in the world.

Introduction to Foundations

The greatest cause of failure in Alaskan buildings is improper foundation design, which leads to differential settlement. Once the foundation begins to shift, the envelope wracks, tears, and loses its integrity. The cracks in the envelope begin an ever accelerating course of self destruction as warm, moisture laden air condenses inside the walls. Fiberglass becomes saturated and loses its insula tion value, and ice may form in the attic or on the inside surface of exterior sid ing. Sooner or later this moisture causes drywall ceilings to come crashing down or comes pouring out of ceiling light fixtures.

Soggy bottom plates of walls become a breeding ground for microbes, bacteria, mold, mildew, and fungi. The walls and floors may rot out in less than 10 years.

Soil conditions in Alaska vary from nearly bottomless muskeg bogs to per manently frozen ground and from ice rich silts to solid bedrock. The only way to know for sure is to test. A preliminary soils test should be undertaken before designing the foundation. Test holes should be drilled within the footprint of the structure to a depth determined by a soil scientist or geologist. If ice lenses are suspected, test holes should be drilled at least 40 feet deep. Gather all the local information possible. Build higher than known flood levels, beware of eroding river banks or wave-cut cliffs, look out for avalanche chutes, and avoid building on permafrost. If you must build on permafrost, design a founda tion that keeps it frozen.

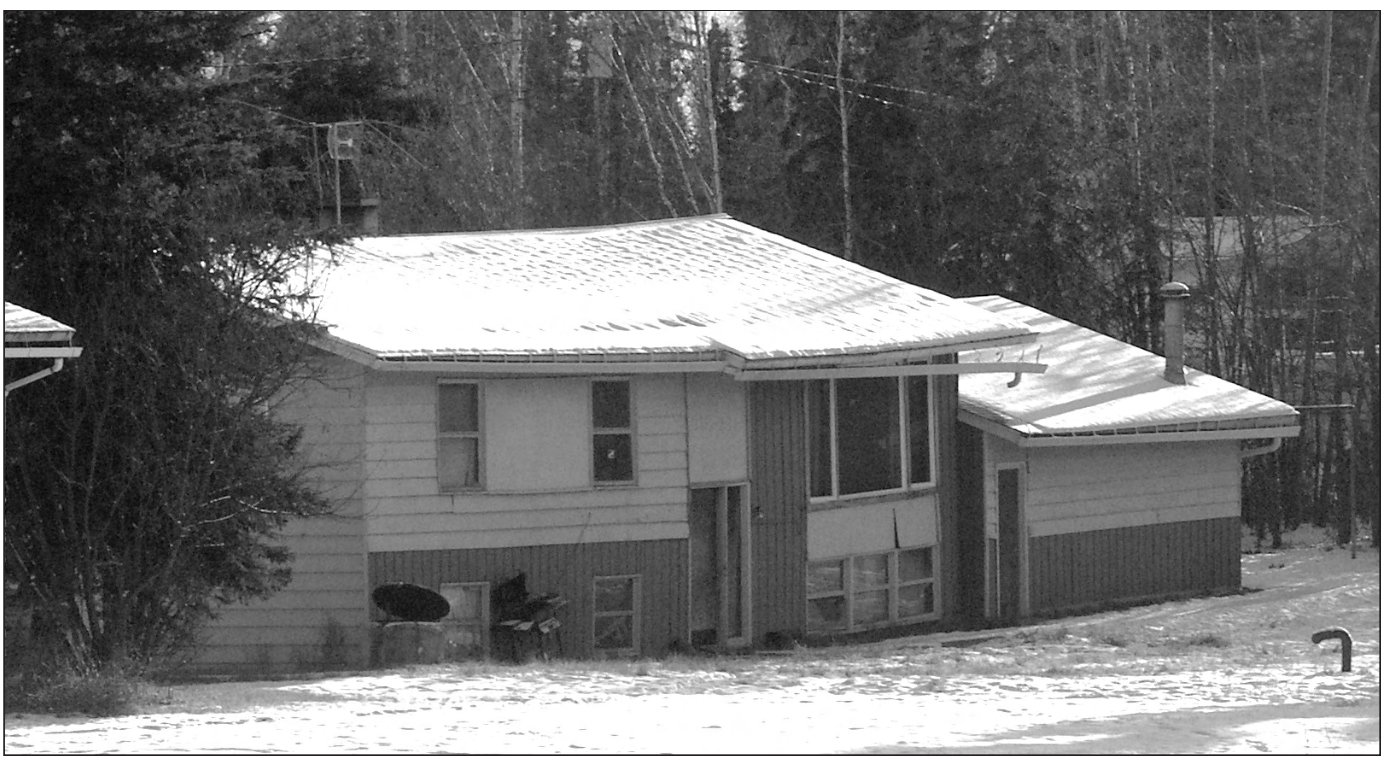


Figure 4.1: This house was built with a conventional foundation on permafrost or an ice lens.

Permafrost: A Special Problem in Alaska

What is Permafrost?

In his book *Building in the North*, Dr. Eb Rice defines permafrost this way: "The most widely recognized definition to day is ground that has been below zero degrees C for two winters and the in tervening summer. If that ground is dry sand, it is permafrost no less than if it were a conglomerate of of soil particles cemented by ice. From an engineering standpoint, frozen soil without ice is nearly as easily handled and worked as similar soils in temperate or tropical regions. Unfortunately, much frozen ground tends to be cemented by ice. It may also contain large ice masses whose melting could cause subsidence, erosion and structural distress" (Rice, 1996).

Because of the importance of under standing permafrost, particularly in In terior and Arctic Alaska, two new manu als devoted to dealing with foundations in permafrost have been produced by the Permafrost Foundation. These manuals resulted from a unique col laboration between the Alaska Housing Finance Corporation and several Uni versity of Alaska professors and private engineers. Their charge was to develop ideas on how to rehabilitate foundations that are in a state of failure and also to assemble a second manual of sound advice for building on new sites where permafrost is present. Both these manu als are now available as downloads from www.permafrost.org/manuals.html. The first is entitled *Design Manual for New Foundations on Permafrost* (September 2000) and the second is *Design Manual for Stabilizing Foundations on Permafrost* (July 2001). This second manual is aimed at providing help in the situation of foundation failures and how they might be saved. Both manuals are public do main, and can be downloaded at the site mentioned above, but can also be pur chased from Lakloey, Inc., 1216 Range View Road, North Pole, Alaska 99705-5352 for $15 each.

What to Do if You Have Permafrost

Page 17 of the *Design Manual for New Foundations on Permafrost* says this: "The best advice for an owner or contractor who is thinking of building on perma frost is 'don't.' If possible, it is almost always better to find a new site than to face the extra expense and the ad ditional maintenance involved in con struction on permafrost. The advice is seldom heeded, however" (McFadden et al. 2000).

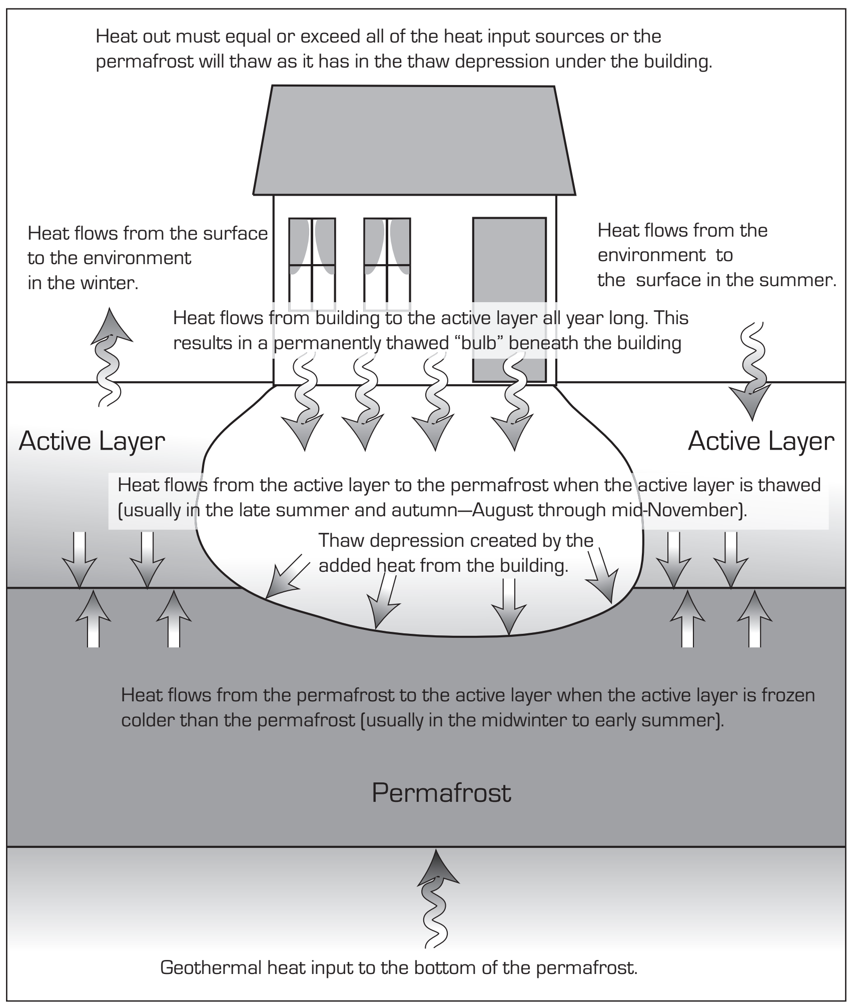


Figure 4.2: Permafrost is a common cause of catastrophic foundation failure in Alaska.

When working in a region such as Alas ka's North Slope, there is no option. In these regions, permafrost is the control ling design parameter. If the permafrost is thaw unstable, it must be protected and preserved, or completely removed either by excavation or complete thaw ing before construction. Except at the southern fringe of permafrost the southern interior of Alaska and Bristol Bay , it is seldom economically feasible or even possible to remove all the per mafrost, and the welfare of your struc ture depends on how well you do this. Since much of the inhabited part of the permafrost region in Alaska is at the southern fringe, another aspect of permafrost should be mentioned. Dis continuous permafrost is discontinuous precisely because the permafrost is very close to the melting point. Roughly speaking, a mean annual temperature of about 25.5 degrees F causes perma frost to form. Much of central Alaska is at or above this transition point. This makes them exceedingly vulnerable to permafrost changes with correspond ing temperature changes. Change the temperature ever so slightly, either way, and you can thaw permafrost, or cause it to grow. Thus, any changes made to a site when building on it can result very quickly and sometimes devastatingly in great changes in the permafrost. This makes building on marginal sites in the Fairbanks, Nenana, Delta Junction, Tok, and McGrath areas and their sur rounding smaller villages particularly vulnerable. If global warming continues as predicted, this situation will worsen. The message is clear: the owner or builder considering use of a permafrost site should approach the job with great caution and care, as the permafrost will likely degrade from multiple causes over the next several decades.

Drainage

Why Drainage?

All foundations must be kept dry. Posi tive drainage away from the building can be assured by proper berming, drain age swales, and control of underground water flow with French drains or with drain tiles and backfilling with clean, non frost susceptible sand and gravels.

Designing Foundation Drainage

Sand and gravel also provide a path for water drainage away from the founda tion, important for the reasons cited above. Given the vast range of pre cipitation in Alaska, local variations in drainage systems to meet local demands always must take precedence when de signing for foundation drainage. Many of our further graphics showing foun dation details do not include drainage pipes at the footing or any drain tile de tails. For much of the railbelt of Alaska, this is fine, since rainfall in these areas is seldom greater than 20 inches per year.

For coastal regions, major drainage issues are common, and proper drainage of a site is imperative. Assure diversion of runoff from the foundation area, and attempt to design all ditching and drainage for maximum historical runoff. These areas are temperate rainforest and water is always a major design issue. Local experience and advice are valuable and should always be sought.

Grading, Backfill, and Drainage Considerations

Regardless of whether houses are situ ated on permafrost soils or normal un frozen soils, Grading and landscaping must be planned to ensure movement of water away from the home and its foundation.

Roof drainage must also be directed at least three feet beyond the building. The slope of the ground away from the house must be at least 5 percent, or one foot for every 20 feet (Figure 4.3) and maintained for at least 10 feet around and away from the entire structure. This builds in the necessary drainage to keep the foundation dry.

A dry foundation prevents most of the freezing and water caused problems from occurring. If there is no water present, there can be no frost heave, no cracked foundations, so no failed foundations.

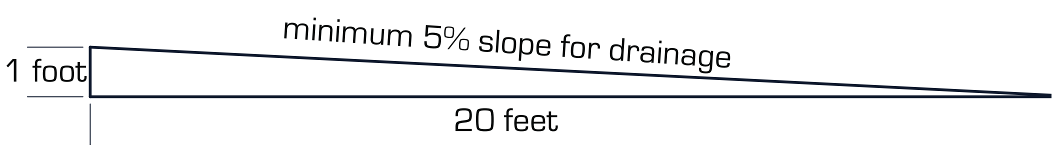


Figure 4.3: Minimum slope for drainage away from a foundation

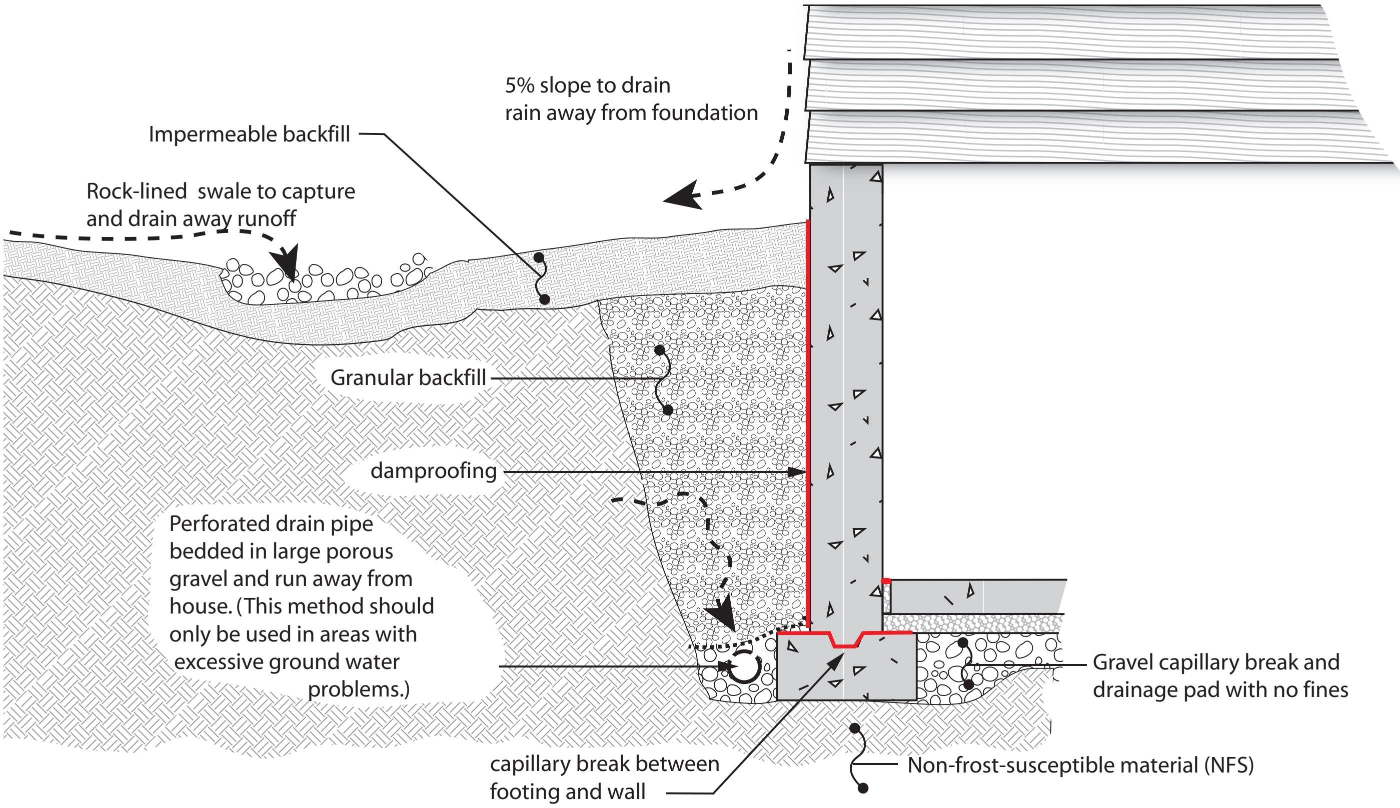


Figure 4.4: Foundation drainage design

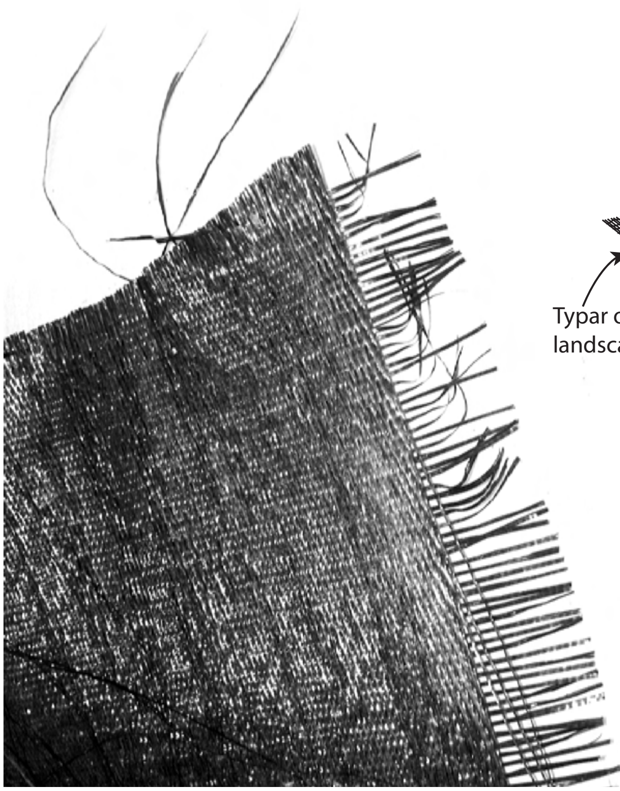


Figure 4.5: Typar or landscape fabric, commonly used to keep gravel in place and keep dirt from filling drainage holes

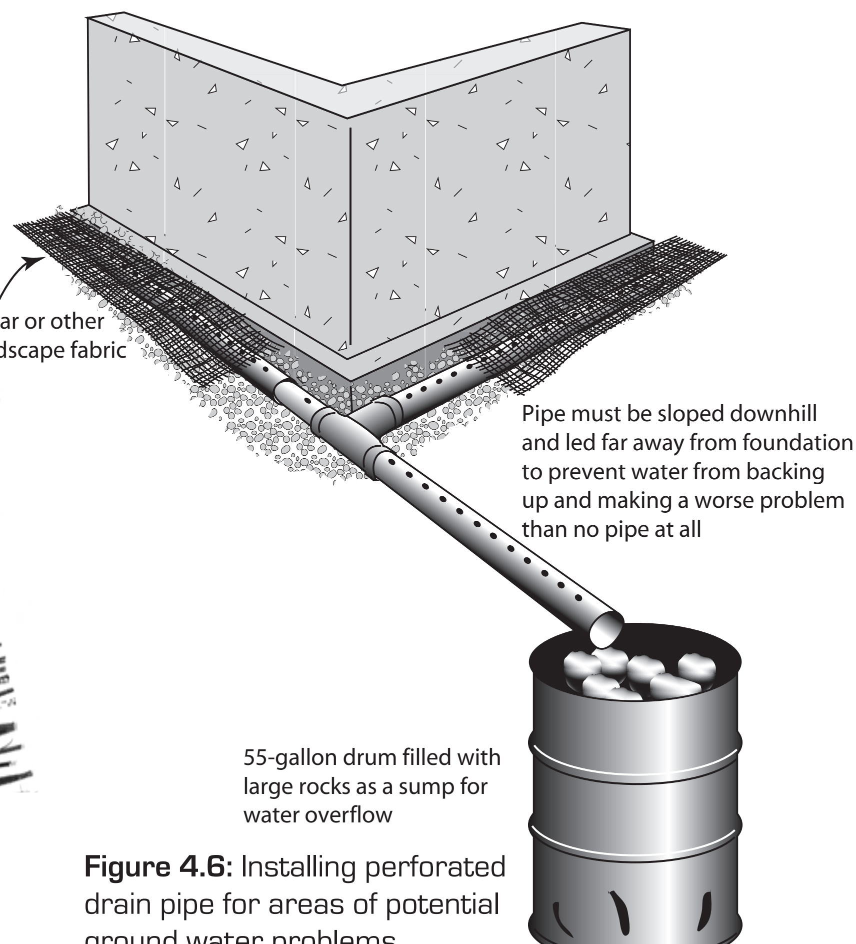


Figure 4.6: Installing perforated drain pipe for areas of potential ground water problems

Site Preparation

Site preparations differ greatly only in the case of permafrost sites. For those sites, disturb the site as little as possible during construction and do NOT remove the organic turf layer if it is present. All additions to the site should be placed on top of the natural vegetative cover. The intent of this approach is to limit degradation of the permafrost as much as possible. Keeping it frozen should be the function of a good permafrost foundation.

In most other situations, all organic material should be removed from under a structure. All footings and floor slabs should be underlain by sand and gravel, material known in engineering jargon as "NFS," the initials for non-frost-susceptible. This simply means sand and gravel of a particle size large enough not to sustain capillary transport of water. Water in the soil near the foundation freezes and expands, and this can lead to frost heaving and foundation failure, so it is a crucial construction detail to attend to. If the existing materials at the site are already sand and gravel, then they can be used. If not, the site materials should be removed and the hole should be backfilled with sand and gravel. This sand and gravel serves several functions.

Leveling Course

The ground under footings and floor slabs should be smooth and well compacted. This is easy to accomplish with sand and gravel and more difficult with virtually any other material.

Prevention of Frost Heave

Frost heave can only occur if soils of the size range of silts and smaller, along with sufficient water content, are present in the soils around a foundation. Both factors—the type of fill material and drainage and moisture diversion from the foundation are crucial for preventing frost heave. No appreciable soil water content, no frost heave, and likewise no small soil particles, no frost heave. All frost susceptible materials should be replaced with non frost susceptible materials under a foundation.

Level, Plumb and Square

Craftsmanship plays an important role in the performance of a building and if

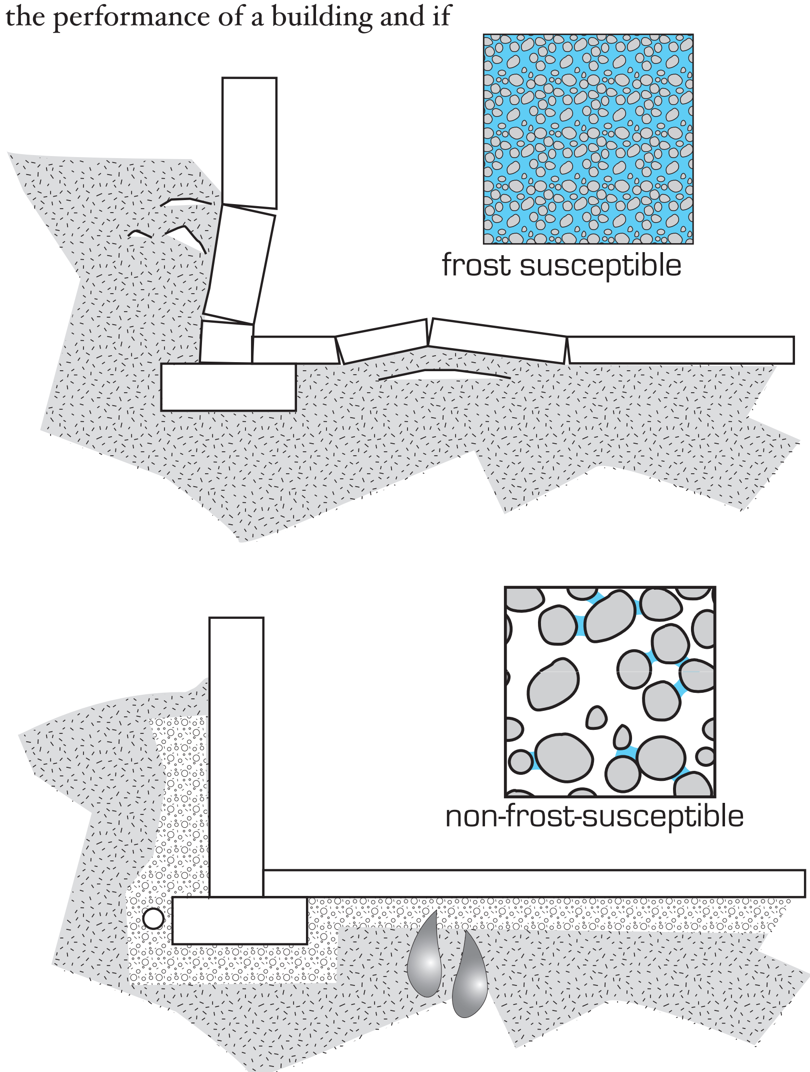


Figure 4.7: Non-frost-susceptible material under a foundation prevents frost heave from destroying it. Non-frost-susceptible simply means sand and gravel of a particle size large enough not to sustain capillary transport of water.

you start with an accurate foundation shape you will save many hours or days of construction time.

The foundation must be level and square. Check the diagonal measurements from corner to corner. These measurements should differ by no more than 1/4 “. The accuracy and effectiveness of the foundation sets the tone for the rest of the structure. Good finish work begins with a good foundation.

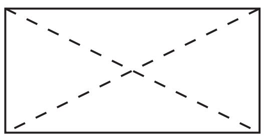
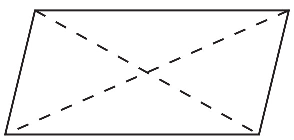
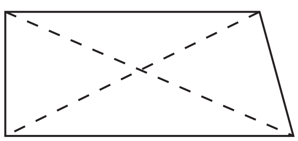


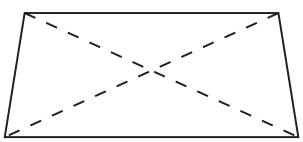
Figure 4.8: These diagonals are equal length, the sides are equal length, and the corners are 90 degrees. This is a good layout.



The sides are equal length here, but the diagonals are not equal length.



These diagonals are not equal length and the sides are not equal length.



These diagonals are equal length but the corners are still not 90 degrees. What is wrong here?

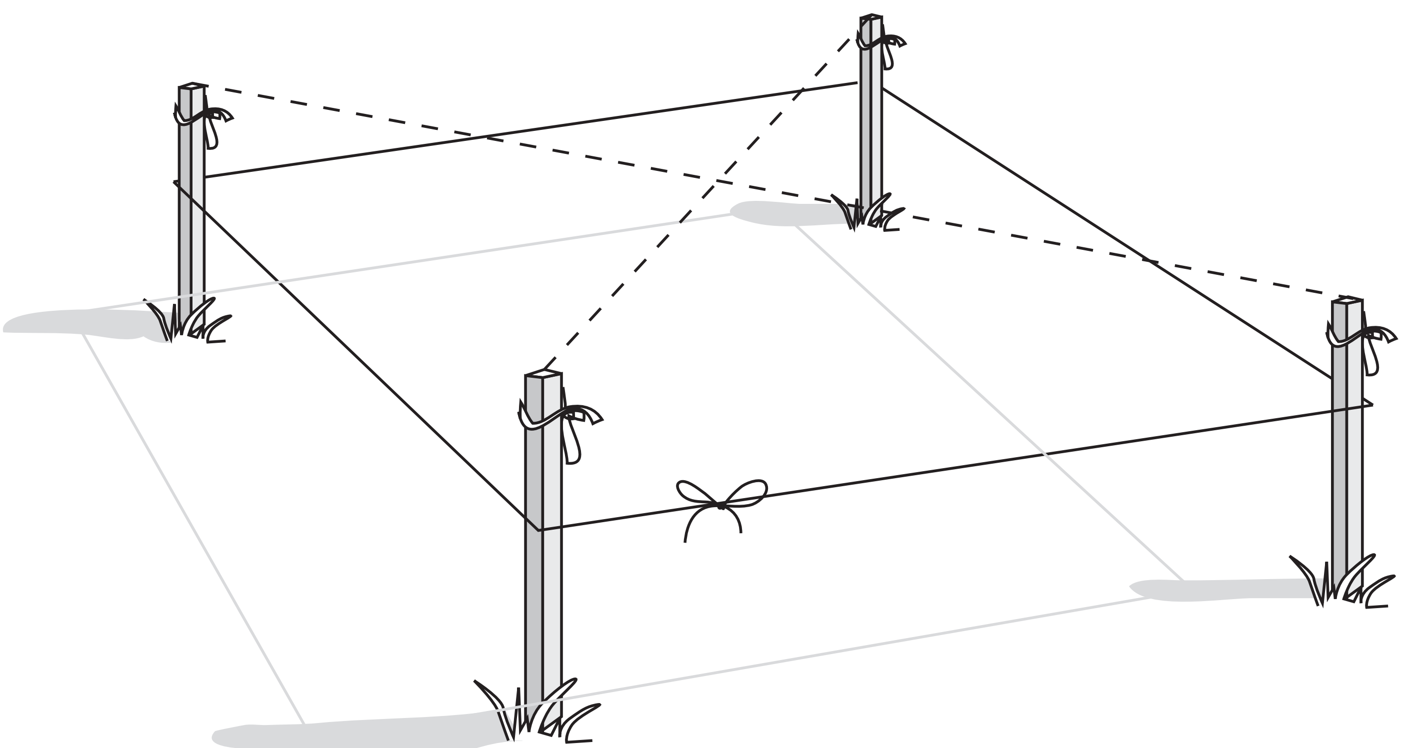


Figure 4.9: Laying out the foundation

Capillary Break

It is necessary to provide a capillary break under footings and floor slabs to prevent water from being transported through concrete to the bases of walls and into the building. The pore size of concrete is small enough to provide very good capillary transfer of water from beneath the foundation to wall bases and through the slab floor of a base ment. Water can be "wicked up" ten feet or more in wet soils by capillary action. A minimum of four inches of course grained, NFS fill is enough to prevent capillary action.

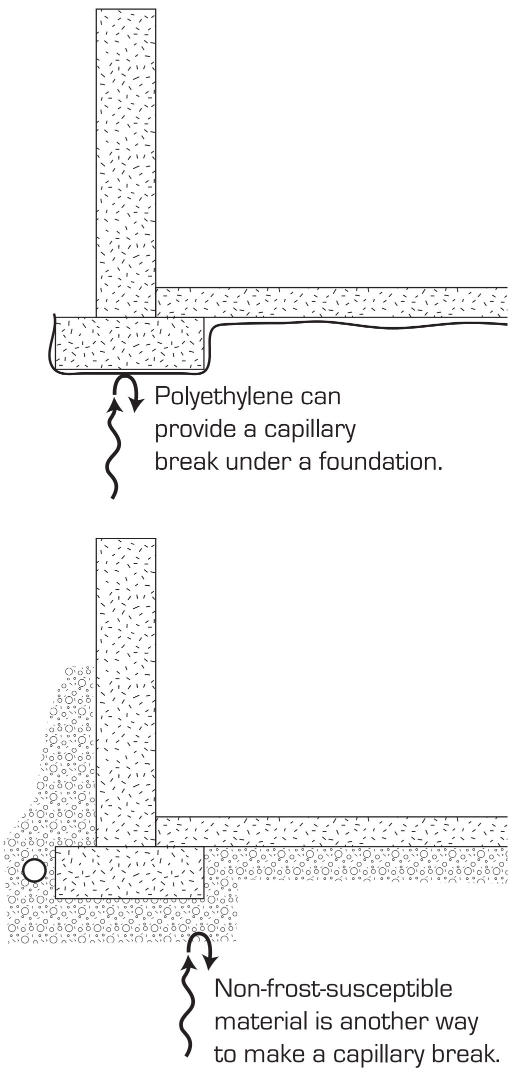


Figure 4.10: Providing a capillary break under a footer

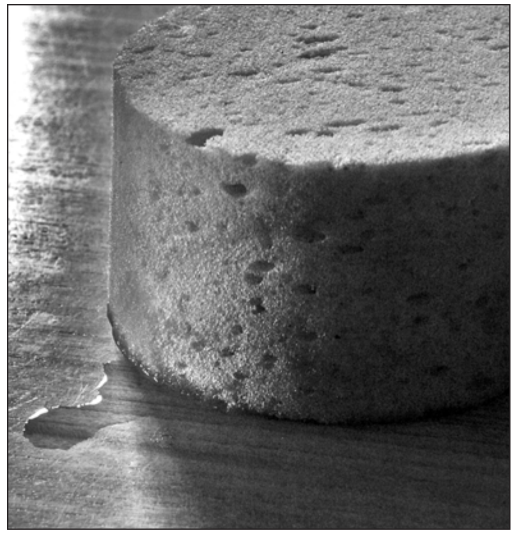


Figure 4.11: A sponge demonstrates capillary action as it absorbs and lifts water off a table

Radon Considerations

This is a good point to introduce radon and its elimination as a concern during construction. Radon is a naturally occur ring radioactive gas that comes from the soil and is a product of uranium decay. The major concern with radon is that it can cause lung cancer in those who are exposed to it over a long period of time (Figure 4.12). Only a few areas of Alaska have this risk, and any permafrost area doesn't need to worry, because radon can only enter a home if the foundation is in direct contact with the soil (Figure 4.13). For areas of concern see www.uaf.edu/coop ext/faculty/seifert/energy.html. At that site is a document titled "Building Radon Out," describing how to construct a new basement or crawl space to prevent radon entry. This is a fairly simple and inexpensive means to prevent a problem before it has a chance to become one. If your building is to be built in a radon risk area, this mitigation technique is worth the effort to prevent future radon problems. Another publica tion at this website, "Radon in homes: The Alaskan Experience," describes what constitutes a radon risk site.

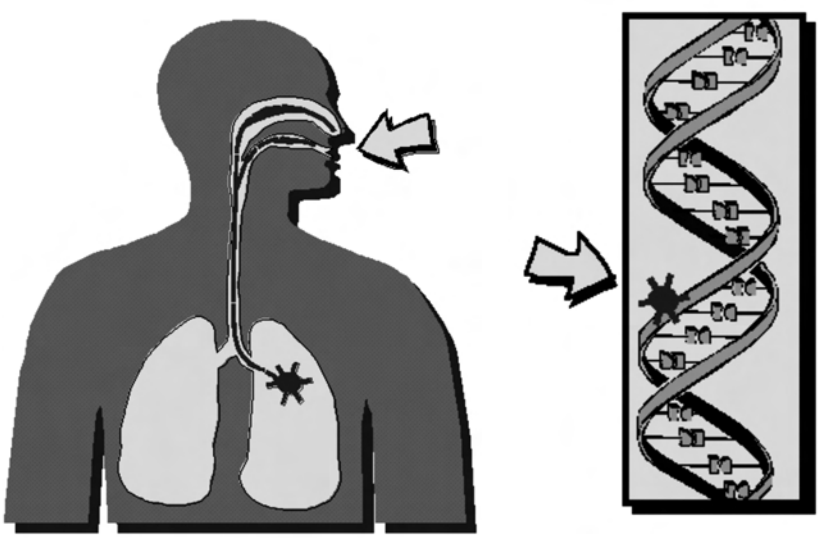


Figure 4.12: Radon decay particles are breathed into the lungs. Energy released from radon decay products damages DNA and causes cancer.

Radon Considerations for Alaska

Not all regions of Alaska are at risk from radon. Radon can be sucked into the lower portions of a house by the operation of a heating system or simply from the natural air movement into and through a heated house in an Alaskan climate (Figure 4.13). Some important areas of concern are the upland areas around Fairbanks, which have a charac teristic schist bedrock that is a source of uranium and therefore, radon. Also at risk are places with granite bedrock, or glacial terrain with eskers and old glacial moraine, such as the Matanuska Valley, particularly east of Wasilla and into the Matanuska River basin. It is always a good idea to test if you don't know the radon risk in your area. Call Alaska's Ra don Hotline if you have questions or to get the latest information about radon: 1 800 478 8324.

An important consideration if you are building on a site where radon risk may be present is to build in a radon reduction system while constructing the house foundation. A radon risk site

- is built high on a hill slope with bed rock consisting of schist;
- has a topsoil depth less than the basement excavation typically eight feet or less ;
- has standard basement construction or daylight basement "notched" into a hillside;
- has an oil-fired combustion heating system; and
- has basement material of concrete or all weather wood.

These conditions constitute an at risk home. Other conditions, like soils that are glacial materials, cobble rocks, with high air permeability, may indicate a risky site for easy radon transport as

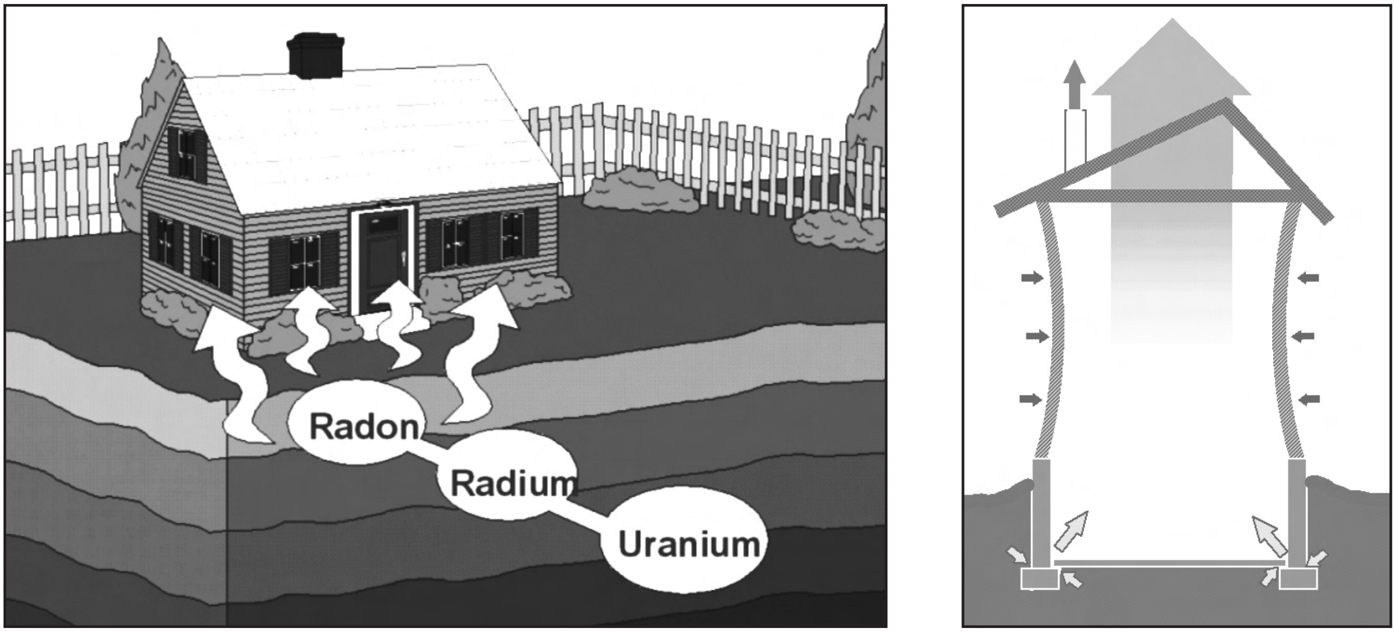


Figure 4.13: Radon gets into your home through the soil and is sucked in by the stack effect.

well. Radon is VERY site-specific, so local conditions can vary widely.

There is no way of detecting radon other than the radon tests that are avail able from various vendors in the state. Call the radon hotline to get a list of vendors if you are interested in testing for radon. EPA recommends that every house in a radon risk area be tested. Tests are typically about 25 and are easy, harmless to occupants, and passive. There are no machines or moving parts required for the long term tests.

Building Radon Out

The best approach to radon control on a risky site is to include radon resistant construction options in the construc tion of the foundation and basement. It is much, much easier to do this as the house is built than after a prob lem is discovered later. See "Building Radon Out," available at http://www.uaf.edu/coop ext/faculty/seifert/publi cations.html#radon. This publication describes a system of under slab perfo rated pipes (Figures 4.13 and 4.14) that can be accessed after construction if a radon problem is found in the home after construction is complete. These sub slab depressurization systems have been found to work best in Alaskan conditions.

For homes that are already built, but have been discovered to have a radon problem, a new EPA publication de voted to this problem has become avail able. The "Consumer's Guide to Radon Reduction" is available at http://www.epa.gov/radon/pubs/consguid.html

Radon has become a very fixable problem, and need not be viewed as a "deal breaker" in real estate transac tions. However, Alaska's climatic chal lenges require some special cautions for radon reduction systems installed here. Most EPA graphics specify that the radon exhaust fan be placed in the unheated attic of the home being miti gated. Since this air stream can be quite moist, placing the fan in an unheated space will cause it to freeze and fail in Alaska's cold winter temperatures. The wet air stream also results in consider able hoarfrost build up at the fan outlet outdoors. If the exhaust stack is mount ed vertically, it could accumulate frost that could fall back down the stack and unbalance the fan, causing it to fail. The climate makes it imperative that the fan be kept indoors and the exhaust from the reduction system be run horizontal to avoid accumulation of hoarfrost.

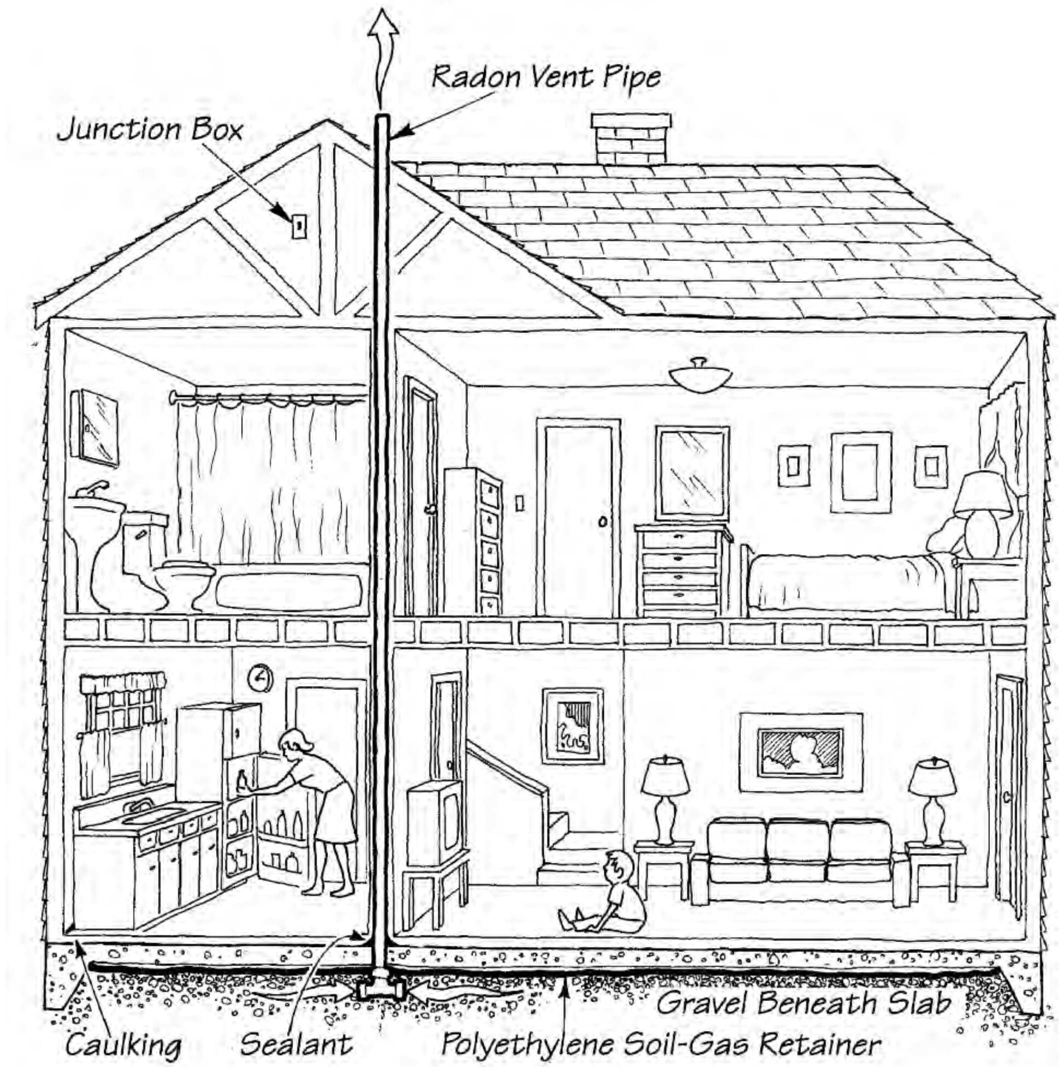


Figure 4.14: Radon mitigation techniques

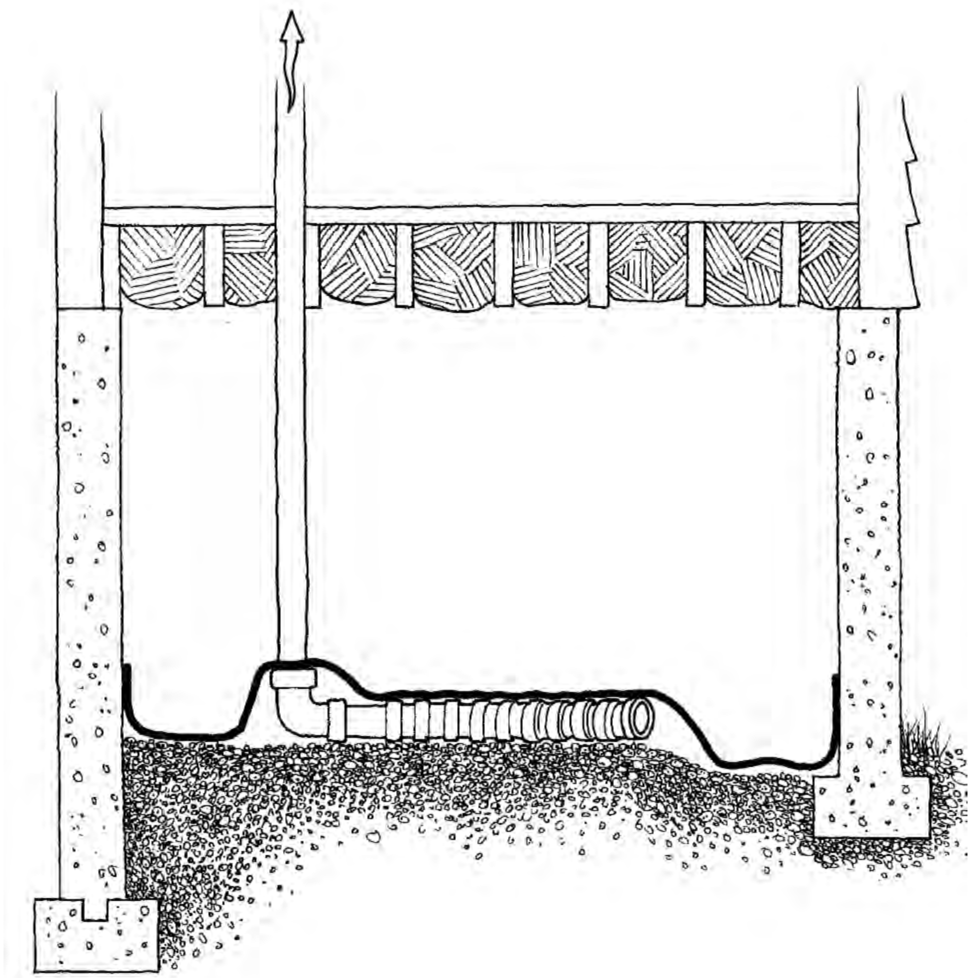


Figure 4.15: Sub-slab ventilation for radon mitigation. Rising warm air carries the radon up and out the vent pipe.

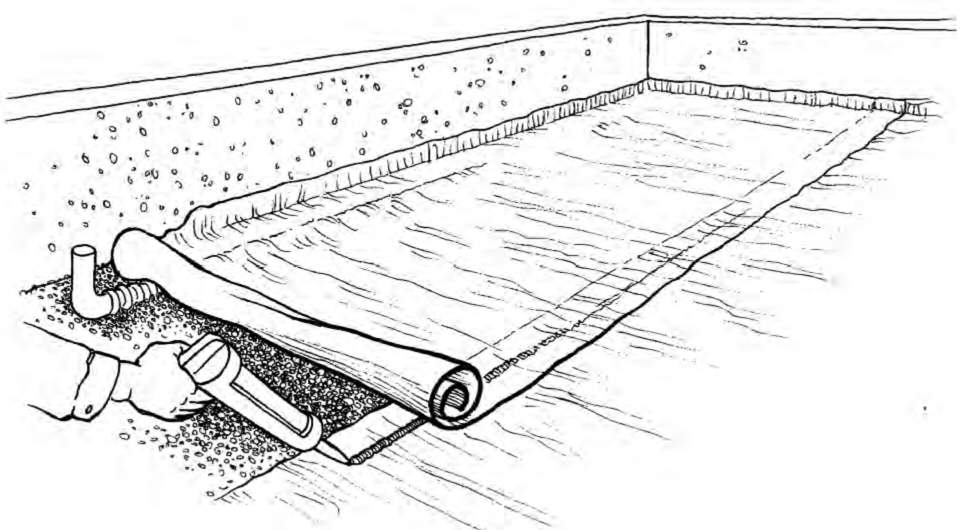


Figure 4.16: Seal the seams in the under-slab vapor retarder with flexible caulk

Foundation Moisture Control and Energy Performance

For moisture control, the foundation must be designed and constructed to prevent the entry of moisture and soil gases i.e., radon, petroleum vapor Semi permeable rigid insulation should be used as both a thermal insulating layer and for vapor control beneath the concrete slab . A 6 mil polyethylene va por barrier is required if rigid insulation is not used there. The best material to use below ground for insulation is ex truded polystyrene rigid foam. Also use radon resistant construction practices where necessary.

Energy performance: A basement in sulation system type of insulation, loca tion, sealing/vapor permeability proper ties, fire rating) for Alaskan conditions (see profile figures which follow__). Some insulations are vulnerable to in sects such as carpenter ants. Consider this carefully for your particular site and selection of insulation type. Insect damage is particularly possible with Sty rofoam insulations. Protect them with covering or flashing to keep insects out.

Figure 4.17: A well-constructed foundation with gravel to protect the vapor barrier and boards holding the vapor barrier in place against the footing for a tight seal.

How Many Feet of Soil Is One Inch of Polystyrene Worth?

For soil thermal conductivity, we'll use a very general Interior Alaska number found in John Zarling and Alan Braley's Alaska Department of Transportation and Public Facilities research report on Heat Loss Factors for Insulated Building Foundations. They used a number for the soil thermal conductivity of 0.7 BTUs per hour/°per foot, which translates to an R-value of about 1.4 per foot of soil. At a thermal conductivity of 0.017, the R-value of polystyrene insulation works out to about 5.7 per inch. So somewhere between 3 1/2 and 4 feet of soil is required to equal the R-value of one inch of Styrofoam insulation, such as rigid extruded polystyrene (Dow blue, Amofoam, Foamular).

Some people credit the insulation value of one foot of soil as equal to one inch of rigid polystyrene. From the analysis above, we see that this greatly undervalues the usefulness of insulation to protect shallow foundations and foundations below grade.

Some of this confusion may come from the fact that snow actually has this insulating value: one inch of Styrofoam insulation equals about 10 to 12 inches of snow.

The R-value of snow, especially when it's fresh and not very wet, is about 0.5 per inch, which means that 10 inches of it would be R-5. Therefore 10 inches of snow is equal to about one inch of rigid extruded polystyrene, which also has an R-value of 5. However, snow is variable from year to year and usually does not build up next to the foundation. If it did, it might cause moisture problems in spring when it melts.

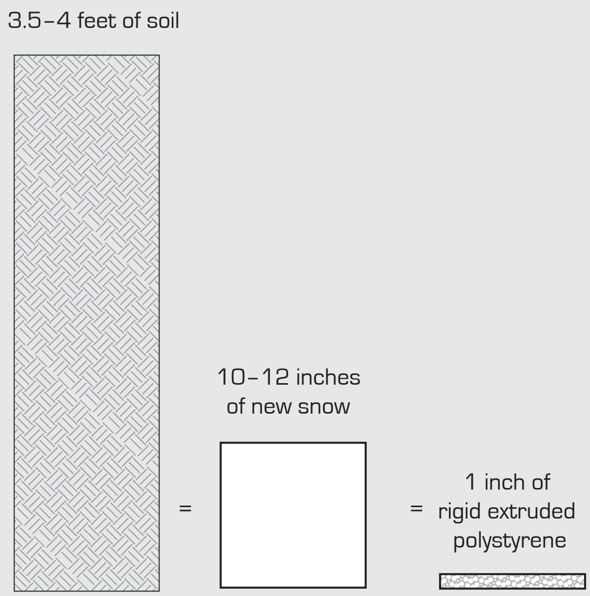


Figure 4.22: Comparison of R-values of soil, snow, and extruded polystyrene insulation

Seismic Design Considerations

Interior Alaska and the small communities in or near the Alaska Range experienced the largest earthquake in the world for the year 2002, on November 3 of that year. The Trans Alaska Pipeline was affected, but sustained no serious damage. This was a clear reminder of the fact that Alaska, particularly coastal southern Alaska, including the Aleutian islands, and the Alaska Range areas, are some of the most seismically active in the world. Designing our residential home foundations in these areas should include consideration of these risks.

Particularly in the past decade, great progress has been made in disseminating information about how to properly reinforce and design foundations to resist earthquake movement and damage. Federal agencies such as the Federal Emergency Management Agency (FEMA) now issue a *Home Builder's Guide to Seismic Resistant Construction,"* FEMA 232/ August 1998, which spells out many of the details that should be standard practice when assembling a foundation and other building elements in an earthquake prone area such as Alaska.

Figure 4.18: A large crack in the highway caused by the Denali Fault earthquake in November 2002.

Although we are dealing only with foundations in this chapter of the manual, details should not be selected at random from a menu of options, such as is given in the guide cited above. As in all aspects of a building, a complete earthquake resistance system requires all the necessary elements to be present. Random selection of details without consideration of the building as a complete system may result in ineffective earthquake resistance. Although we will not go into great depth in this manual about the nature of earthquakes and the principles behind good earthquake resistant design, we will show aspects of it and examples of good practice that can provide protection in residential construction. Most Alaskans live in areas of high earthquake potential, and so these designs should be standard practice.

Underground basement walls must support the weight of the structure above, a sum of the floor and roof loads, and earth pressures and earthquake loads perpendicular to the plane of the walls. Basement walls must act as shear walls, and can be thought of as a continuation of the shear walls above and resist the earthquake forces transmitted to these shear walls by the horizontal floor diaphragms.

To be a "shear wall" the wall must resist a force which is applied to it at its narrow edge to "accordion it" , or collapse it along this dimension. Any wall built with proper wall rigidity resists shear along its length, and is a "shear wall". Clearly, foundation walls must be shear walls.

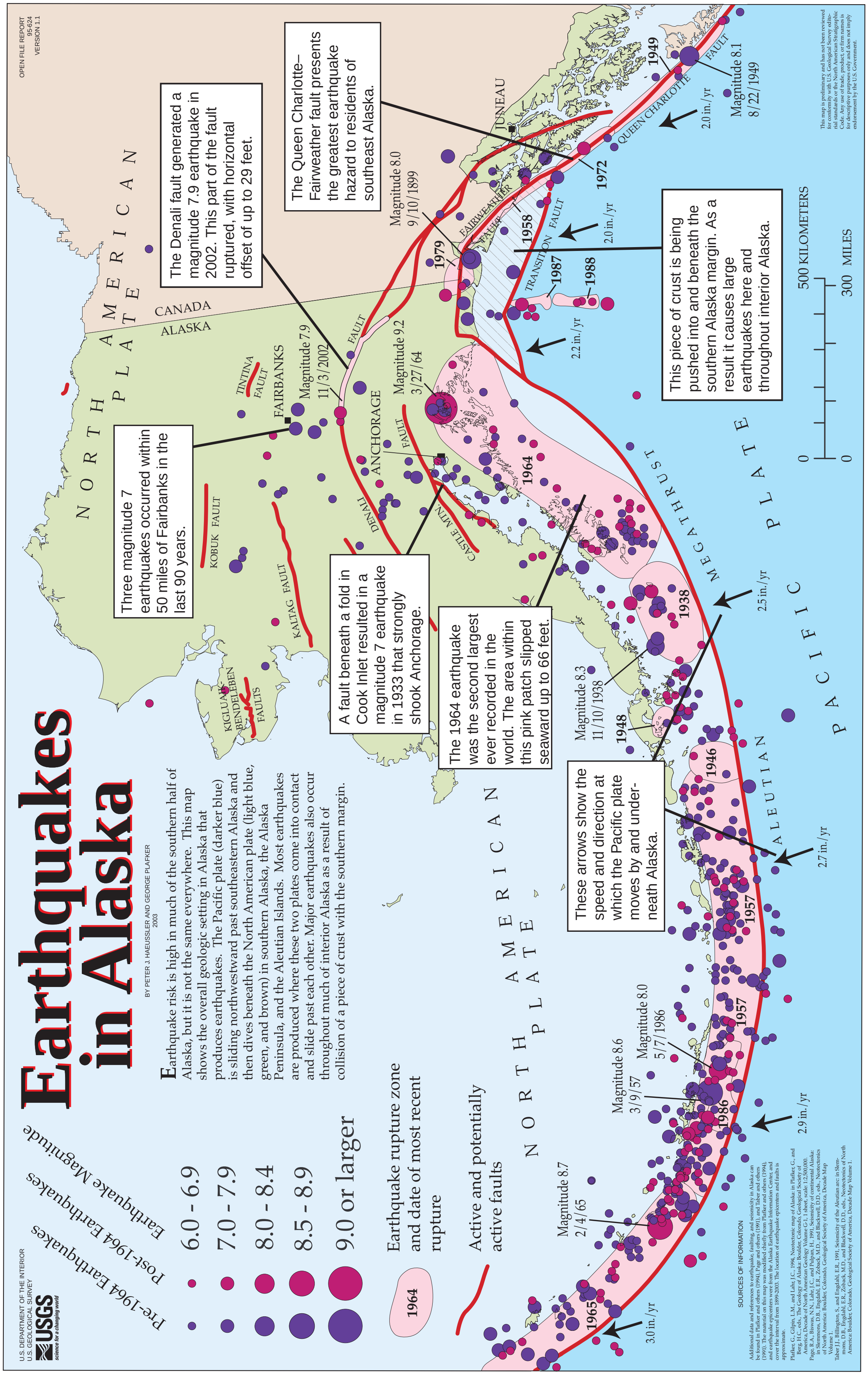


Figure 4.19: Earthquakes in Alaska

Sill plates on basement walls, when properly anchored, keep the shear walls above from sliding or moving. The mini mum bolting requirements for moder ate or low seismic risk areas is ½-inch diameter by 10 inch long bolts, spaced a maximum of 6 feet on center, with 7 inches of embedment such as in con crete). For high-risk seismic areas, bolts should be ⅝-inch diameter by 1 foot long, and spaced at 4 feet maximum on center, embedded 7 inches. Sill plates are normally 2 inch nominal material, but in areas of high seismic risk, 3 inch nominal sill plates provide better pro tection against splitting. Avoid counter sunk washers and nuts in sill plates. In areas of high risk, sill bolts should have plate washers under the nuts. Use 3 x 3 x ¼ inch plate washers for ½ inch and ⅝ inch bolts, and 3 x 3 x ⅜ inch plate washers for ¾-inch bolts. At the ends of sill plates, bolts should be placed 9 inches from each end of each piece (Figure 4.21).

Local and western uniform building codes should be consulted for further guidance and whenever questions arise (FEMA 1998).

Figure 4.20: A model layout of a foundation with seismic anchors and connectors. This model is used by FEMA to demonstrate materials and examples of seismic reinforced foundation and house design.

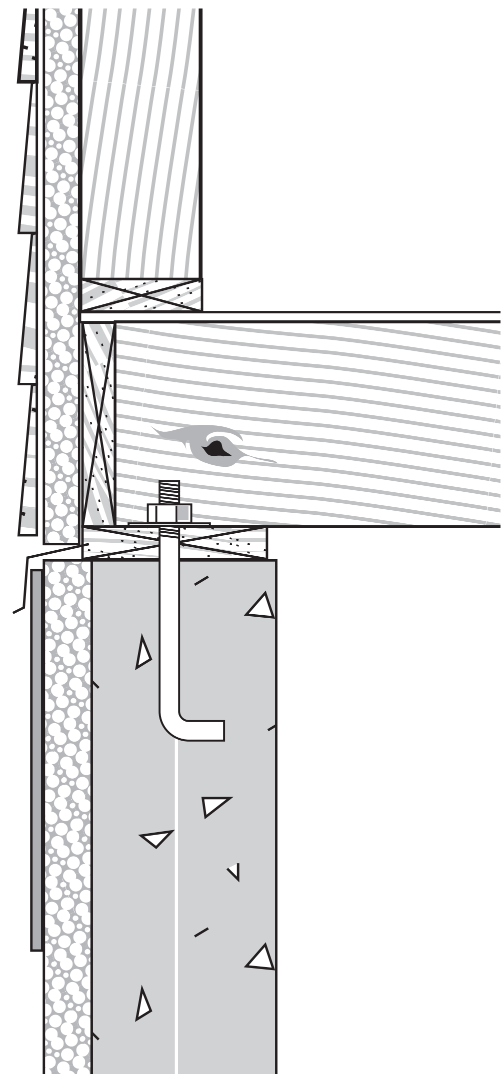


Figure 4.21: Tying the foundation wall to the sill plate using a J-bolt.

Putting it All Together: Foundation Types

Now we will discuss the various types of foundations in use for various Alaskan conditions. First we consider typical foundations on nonpermafrost sites where you can use spread footings of concrete or all weather wood AWW . The footing is required by code to be at least 42 inches below the ground surface called “below grade” in construction jargon . However, many of our graphic depictions of foundations include the frost protected shallow foundation option or show extra insulation protection below grade to provide extra freeze protection. In Alaska’s severe climate, using insulation for freeze protection is our best tool, and ample use of below grade insulation to protect the foundation is included in our graphics and strongly endorsed as wise building practice. Successful foundation types are as varied as the geography and geology of Alaska. In Southeast coastal communities, many buildings are built on pilings, like docks or bridge supports. Away from the waterfront, they may have conventional stem wall foundations with concrete footers or pressure treated wood foundations resting on compacted sand and gravel. Further inland, on the muskeg, pilings may once again be the foundation of choice. On the North Slope and northwest coast, pilings are used to avoid melting the permafrost. In Southcentral and in the Interior, standard concrete foundations with heated crawl spaces or full basements are quite common, but they should not be used on permafrost risk sites. Further details are also available from the University of Alaska Cooperative Extension Service publication, “Permafrost, A Building Problem in Alaska,” HCM 00754, by Richard D. Seifert.

In the southwest and the rural Interior, we find a number of post and pad or crib foundations or pilings in permafrost areas. A promising new foundation type called the space frame is being tried in several of these areas.

> A spread footing is a common foundation base, typically a 16-inch wide, eight-inch high base of a wall, which “spreads” the weight of the wall and the entire house above it across a wider area than would be the case if the base were only as wide as the wall.

Regardless of the type of foundation except open crawl spaces , the designer must include the foundation as part of the thermal envelope, with appropriate measures specified to resist the flows of heat, air, and moisture. The plans must show how the insulation, vapor retarder, and air or weather retarder are to be installed and how they are integrated with the wall system. When you know what foundation you intend to use, next you must design the thermal envelope from the foundation through the floor, wall, and ceiling systems and back again to the foundation. You must be able to detail a truly continuous air/vapor retarder, insulation system, and weather retarder that meets all of the building science principles outlined earlier in this manual as well as meets the mandatory measures outlined in BEES. We urge you to use AkWarm energy analysis software. It will guide you in choosing optimal levels of insulation to meet an annual energy target. If you do not use AkWarm, then use Table 1 in BEES.

Crawl Spaces and Full Basements

These common, useful foundation types provide continuous support of the structure, and support the ground floor (see Figure 4.22). These foundation types provide:

- space and protection for mechanical systems
- storage space
- use of wood in the flooring system above the foundation
- wide choice in insulation placement and type

Crawlspace Ventilation

A significant number of moisture and mold problems in the home are caused by ground moisture sources in crawl spaces. Moisture from the crawlspace is pulled into the home via air transport due to the stack effect. Adequately covering and sealing the crawlspace floor with polyethylene significantly re duces the amount of moisture released from the ground into the crawlspace. Concrete foundation walls that are in sulated on the exterior should also be covered with a vapor retarder material. Interior insulated walls and insulated concrete forms (ICFs) allow the con crete to be significantly cooler than the conditioned crawlspace air and will not release water vapor into the crawlspace due to higher vapor pressures in the crawlspace than on the surface of the damp concrete. The concept here is that interior insulation or ICF's don't get as cold and aren't as vapor porous as concrete so the condensation potential is much less. These foundation walls would need no additional vapor retarder.

Crawlspace ventilation is required by code. Typically, the code ventilation re quirements are met by installing perime ter vents you should check current code requirements , which in cold climates are supposed to be opened in the summer

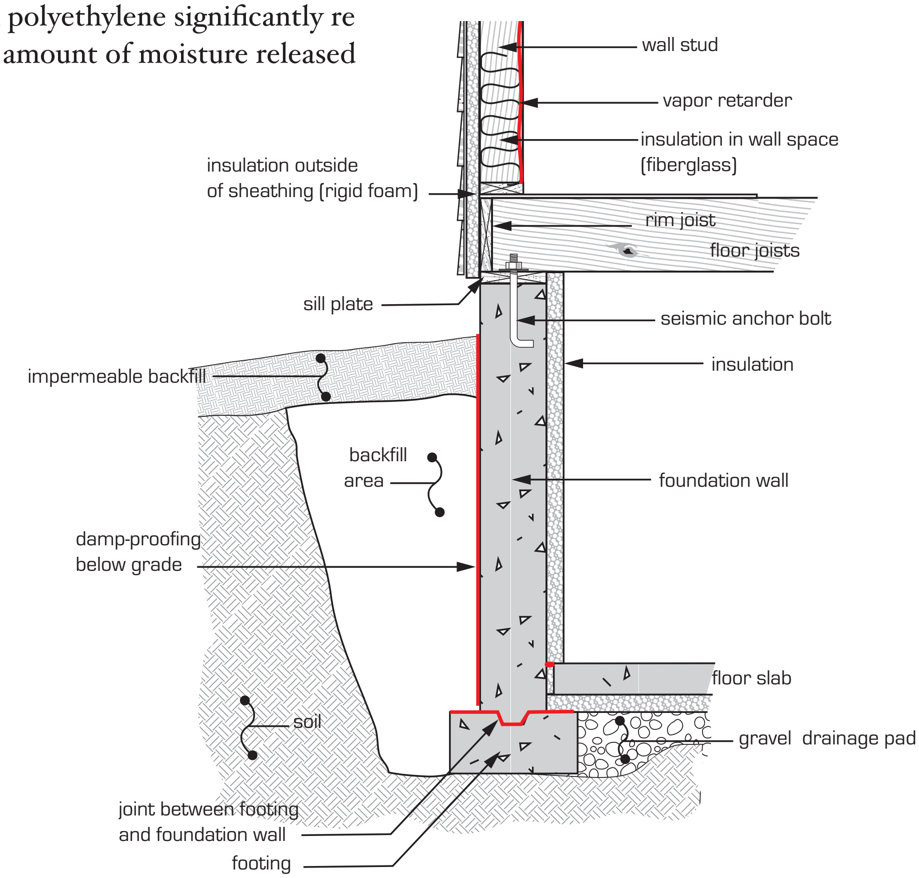


Figure 4.22: Elements of a typical full basement foundation

and closed by the occupant in the winter. It is uncertain whether crawlspaces need more outdoor ventilation in the sum mer, or if the occupants will operate the vents as needed. Although it is not much of an issue in Alaska because of the few warm days, venting a crawlspace during warm humid days may actually create a moisture problem in a cool crawlspace by drawing in warm moist air that will con dense on the cool crawlspace surfaces. Mechanical ventilation of a crawlspace is a code option.

Natural air leakage due to the stack effect draws air into the home low and forces it out of the house near the top. For years, building scientists have made the connection between damp base ments and attic moisture problems. With leaky rim joists and perimeter vents, a significant portion of the natu ral air infiltration of a home originates in the crawlspace, flowing through the house, and leaving through the attic.

A simple way to prevent crawlspace air from leaking into the home is by us ing an exhaust fan as a pressure manage ment strategy. By reversing the natural flow of air caused by the stack effect from the crawlspace into the home, pol lutants and moisture in the crawlspace air will be vented out through a dedi cated exhaust fan. The more airtight the crawlspace is constructed, the smaller the fan flow that will be needed to maintain the desired negative pressure relative to the house.

The air quality of a crawlspace is af fected by moisture; soil gases radon ; storage of paints and other hazardous materials; the accumulation of dust, bugs, and debris even Martha Stewart probably doesn't clean her crawlspace regularly); and floods or plumbing leak damage in the past or future. Unless you can be confident the air quality of a crawlspace will always be satisfac tory, a proper ventilation system should minimize the amount of crawlspace air entering the home.

Leaky furnace ducting in the crawl space will have a significant impact on the relative pressures in the crawlspace and the amount of crawlspace air circu lated throughout the house. Substantial depressurization of the crawlspace with leaky return ducts can result in in creased soil gases and moisture coming into the home. Leaky furnace ductwork can easily overcome any pressure con trol of a small bath fan. Furnace duct work within a crawlspace presents a sig nificant challenge to min imizing the flow of crawl space air into the home. Be especially careful to assure a clean, warm, and dry crawlspace and

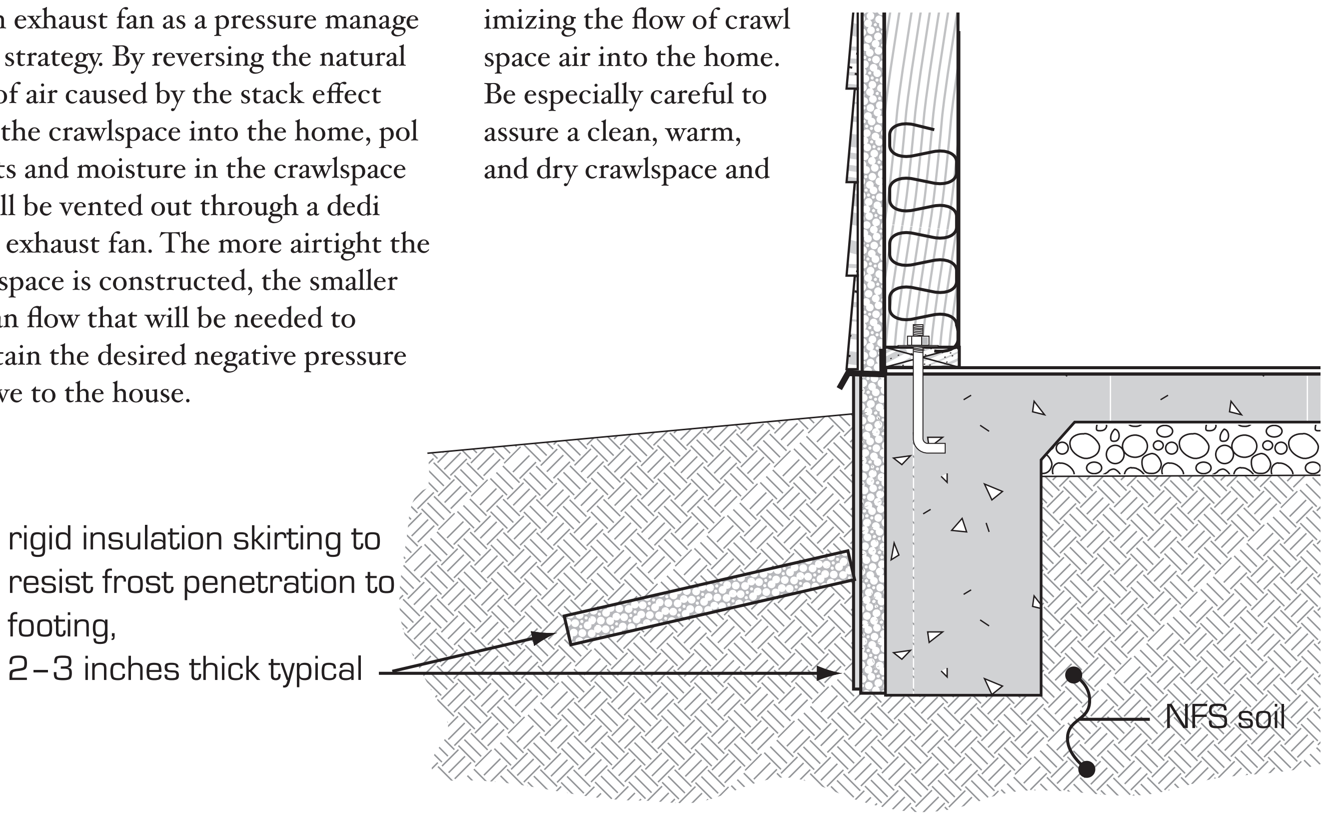


Figure 4.23: Frost-protected shallow foundation

to seal the ductwork. Pressures should be measured in the crawlspace with the furnace fan on to determine if excessive supply or return air leakage is causing a potential problem. Several ventilation options exist that offer reasonable solutions, but in any case starting off with a clean, dry, and properly sealed crawlspace is essential.

Passive perimeter venting may increase the flow of air from the crawlspace into the home. Leaky or open perimeter vents increase the natural air leakage rate of the house along with warm air and moisture entering the attic. During windy conditions, some of the crawlspace air would be vented out the leeward vents but there is likely still some air leaking into the house from the stack effect.

An **exhaust-only fan** in the crawlspace can slightly depressurize a tightly sealed crawlspace. This depressurization may potentially increase the amount of soil gases released into the crawlspace, but if the exhaust fan continuously reverses the flow of air so air flow is from the house into the crawlspace, all those pollutants are exhausted to the outdoors. Installing a speed controller and a dehumidistat can establish a continuous exhaust flow rate to maintain a slight negative pressure with respect to the house and to provide a boost in flow if the relative humidity gets too high. The energy penalty for the exhaust only fan is minimized because the net flow of the exhaust fan and the natural air leakage is less, so that the exhaust fan is only increasing the overall flow rate by approximately 50 of the exhaust fan flow. In-line or quality bath fans can be used. Where pony walls may divide the crawlspace, inline fans have the benefit of being able to exhaust air from several locations within the crawlspace.

Exhaust and supply fans would provide a balanced ventilation strategy with good potential for high ventilation flow rates when needed. It does not provide pressure control.

A **furnace return air register** in the crawlspace would depressurize the crawlspace, potentially increase the release of soil gases and distribute them throughout the house. This is NOT recommended, though is common because of leaky return ducting in crawlspaces.

A **furnace supply air register** would pressurize the crawlspace, potentially reducing the release of soil gases, but increasing the flow of crawlspace air into the home and providing no pressure management.

Furnace supply and return air registers could maintain a neutral pressure in the crawlspace and assures good mixing of crawlspace air with the home. With very clean dry crawlspaces this would be acceptable.

HRV's heat recovery ventilators can be used to ventilate crawlspaces. The disadvantages are that it may require a larger HRV and it only ventilates the crawlspace when the HRV is operating (during summer the HRV may be off).

An **HRV supply** would help keep the crawlspace dry but would not prevent crawlspace air from entering the house. Humidity controls could be implemented to increase the flow in the crawlspace if the humidity is too high.

An **HRV exhaust** can reduce the air flow from the crawlspace to the house and directly exhaust the crawlspace air to the outdoors. The newer HRV's use a recirculation defrost strategy so that the exhaust air being pulled from the crawlspace would be recirculated throughout the house. This will only occur during that small fraction of time that an HRV is operating in the defrost mode. Additional humidity controls could be implemented to increase the flow in the crawlspace if the humidity is too high. The house would become slightly posi tively pressurized unless the HRV were allowed to go slightly unbalanced.

An **HRV balanced** system has good ventilation and mixing potential but would not provide pressure man agement control of air leakage into the house.

Inside vs. outside foundation insulation systems deserve a special discussion. Placing insulation on the inside of a foundation, particularly a concrete foundation, cools the concrete and reduces any moisture entering the crawl space. On the other hand, placing insulation on the outside of the founda tion provides for a warm concrete wall that can release moisture into the crawl space if the concrete is damp. Since the outside insulation option provides for a warm interior surface, it is a good choice for full basements. This option also limits the condensation potential that would be present with the inside insulation option, since that option de pends on sealing the insulation to the outside wall to prevent moisture migra tion. Both these options function much better if capillary and moisture control is included in the foundation as it is constructed for example, polyethylene vapor barrier installed below the floor slab and footings .

A major additional advantage of the outside insulation option is that the foundation footing is kept warmer. If there is one place in your structure that should never see freezing temperatures, it is underneath the foundation foot ings. Outside insulation, with the ad dition of a "skirt" of insulation shown in Figure 4.22) placed horizontally out from the footing, ensures that this doesn't happen.

The inside placement option has many more vulnerabilities for moisture penetration and possible freeze cycle damage for the outside exposed wall. The disadvantages of outside insula tion are incidental physical issues with construction and cost, but none are risky. Outside insulation of the founda tion seems to be a clear choice, unless for some construction reason it is not possible.

Frost-protected Shallow Foundation System

Frost Protected shallow Foundations are a good choice when there is no perma frost risk, and well drained soils where ponding is unlikely. This foundation sys tem originated in Norway to avoid hav ing to excavate deeply for foundations in cold regions. Ironically, this system should only be used south of the Alaska Range and the Aleutians in Alaska, because it was never intended for use in areas at the margin of permafrost. Regardless of this limitation, many of the graphic depictions in this text sug gest use of extensive insulation of all standard foundation systems. A shallow foundation can be installed as a footing with a stem wall providing a crawl space, or as a thickened slab.

A thickened slab is a slab on grade with a thickened portion around the pe rimeter that serves as a footer. Slab and footer are poured monolithically simul taneously . A key detail in either case is to insulate the entire ground below the house.

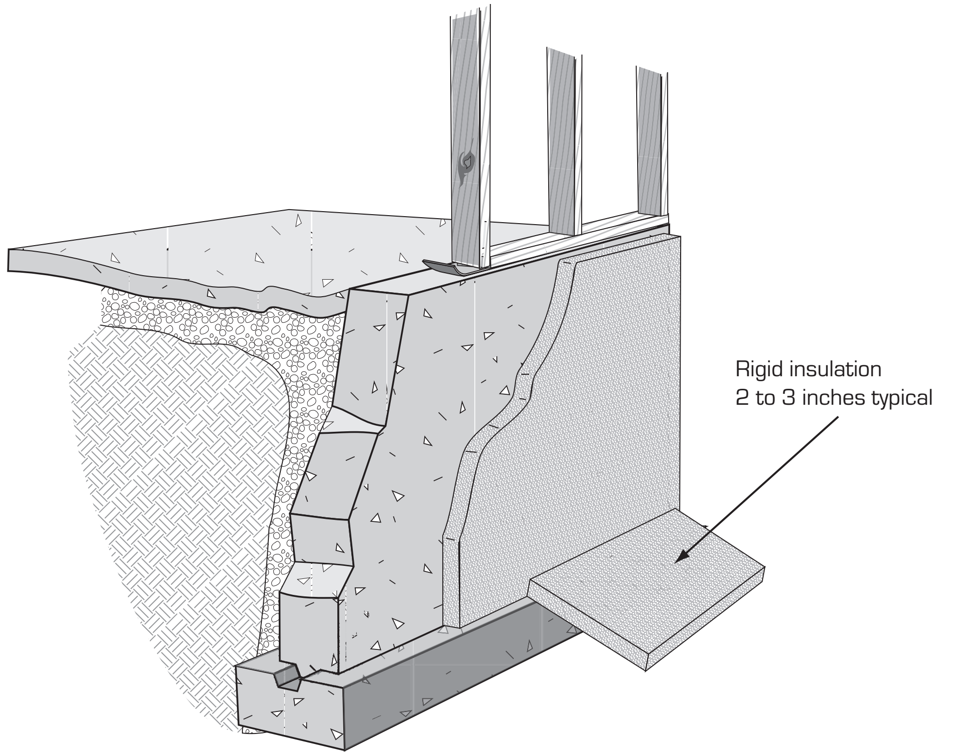


Figure 4.24: Rigid insulation used to protect the footing from frost heave

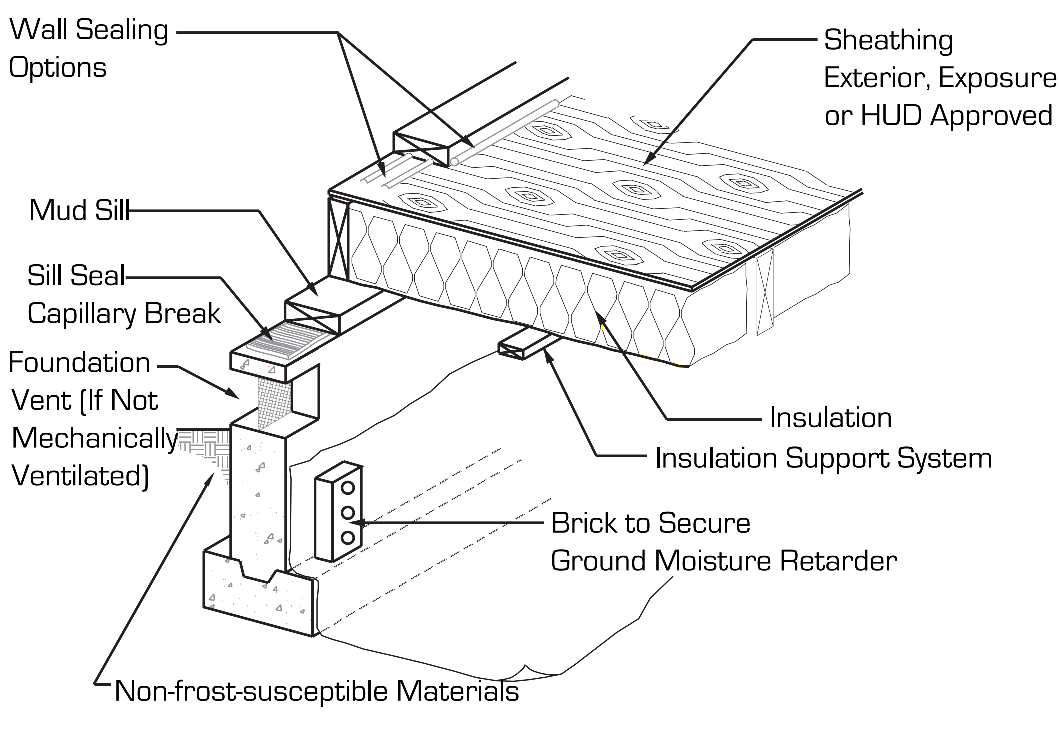


Figure 4.25: Sealing a joisted floor and ventilating the crawlspace

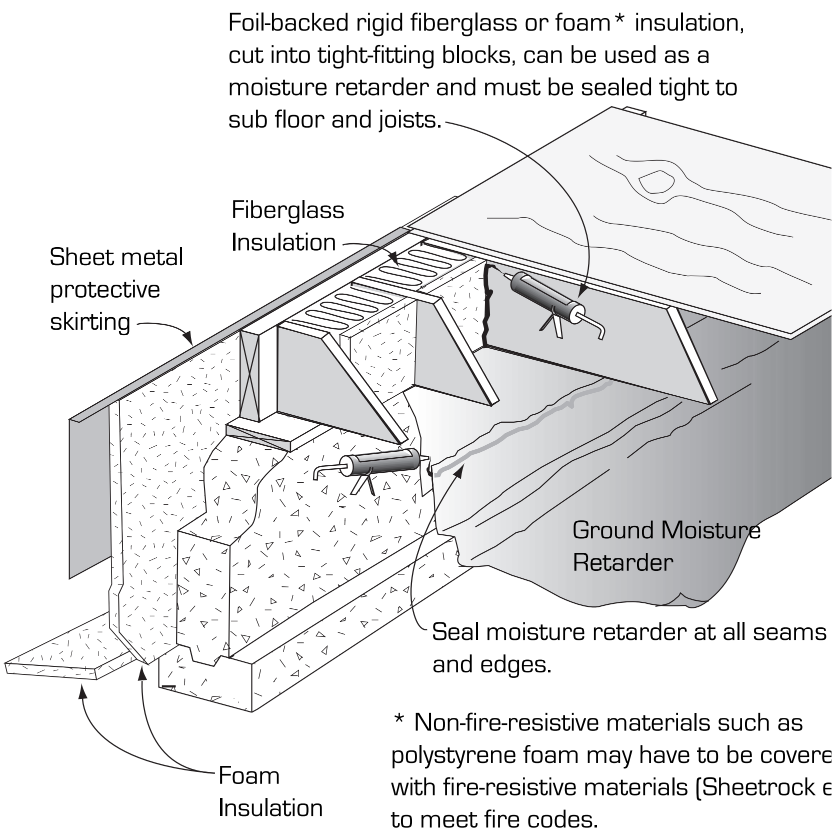


Figure 4.26: Sealing an insulated crawlspace

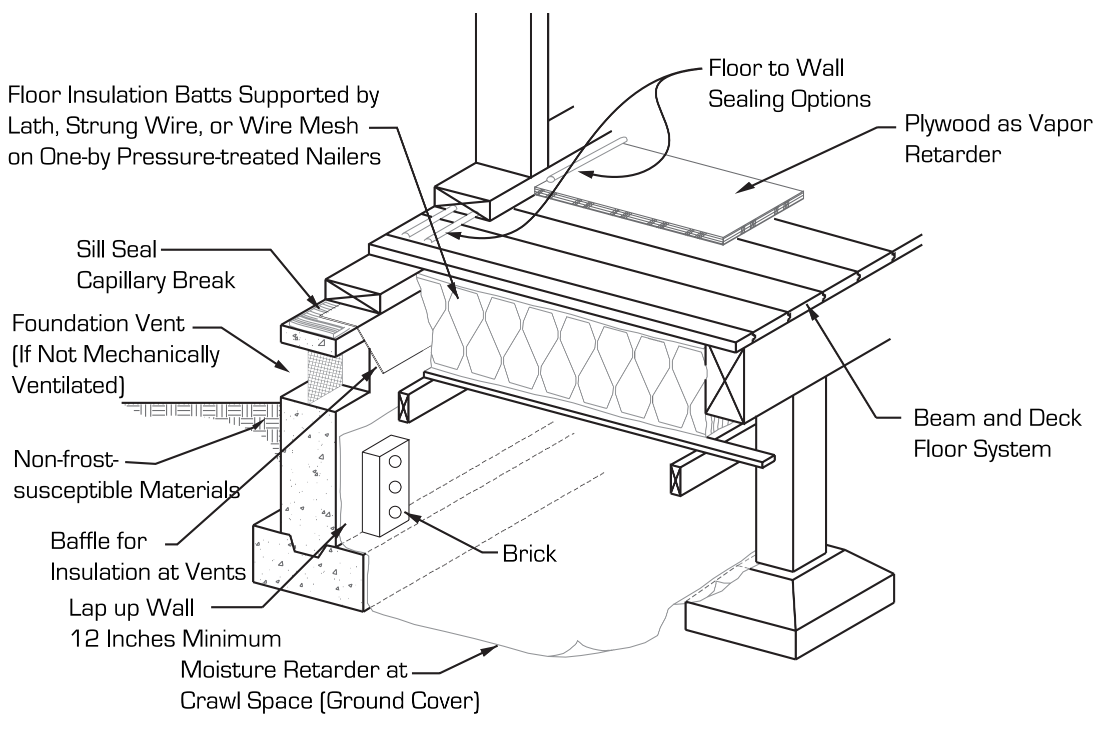


Figure 4.27: Sealing a post and beam floor with a decking subfloor

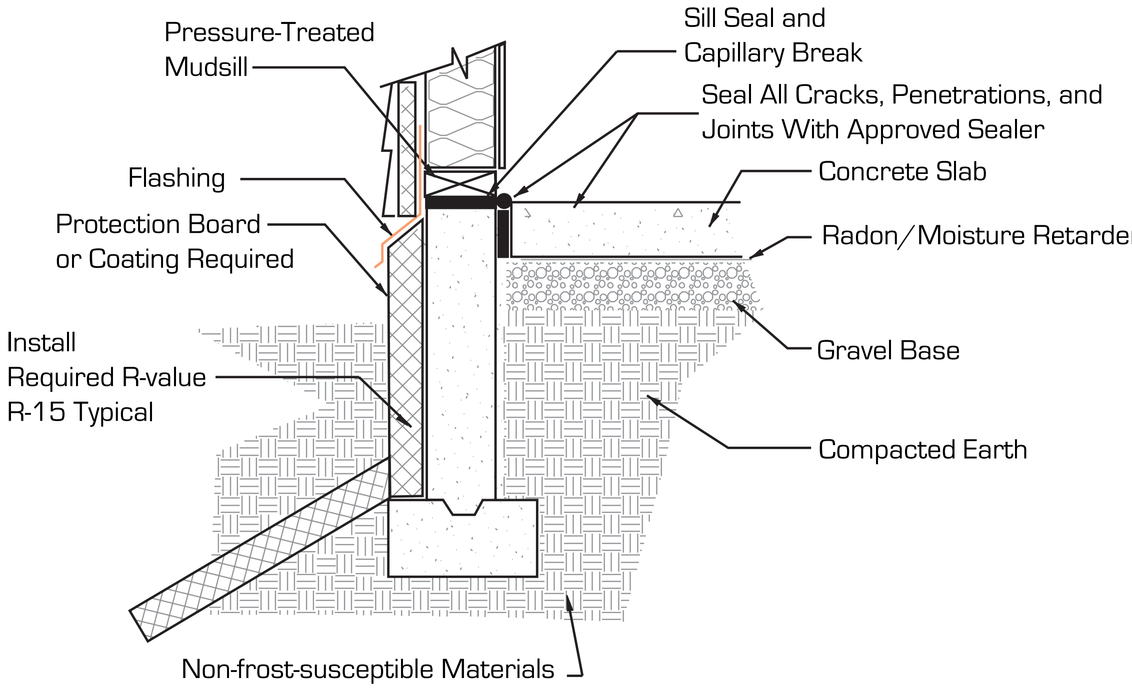
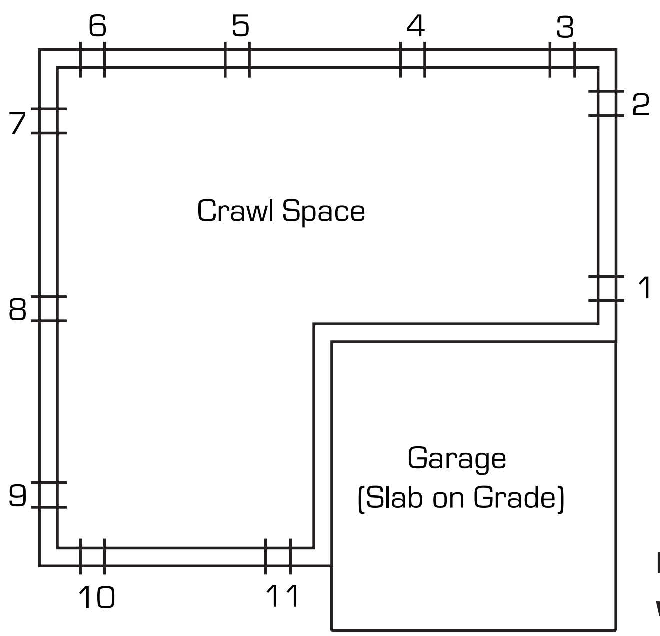


Figure 4.28: Floating slab on grade with exterior perimeter insulation



Sample Venting Calculation

UBC Section 2516(c)6 requires
1 sq. ft. net free area of vent per
150 sq. ft. underfloor area

$$\frac{1400 \text{ (crawl area)}}{150} = 9 \text{ sq. ft. (total vent area required)}$$

$$\frac{9 \text{ sq. ft. (total area required)}}{.8 \text{ sq. ft. (net area per vent)}} = 11 \text{ vents}$$

Note: In most of Alaska, temperatures are often well below freezing, and the crawl space is heated. We recommend that you ventilate a heated crawl space mechanically through the heat recovery ventilation system. One supply and one exhaust, at opposite sides, will usually get the job done.

Figure 4.29: Crawlspace ventilation calculation

Figure 4.30: Spray urethane foam is used here to insulate and seal the rim joist on an all-weather wood foundation. (Rigid foam was used on the outside of the foundation wall)

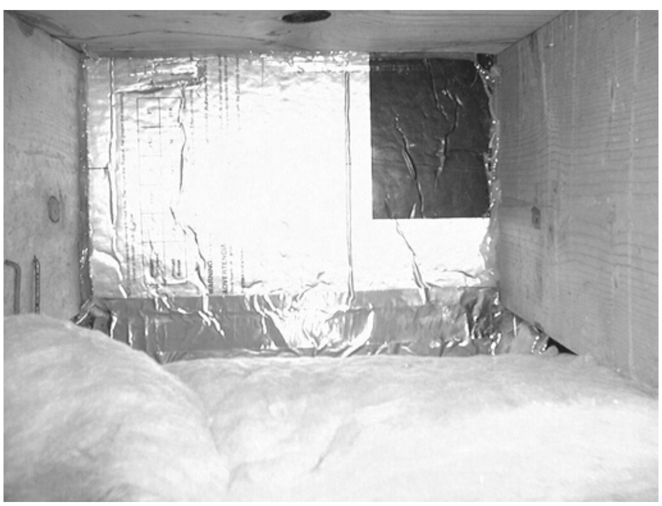


Figure 4.31: Rigid foil-faced foam used to insulate and seal the rim joist. It is caulked to the joists and taped with foil tape to the polyethelyne vapor retarder.

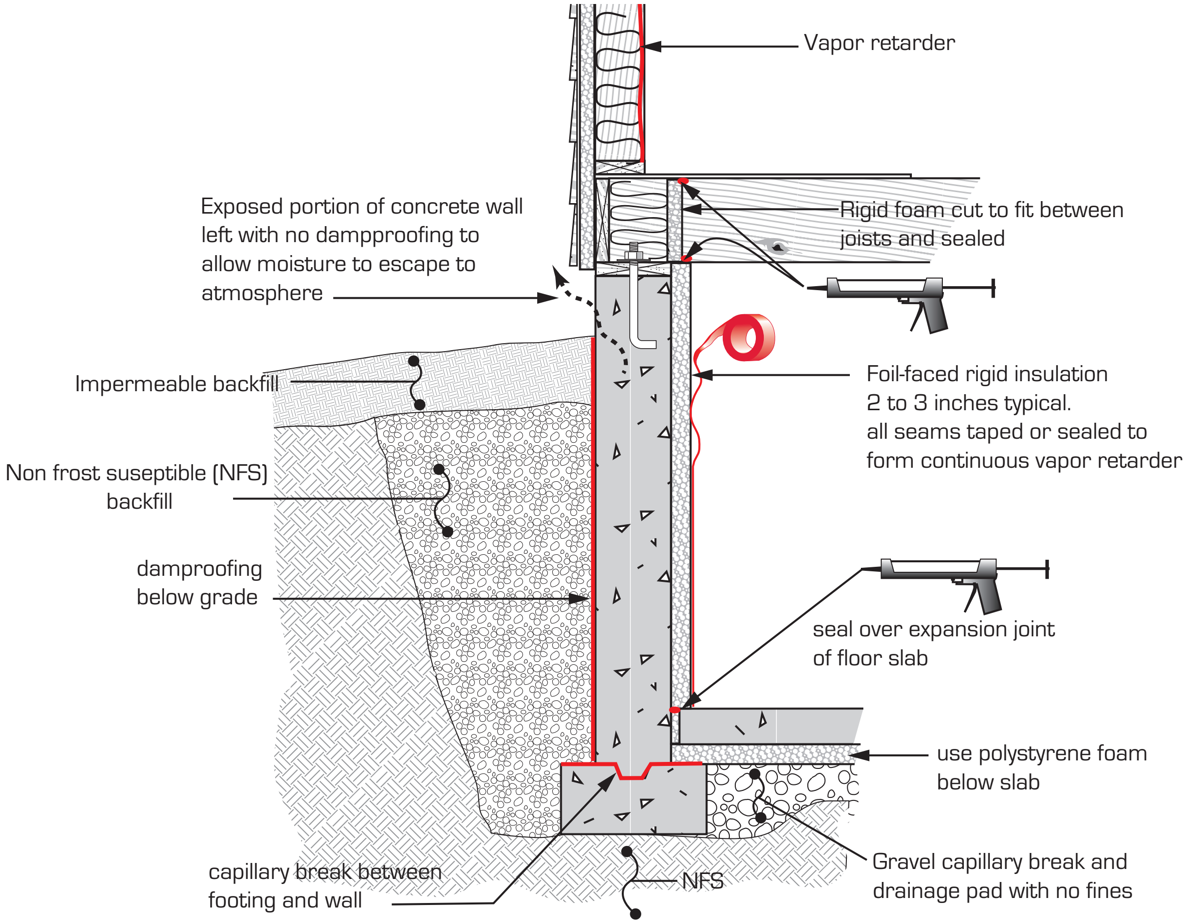


Figure 4.32: A foundation wall with insulation on the interior

Figure 4.33: A well-sealed crawlspace. Note seams of vapor retarder are sealed with tape.

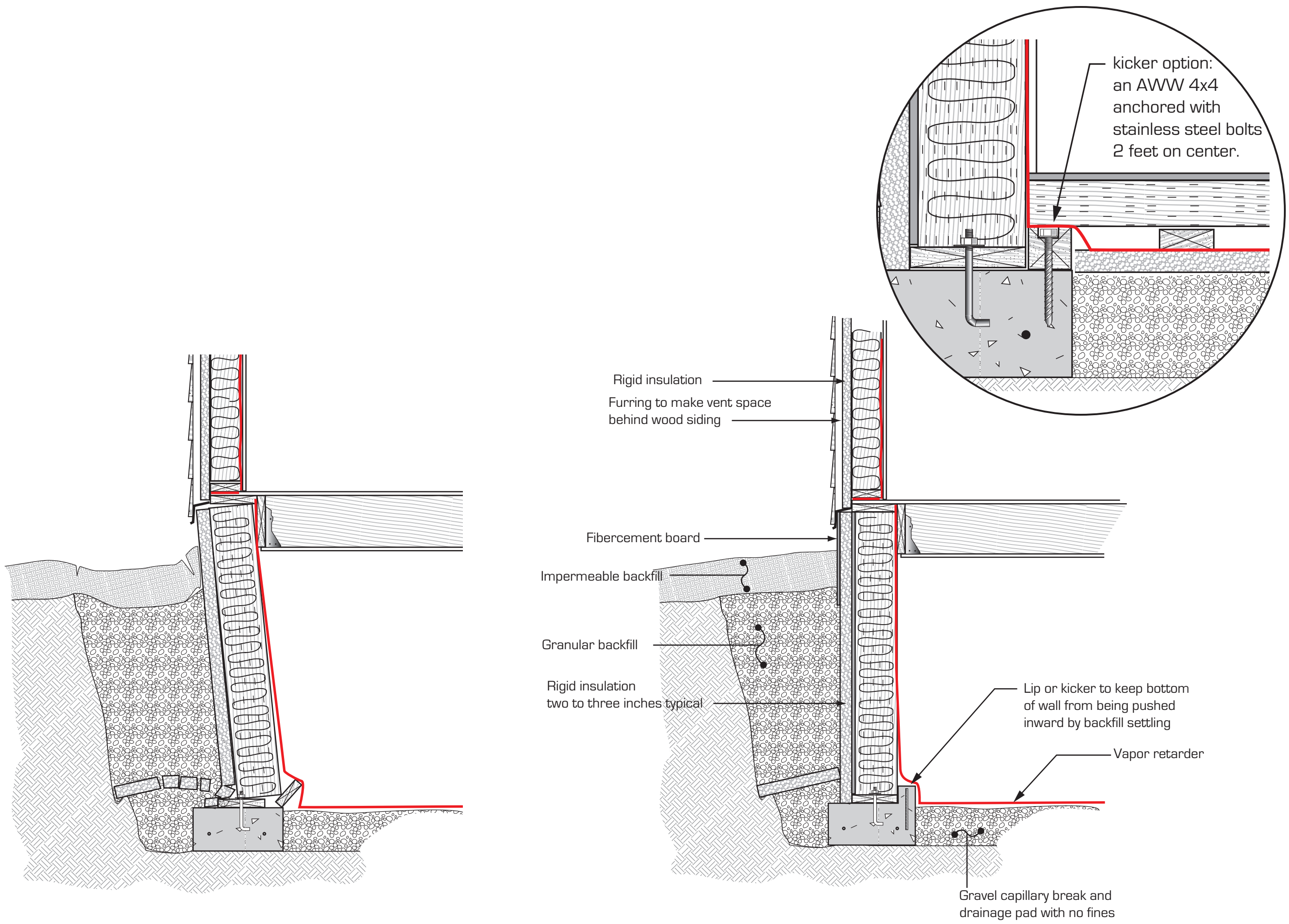


Figure 4.34: Foundation failure from backfill settling and how to prevent it using a kicker. Inset shows a kicker built after the footing is poured.

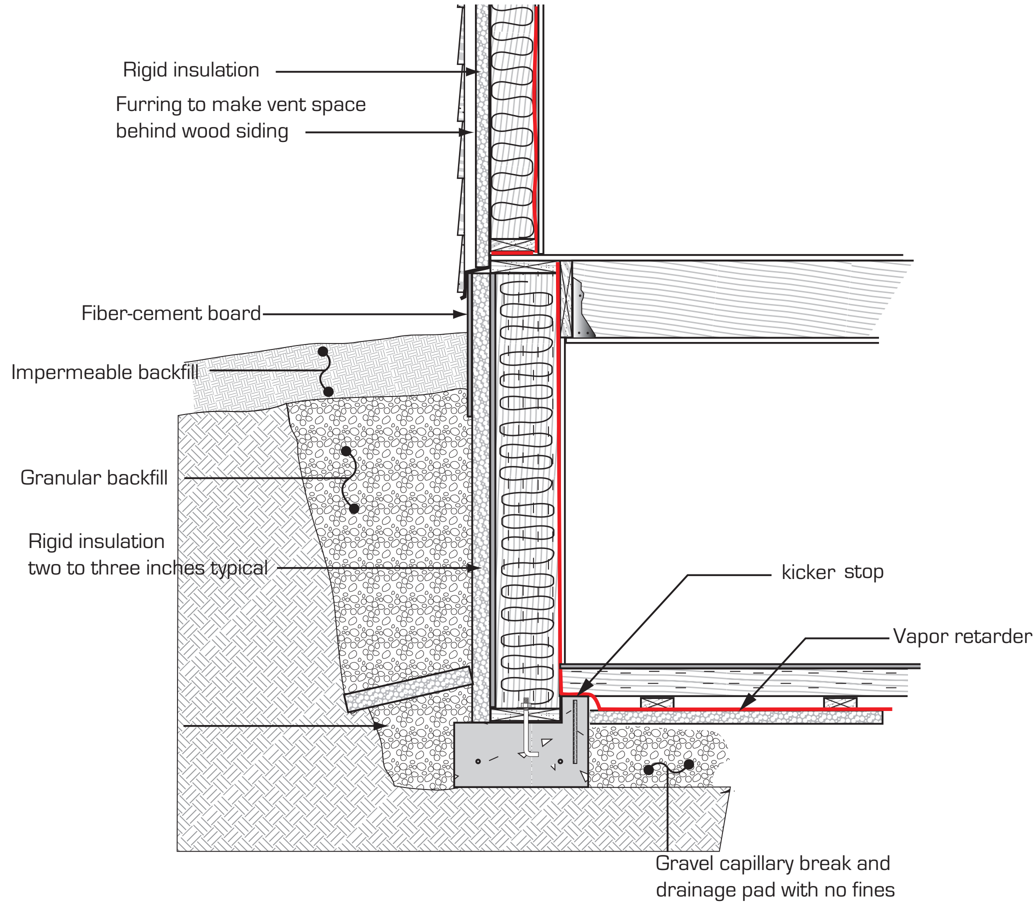


Figure 4.35

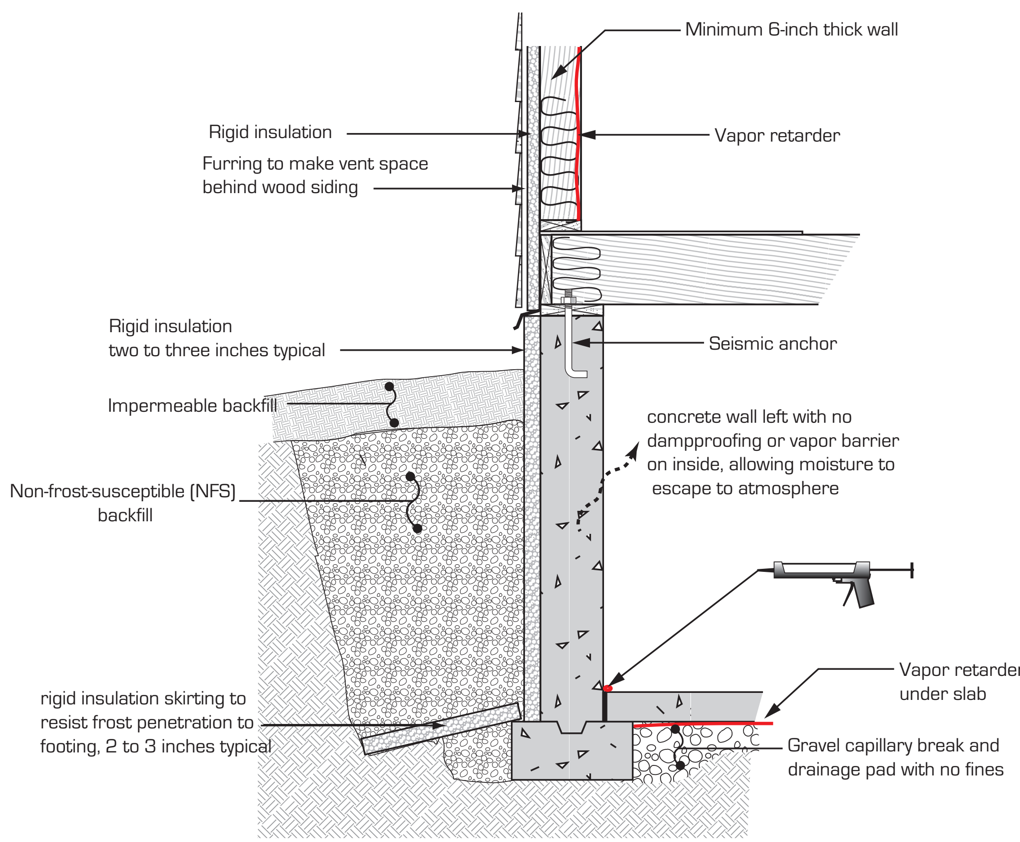


Figure 4.36

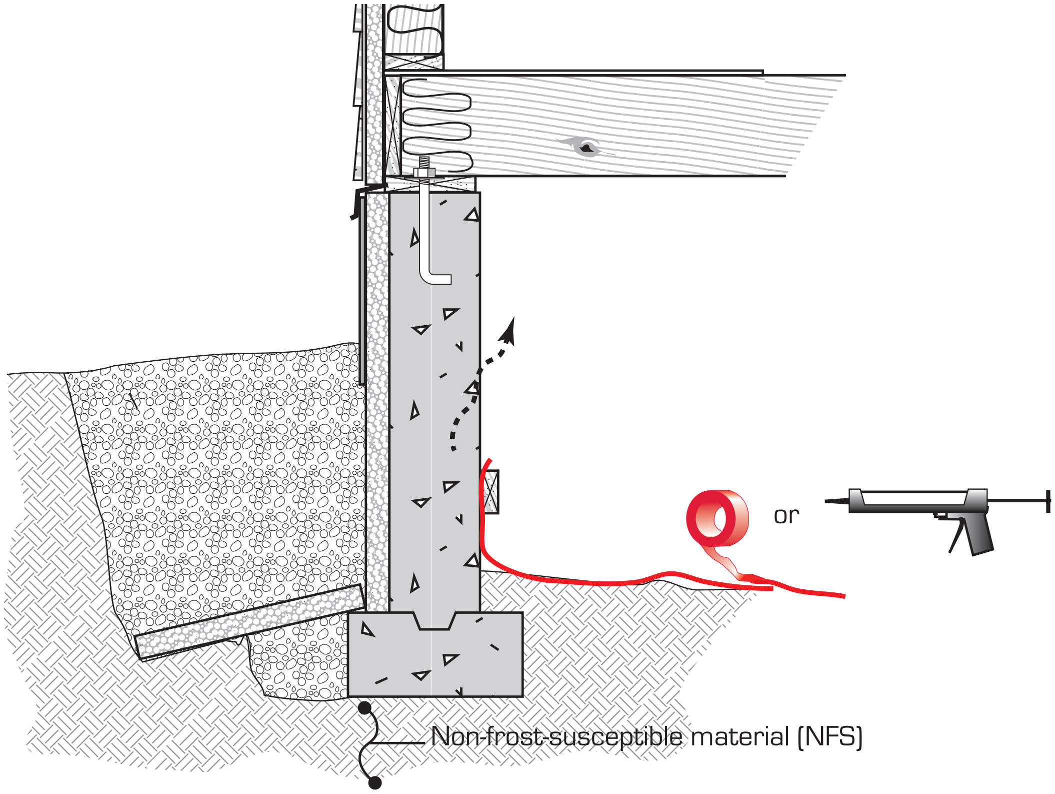


Figure 4.37: If the foundation is insulated on the outside, the basement wall should be allowed to breathe on the inside.

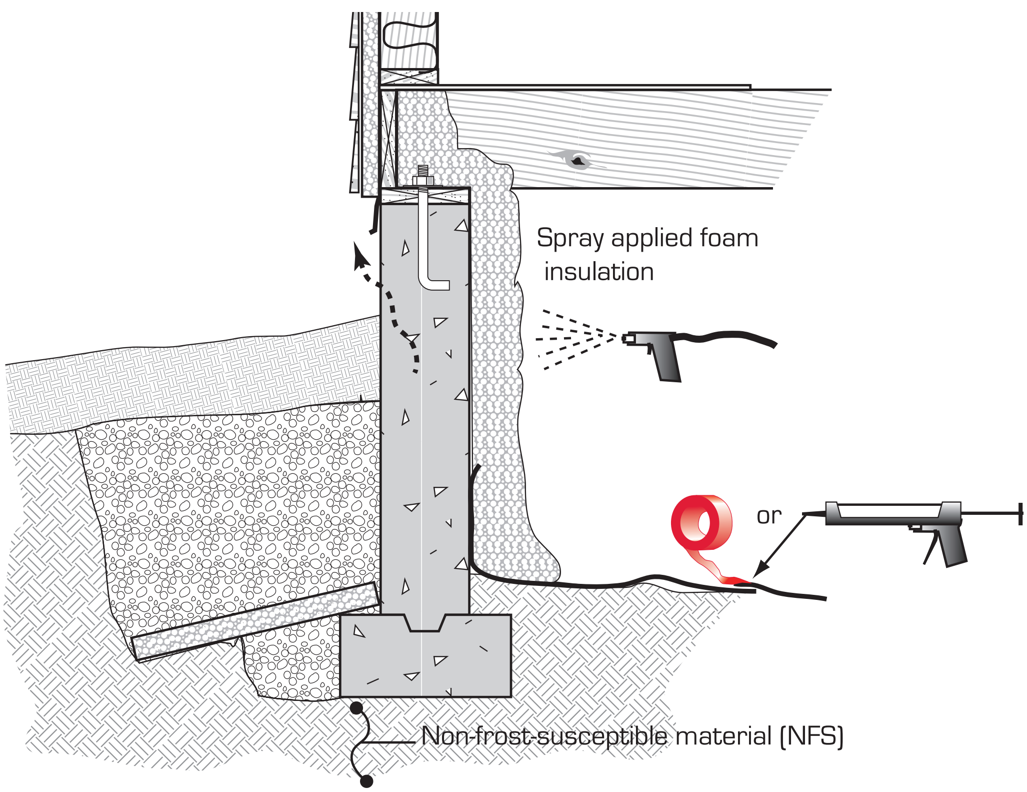


Figure 4.38: If the foundation is insulated on the inside, moisture can escape above ground outside.

Figure 4.39: This post and pad system has no adjustment and should be used only on stable soils.

Figure 4.40: This welded steel foundation was custom prefabricated for a building site with discontinuous permafrost and has adjustment to compensate for settling.

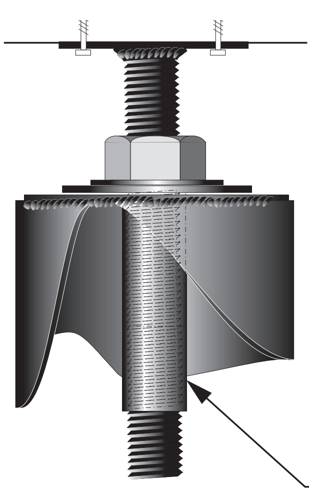


Figure 4.41: A tube just large enough to fit over the adjusting screw is welded inside the pipe to the end plate. This helps resist tipping of the screw due to lateral forces.

Post and Pad Foundations

Small houses and houses on permafrost are frequently placed on post and pad foundations. A gravel or tailings pad is placed on the ground to provide a base to place the posts and pads to sup port the house, and it also provides a separation between the permafrost and the foundation system. As previously discussed, all construction materials should be placed directly on the exist ing organic materials on the site, and those materials should not be disturbed. These organic materials act as the insu lation for the permafrost and limit its degradation and thawing. The structure should shade the pad beneath as much as possible. An additional suggestion is to further shade the south portion of the foundation and the exposed area in front of the structure. Experience shows that this south area is the most vulner able to degradation, and a shading deck or other thermal shade can prevent dif ferential settlement of the south side of the foundation. Some mechanism for leveling the foundation should also be included in this type of design. See Figures 4.39 through 4.42. More infor mation on permafrost foundations can also be found in the two permafrost foundation manuals cited earlier in this chapter.

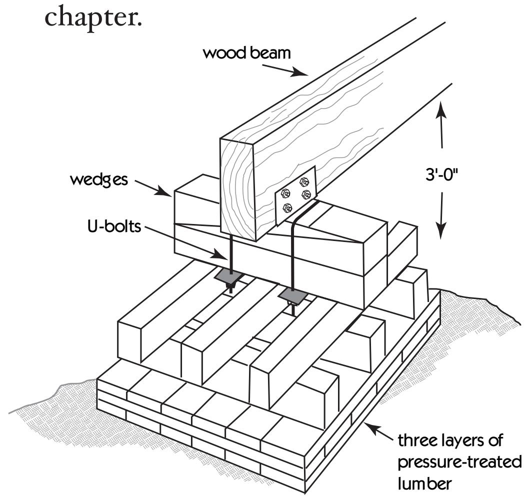


Figure 4.42: A common foundation for permafrost soils, using a pad of pressure-treated lumber.

Figure 4.43: The underside of the house in Figure 4.40, showing the concrete pads supporting the posts and the ties holding the posts upright.

Figure 4.44: A house in Hooper Bay supported by a Triodetics brand frame.

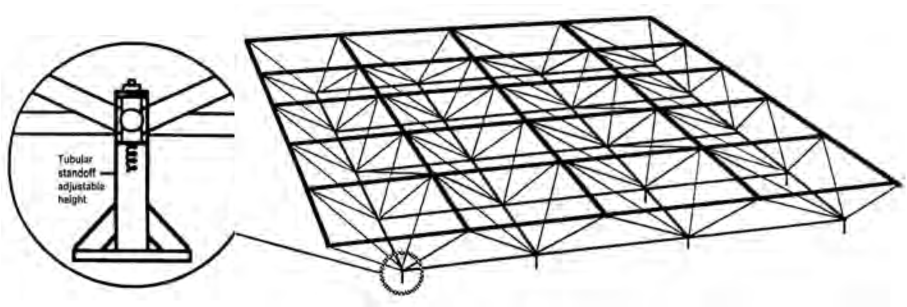


Figure 4.45: Schematic of the Triodetics Space Frame.

BYGGFORSK

NBI: A541.702

FOUNDATION RETROFIT & REHABILITATION

ALASKA BUILDING RESEARCH SERIES HCM-01555

Introduction

This publication is one of nine that has been translated from Norwegian. They are taken from a series of publications produced by the Norwegian Building Research Institute (NBI) series, "Byggdetaljer," which literally translated means "building details." It is hoped that Alaskan builders will be able to glean useful ideas from these publications. The translations were done by Dr. Nils Johanson and Richard D. Seifert of the University of Alaska Fairbanks with the cooperation and permission of NBI, Oslo, Norway. The financial support for the translations and printing came through the Alaska Department of Community and Regional Affairs, from USDOE Grant DE-FG06-80CS6908. The publications use the original index code of the Norwegian "Byggdetaljer" series so that specific translations can be directly cited. All questions on these translations should be directed to Richard D. Seifert, Alaska Cooperative Extension, P.O. Box 756180, University of Alaska Fairbanks, Fairbanks, Alaska 99775-6180. Phone: 907-474-7201.

0 GENERAL

01 This bulletin gives an overview of the various methods that can be utilized to improve older building foundations and to retrofit building foundations. It also gives information about common damage to foundations and basement walls.

02 The condition of the foundation can be a determining factor as to whether a building can or should be improved. Extensive repair or retrofitting are quite expensive to carry out and must be carefully evaluated ahead of time. A certain amount of tilt and some cracks in old buildings is acceptable if settlement has stopped. All large scale retrofit work demands professional assistance in evaluating the geotechnical and structural conditions.

03 A technical survey combined with a historical survey of the foundation and foundation walls should be carried out in connection with improvements. The extent of the analysis depends on the size of the building, its age, foundation conditions, changes in use, and so on. The analysis may include the following:

- Investigation of construction records and government archives to map the soil conditions
- Survey of foundations and foundation walls
- Report of damage
- Visual survey and ground excavations
- Crack survey
- Foundation survey including drilling, testing etc.
- Report of settlements and time dependent settlements (precision leveling, precision settlement measurements)
- Calculation of the foundation load (static system)
- Measurements of groundwater level and pore water pressure
- Leveling and straightening of foundation and other walls
- Stress measurements in existing tension ribbons
- Vibration measurements
- Control of material quality

04 Changes and improvements in the building foundation can lead to great problems with adjacent structures. For instance, buildings that are still settling may "hang up" on the area that has been improved. Strengthening or retrofitting must, therefore, take neighboring structures into account.

05 Rehabilitating the foundation may also require correcting already existing differential settlement. Such correction is often possible by jacking wooden frame houses. Masonry construction is often sensitive to movement and should not be jacked or leveled.

1 TYPES OF FOUNDATION DAMAGE

11 Erosion

111 Natural rock

The durability and strength of rock is determined by the amount and distribution of the smallest and weakest mineral. As these minerals are worn away everything breaks down or dissolves, and there are no connections left between the other stronger mineral groups. The original stone then consists of a conglomeration of loose particles. If the foundation surface has been damaged by frost action, salt washing or the like, the deterioration accelerates. It usually takes a long time before natural rock starts to erode, but limestone, sandstone, and shale are more likely to be exposed to problem-causing erosion.

112 Brick

Brick is the most porous foundation material and will absorb moisture. The moisture leads to frost damage which materializes by exfoliation or splitting of the surface parallel to the outside. Large continuous cracks can totally destroy the bricks. The brick's frost resistance depends on material properties such as pore distribution, water absorption, and strength. Other factors such as moisture, climate, number of freeze-thaw cycles, and the freezing speed are also important.

12 Rot

Fungus rot is the most common reason for damage to wood. Fungus thrives on nutrients that are found in wood. However, the temperature must be between 0 and 40°C and the wood must have at least 20% water with respect to its dry weight in order for the fungus to grow. Another important element in fungus rot in wood foundations is the availability of oxygen.

Raft and pile foundations are subjected to attack by fungus rot when the water table sinks below the top of the foundations (see Figure 12; see also Point 151.)

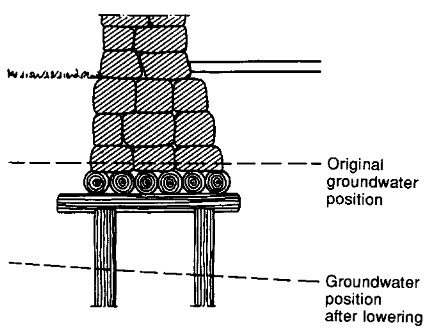


Figure 12
Groundwater lowering leads to raft and wooden piles being exposed to air and thereby rotting.

13 Insects

Insects can attack wooden foundations above ground level. Boring beetles and carpenter ants are the wood boring insects that do the most damage. Certain parts of the country are more exposed to attacks than other parts. Most wood-boring insects are active between 0 and plus 30°C (32°F and 85°F). Wood that has already been damaged by rot is especially vulnerable to attack by wood boring insects. The same conditions are true for caissons and poles at beaches.

14 Moisture damage

Walls where lime and clay are used as a mortar often absorb moisture. This usually does not lead to significant problems as long as the wall has been untreated or has been covered with lime mortar. Local repairs with cement mortar on an original lime mortared foundation wall does not work very well. The cement mortar, which is relatively tight, disturbs the moisture balance in the wall, and the mortar does not breath enough, nor does air escape. Moisture can thus penetrate farther up into the wall before it finds an exit (see Figures 14a to c). Old buildings are often surrounded by terrain which, because of occasional filling, asphalt work, and so on, lies higher than the original terrain. Mortar, masonry work, and possible wood construction, which were never designed to be in contact with the soil, can in this way suffer from significant moisture damage.

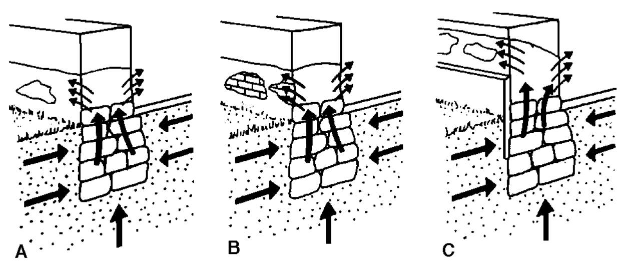


Figure 14
Moisture damage on foundation walls
a. Moisture penetrates up through the wall
b. The old mortar covering deteriorates
c. By repairing of old imperfections the evaporation zone is moved higher up on the wall.

141 Frost wedging

Water that penetrates up or out through the wall can freeze and break it in pieces; the mortar material crumbles and loses its binding ability. In box walls the core can be torn to pieces, leaving the shell standing without any significant mortar.

142 Salt bloom

Moisture that travels in foundation walls can carry with it easily soluble salts that occur in mortar and stone material. These materials are carried to the outer surface where the water evaporates and the salt crystallizes. This "salt bloom" can damage the surface. Crystallization may also occur inside the rock or the cover and lead to of salt build-up, which can then flake off the covering mortar or rock material (see Figure 142).

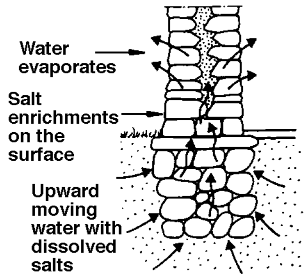


Figure 142
Moisture migration and salt bloom in masonry work

15 Settlement

151 Groundwater lowering

The main reason for settling in Norwegian buildings is the lowering of groundwater. Settling occurs as a result of increased stress on the soil which causes compression of compressible soils. Raft foundations and the upper portion of wooden piles rot when the groundwater level sinks.

Changes in groundwater level or pore water pressure in the ground can be the result of one or more conditions.

- In Norway, ice static rebound following the last ice age that is still going on
- There have been many instances of groundwater table depression because of dewatering, especially in cities. Ditches and pipes that are placed below the groundwater level have contributed to its lowering. Construction of new buildings with deep foundations and basements has caused further drainage of the ground, as has tunneling through open loose rock. Local groundwater storage may also be disturbed by the removal of foundation sills.
- In towns and other built-up areas more and more of the terrain surface has been used for construction or covered with asphalt roads and parking places. In addition, there has been effective removal of the surface water via the drain system. A much smaller portion of natural precipitation reaches the ground and this contributes to a lowering of the groundwater level.
- Deciduous trees with large root systems have great demand for water. In certain cases they pull so much water from the ground that local groundwater levels are lowered and settling problems can occur.

152 Ground with limited bearing capacity

Some older building foundations are built without any concern for the bearing capacity of the underlying soil. Even in the construction phase, the building can start to settle. In extreme cases the foundation or the foundation wall will crack.

153 Uneven bedrock depth

When a building is constructed partially on bedrock and partially on fill mass with poor bearing capacity, differential settling results. In masonry walls, such settling can have major consequences. Cracks can spread up through the various floors and, as a worst case, affect the stability of the entire building.

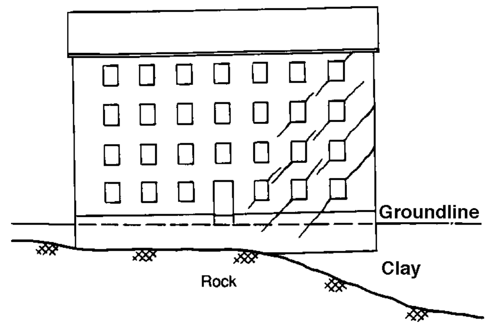


Figure 153
Differential settlement damage resulting from uneven depth to bedrock.

154 Excavations under foundations and poor backfill

With high loads and unfavorable ground conditions just excavating down to foundation level can cause settling. See Figure 154.

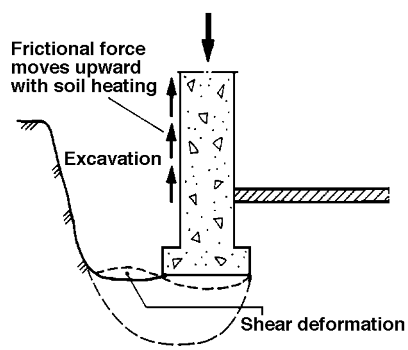


Figure 154
An excavation which can cause local settling.

155 Increased Load

Buildings which have stood without damage for many years can experience settling if the load conditions are changed. Changes in use are often the reason for differential settlements and other damage to the foundation.

156 Removing neighboring houses

In cities where large buildings are close together, tearing down one structure can result in the neighboring building being left standing without lateral support. A slide, may then occur, and it can have serious consequences for the stability of the building.

16 Horizontal movement in the ground

In inclined terrain, by filling in of terrain, damage in the form of collapse of the foundation and basement walls because of increased earth pressure or poor stability can occur. In some cases, movement can also be caused by frost action, temperature variations or moisture variations.

17 Frost heave/adfreezing

Small older houses are usually not founded to frost-free depth if they do not have a basement. On frost-susceptible soil the damage to small house foundations can be extensive because of the adfreezing or the lateral grip of the frozen soil. The damage is normally more significant on walls where there is mortar between the blocks. Surface damage can also occur where there are connections with log houses (see Figure 17).

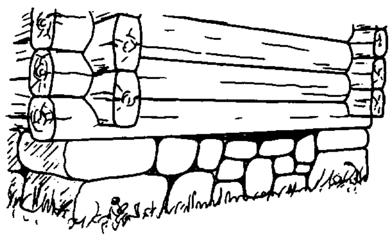


Figure 17
The filled in area between point foundations on log houses often settle without this causing a problem for the stability of the building.

18 Alum Shale

Alum shale contains pyrite, which when exposed to oxygen (for instance by a lowered groundwater table) will be converted to sulfuric acid. This acid attacks concrete and metal. Sulfuric acid and lime form plaster of gypsum. When this process takes place there is a volume expansion which, in the worse case, can lift the foundation. Foundation damage in connection with alum shale is first and foremost related to the Oslo area. (Editor's note: There is no known alum shale in Alaskan communities.)

2 IMPROVEMENT METHODS

21 Preventing Moisture Damage

211 Coating of the foundation wall. This method, which is little used in Norway, consists of establishing a capillary barrier in the foundation by drilling and injecting a mixture of polyester and rock flour.

212 Electro-osmosis

Electro-osmosis can also be used to prevent capillary absorption of water in masonry work. Electrodes are placed in the incision zone between the foundation wall and the soil. By changing the electrostatic conditions, the capillary rise can be reduced.

213 Drainage and irrigation

In some circumstances drainage and irrigation of the foundation can yield good results by reducing the moisture availability.

Draining and securing from moisture damage on the outside of basement wall is carried out after excavation.

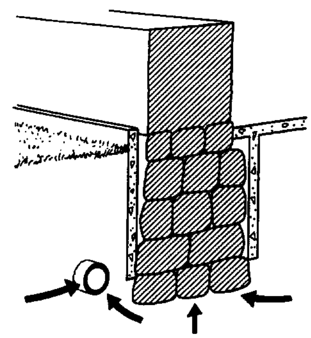


Figure 213
Draining and airing of foundation

214 Sealing joints with lime mortar

This does not prevent air from entering the masonry work but it can reduce the extent of damage when the wrong kind of mortar has been used for improvements. Pure lime mortar is porous, and moisture which has been added can evaporate. Loose or poor-quality mortar should be chipped away and the cracks cleaned of dust and leftover mortar pieces. The cracks should then be moistened and filled with a lime mortar as similar as possible to the original mortar. The foundation wall should not be exposed to sun or rain during the curing time.

215 Injecting mortar

This method may be used in the middle room of a box foundation. Mortar injection strengthens the wall and reduces damaging moisture penetration. The loose mass inside the wall should be removed to the greatest extent possible by excavation or flushing with water. The cement mortar is injected through openings in the outer wall. Numerous openings will give the best distribution of the water (see Figure 215).

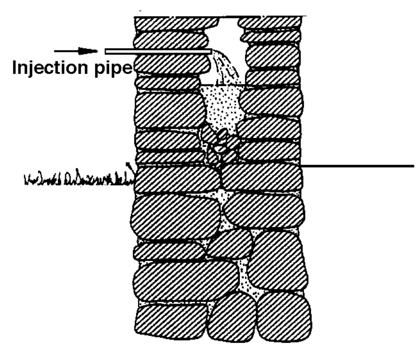


Figure 215
Injection of mortar in box foundations

22 Preventing frost damage

Movement in the foundation/foundation wall as a result of frost action can often be prevented or reduced by ground insulation laid out along the building. A problem with this is that old construction will act as a cold bridge where the frost can penetrate down regardless of insulation (Figure 22).

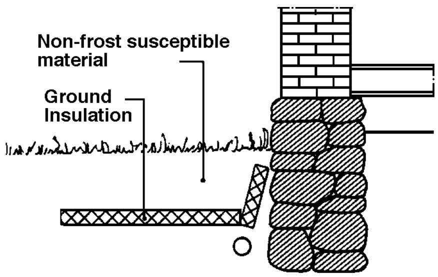


Figure 22
Frost protection of foundation with ground insulation

23 Raising the groundwater table

Raising the groundwater table can protect the existing support system of wood from damage in areas where the water table is shrinking. The wood must be healthy at the start, however, otherwise the method has little going for it. In areas where settling is occurring, it may be desirable to stop this by increasing the poor pressure in the soil. This method requires infiltration through permeable soils since a local increase in water table will normally not be sufficient to raise the groundwater table in dense soil masses.

231 Controlled watering

In this method the upper groundwater storage aquifer is filled to prevent exposure of the wood in rafts above the water surface. A well is dug next to the wall, down to the upper part of the raft. The well must be supplied with water so that the water table always covers the wood. This can be maintained by installing an automatic leveling regulator. Several observation pipes must be installed along the circumference of the building to control the water level. Controlled watering requires a permanent survey system.

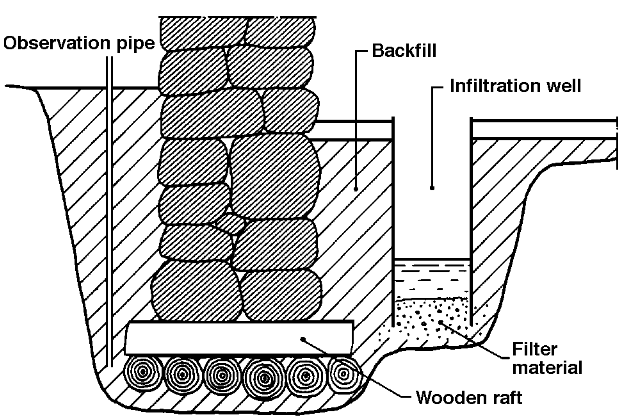


Figure 231
Example of controlled watering

232 Removing large trees

If large deciduous trees are next to the foundation wall, the roots can absorb so much water that the local groundwater table is drawn down.

233 Infiltration

Surface infiltration is done by connecting shallow wells or pipes to the water bearing layer (see Figure 233).

Deep infiltration is done through shafts in rock or through pipes that extend down to the actual depth of the water table. The water must normally be supplied under significant overpressure with respect to the existing pore water pressure.

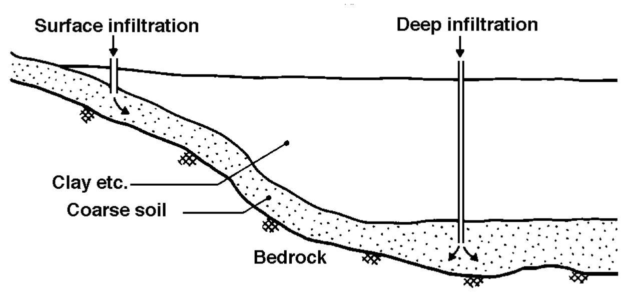


Figure 233
Infiltration of building soil

Infiltration must be monitored by installing pore pressure meters (Piezometers) in the ground. Shafts and pipes must be constructed so that they can be cleaned on a regular basis.

A permanent infiltration system is difficult to maintain and must be planned by specialists. Practical experience from Norway is limited.

24 Constructing a dry wall

Small walls are, as a rule, easy to repair, but they must first be secured against further damage, for example, by placing ground insulation under them. See Point 22.

Rocks that have fallen out and rock that has been displaced must be removed. With larger walls, one must determine what kind of construction should be used before the wall work commences.

25 Reinforcing drywall with concrete and reinforcing steel

Drywall foundations were originally thought to conduct vertical loads only from the walls to the ground or raft. Local settling, rot in raft foundations, and so on can make it desirable to strengthen the wall so that it can take lateral as well as vertical stress. Such strengthening can be combined with piling along the foundation. See Point 28.

251 Concrete Beams

If there is plenty of room and if it is possible to dig down on either side of the wall, the simplest strengthening method is to pour a reinforced concrete beam on either side of the wall. These beams, take over the whole support function and tie in with prestressed stays or by cross bracing through the wall. If much stress are expected, the new beams may require quite a bit of room. Strengthening with concrete beams can also be combined with piling. See Figure 251.

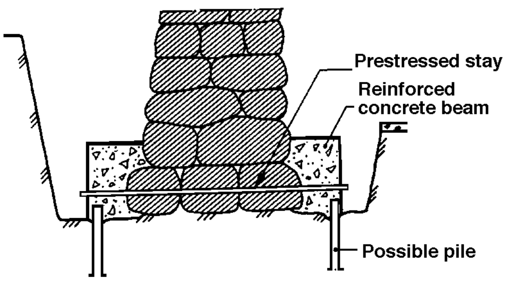


Figure 251
Drywall strengthened by reinforced concrete beams and piles.

252 Shotcrete

This method requires digging down on both sides of the wall so that it can be cleaned on the surface. Loose materials can be removed by scraping and washing. Shotcrete is sprayed on the mortared side in relatively thick layers. For extra strength fiber reinforced shotcrete should be used. Tension and shear reinforcement must be put into the concrete. Through-the-wall holes can be drilled for cross-bracing, and they may be prestressed. The braces must be rust protected. See Figure 252.

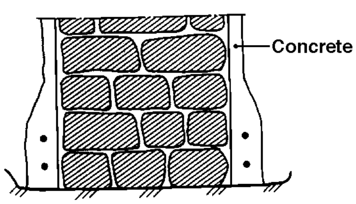


Figure 252
Drywall with shotcrete and reinforcing

253 Shotcrete and injection

If the dry wall is made of poorly matched rocks one can, in addition to the strengthening described in Point 252, inject concrete into the hollow spaces between the rocks. If this method is used piles must be placed, rinsed, and injected into the outer concrete layer which, after hardening, acts as a reinforcing box.

Cleanse the wall inside via the pipes. Concrete is then injected so that as much of the inside hollow space as possible is filled. Both water pressure and concrete injection pressure ought to be at a moderate level. For concrete about 0.05-0.1 MN/m^2. See Figure 253.

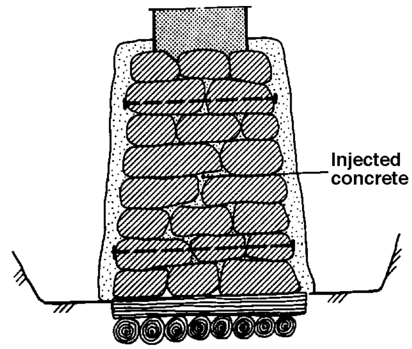


Figure 253
Dry wall injected with concrete.

26 New concrete foundation/underpinning

261 Point foundations

The loose, and often course, rock that is found under the corners of rafted houses is often exposed to settling and movement because of frost. The house should be lifted back to the original elevation. The point foundation can then be removed temporarily while a pressure distributing concrete slab is poured to frost free depth. The point foundation is then reconstructed after the old pattern. Rock that does not fit very well should be encased in mortar (see Figure 261).

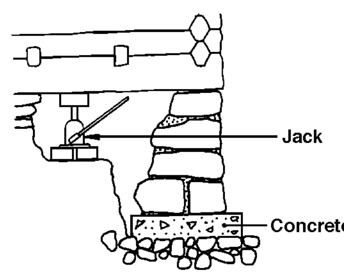


Figure 261
Concrete pad under point foundation of natural rock

Alternatively, the foundation can be secured against frost damage as discussed in Point 22.

With especially poor soil conditions, a continuous foundation can be poured to the level of the terrain. Above the terrain, mortar work is done with natural rock. See Point 263.

262 Underpinning

Underpinning can be used only in foundations which have a certain amount of internal strength. For example it can be used in sections where the foundation or foundation wall has been mortared together or in sections which have already been reinforced. To underpin, one should dig down on both sides of the wall. Then remove the material underneath the foundation in sections. The length of the sections being removed must be adjusted depending on what the old wall can tolerate. Normal length is 1 to 1.5 meters. Settling must be anticipated, and underpinning should be continued along the whole wall to avoid uneven settlement. When the material has been removed to the desired depth and width, the reinforcing and falsework are placed. Reinforcing should be made longer than the sections and be bent to the sides so that it can be spliced with the next section when this section is being poured. Under some circumstances, the soil side can be used as false work. A layer of expanding concrete is placed on the completed poured section to prevent building settlement while the intermediate parts are being reexcavated and poured (Figure 262).

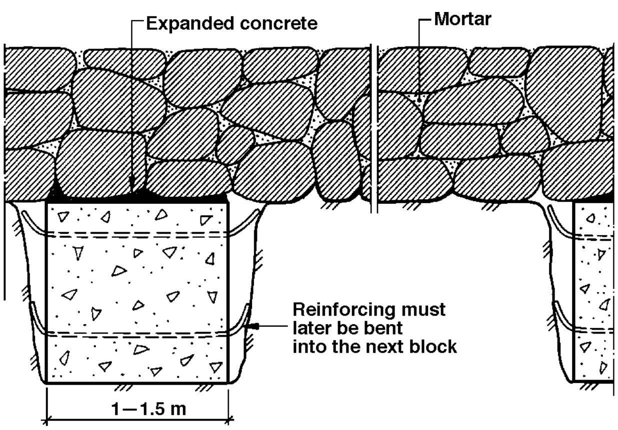


Figure 262
Sectionally underpinning of the foundation

263 New ringwall

A new concrete ringwall should be used only when the foundation or foundation wall is in such poor condition that it is not worth saving. Wooden buildings can be jacked up and renovated while the old foundation and foundation wall are being removed. Dig down to frost free depth to bearing ground before a new foundation is poured or rebuilt, for example, with lightweight concrete blocks. The part of the foundation wall which is visible ought to be surface treated or treated so that the wall looks like the original (Figure 263).

264 Concrete slab

Pouring a whole slab of concrete under the entire building can be used in circumstances where the foundation must be rebuilt anyway. For instance, a concrete slab may be desirable if the building is going to take large loads on the first floor, or if the basement floor is destroyed. This method can also be considered as an alternative to pilings when difficult soil conditions are present (Figure 264).

Wooden buildings can be jacked up and relocated so that the old floor and foundation wall can be removed. The ground should be leveled and drained if necessary. The concrete slab with ringwall is poured on a foundation of drained fill with adequate load-bearing capacity. The house is then jacked back in place. With brick buildings, the whole slab can be poured in sections.

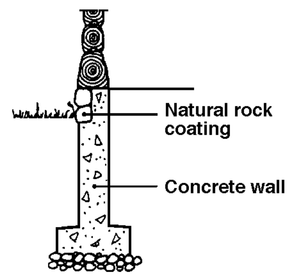


Figure 263
Old house with new ringwall of concrete

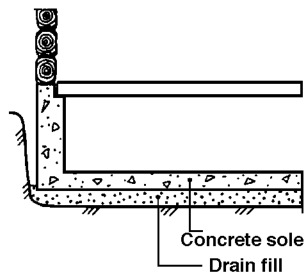


Figure 264
Pouring of solid slab under an old house

27 Repairing existing piles

This method consists of replacing rotting wooden portions with steel or concrete piles. Repairing existing piles must take place in steps. Missing information about the number of piles, dimensions, lengths, bearing capacity, and so on makes the planning of such a job quite difficult.

Dig down in sections along the wall to a point where it is possible to remove the remains of rotten rafts. Then cut the old piles some distance under the water table, taking into account possible further lowering of the water level (Figure 27a).

Place new piles between the foundation walls and / or pad and the top of the cutoff piles. Use piles of concrete or steel. Steel piles must be corrosion protected with plastic asphalt or concrete or have room for corrosion. Ensure that there will be an even distribution of the forces from the wall. The joints must be strong enough to ensure that the new piles will be rigid in terms of stress transfer. This can be done by pouring the concrete pad over the old piles (Figure 27 b-d).

28 Piling

281 General

Many piles and piling methods have been developed. When doing refoundation work it is often necessary to push down the piles or ram them down with a

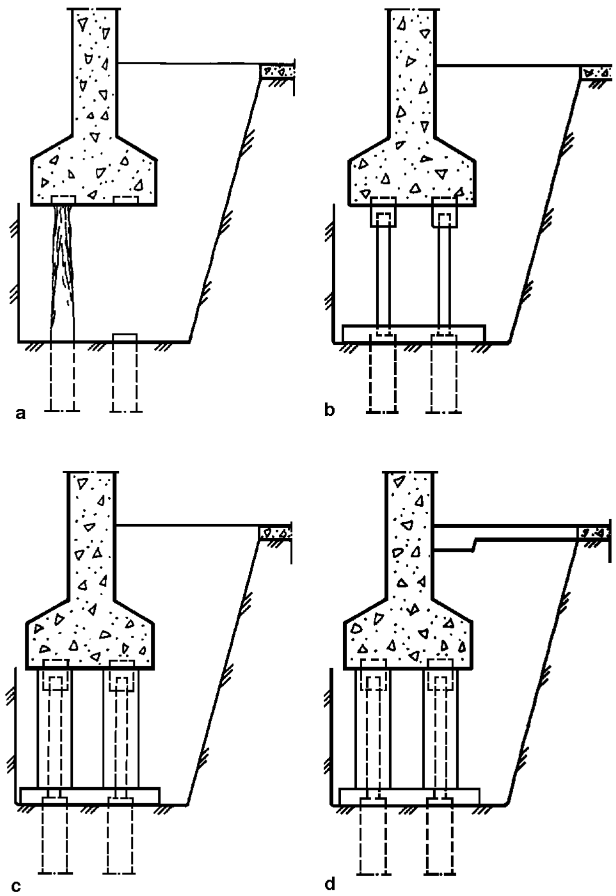


Figure 27
Repairing existing piles.

light air hammer. Another method is to install piles in drilled sleeves. Both pushing piles and ramming piles with a light air hammer requires that the soil is homogeneous. It is very important to look for solid mineral soil and rocks in the ground, to map the rock types, and to be aware of inclined rock surfaces. It is also very important to recognize alum shales and to know where erosive groundwater exists. Installing piles requires thorough technical evaluation and planning. For example, placing piles next to foundation wall, establishing a foothold, evaluating of rock bearing strength and straightness of the pile can all affect the success of the foundation. It is also necessary to take into account possible damage to the structure by excavation and reestablishment of loads. There are examples given of several pile types that can be used. Figure 282a to 282b.

282 Driven or rammed steel piles

There are several types of driven or rammed steel piles, including rolled steel piles, light, hollow steel piles, steel profiles, and steel pipe piles.

Use rolled steel with steel quality ST37 with variable cross section (i.e. 40 mm x 40 mm to 120 mm x 120 mm). The pile length should vary between 1.5 m and 2 m. The point on the pile should be hardened, axle steel. The piles can be spliced at each pile segment in the upper end and welded on a box of angle steel with a length of about 500 mm of which 250 mm should protrude above the top of the pile segment. There should be a clearing between the rolled steel segment and the sleeve of angle iron of about 1 to 2 mm. The sleeve can be centered in the length of the pile by wedging it with steel pieces. See Figure 282a. The sleeve is then filled with a small amount of epoxy and the next pile is mounted so that the epoxy flows out into the hollow space between the rolled steel piece and the sleeve of angle steel. The overlying pile segment is centered with steel wedges, and the sleeve is warmed up to about 40°C to get a rapid hardening of the epoxy. This type of pile is quite suitable for use with homogeneous soil conditions. The joint is not, however, particularly movement resistant, and because of the small surface area, the pile is not very sensitive to corrosion. The pile has, however, a relatively large load capacity. For piling work, the roof height in the basement should be at least 2.5 m; however, with short pile segments the room height can be as low as 2 m. The smallest distance from the wall to center of a pile should be 150 mm.

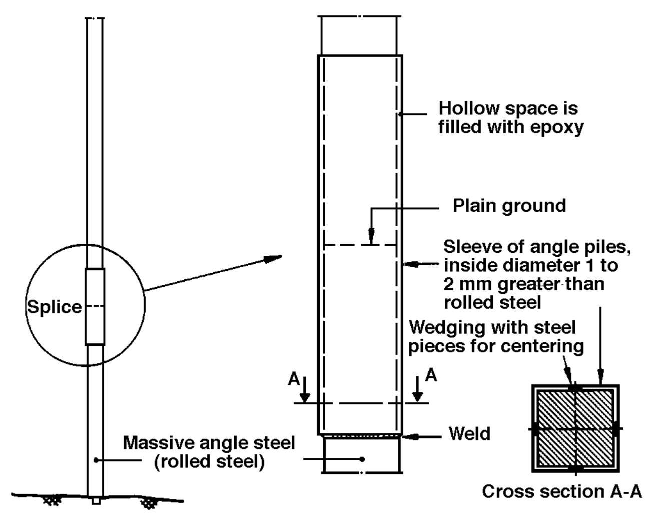


Figure 282a
Example on pile of rolled steel

There are numerous light hollow pile types on the market. An example is the steel plastic pile which has a diameter of 76.1 mm and a wall thickness of 4 mm. The steel quality is ST52. Externally the pile is rust protected with a 1.8 nicron thick layer of polyethylene. (Figure 282b). The pile comes with an epoxy treated pile edge. The top plate consists of a steel plate with a pipe welded on and fitted to the inner diameter of the pile. The joint consists of an concentric sleeve with a wall thickness of 3.65 mm. The sleeve is threaded in place by a layer of polyethylene on the joint. The polyethylene is fused at the adjoining pile ends by heating it up. The sleeve is heat-shrunk to 80 microns in thickness. After the pile is installed, the inside volume is filled with concrete. The pile is quite easy to handle. It can be driven with an air hammer and is easy to use under tight conditions. The hollow space inside the pile makes it possible to control its straightness. The joint must be set to be movement stiff. The steel cross-section is, however, only 950 mm^2, and the load capacity is, therefore, limited. The necessary height for the rig is about 2.1 m. The center pile should be placed 150 mm from the edge of the wall.

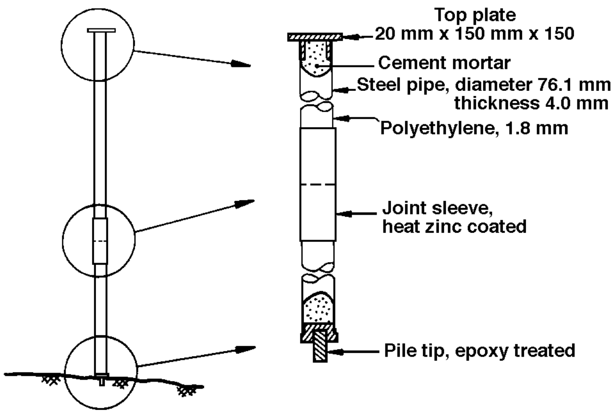


Figure 282b
Steelplastic Pile

There are many steel profiles in use. Streetcar and railroad tracks have been used with good results. A special profile is the so-called SW-steel pile which has a cross-shaped cross-section, which gives the pile a relatively large bending resistance with respect to the area. It is available in three sizes with cross-sections of 2,600, 6,100 or 8,100 mm^2. The steel quality is ST37 (see Figure 282c). The pile is provided with a pile point and a top plate of steel. The top plate is fixed, either with guide ribs or by welding, to the center portion of the pile. The pile is joined at each pile end, being welded to a steel plate so that the connection can be established with four bolts. The joint is relatively shear resistant. The smallest pile can be driven down with a light air hammer. The larger types demand a greater ram capacity. The piles are normally delivered untreated, and they

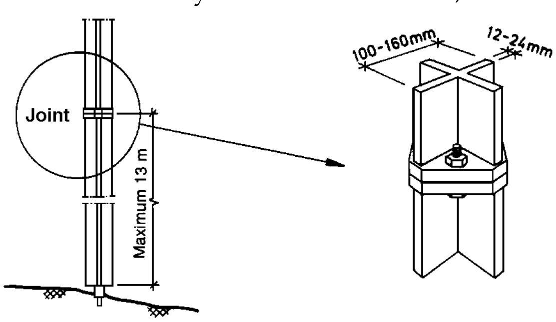


Figure 282c
SW-steelpile

will, because of their large surface area, be somewhat subject to corrosion.

The megasteel pile is a square steel pipe pile which is pushed down into the soil with a hydraulic jack while the soil mass is being flushed away from the edge of the pile. If the soil is difficult to hose away with water it can be drilled down through the pipe. The joints are made by welding. The piles can be pushed down and supported on solid rock or a small man-made concrete lump in the soil. In the latter case, the pipe is rammed to a desired level and concrete is pumped into the soil to create a massive bearing surface under the pile. This method can be used only in friction soils which can be penetrated easily enough for concrete to be injected. When the concrete has hardened and has full bearing capacity, the rest of the pile is filled with concrete. The pile can be dimensioned as if it consisted only of steel. The concrete protects against corrosion and should prevent bending. When calculating capacity, take into consideration the external corrosion and the danger of concrete breaking in loose soils (see Figure 282d).

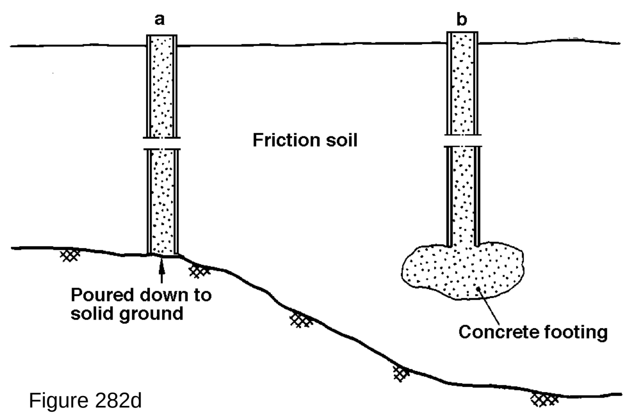


Figure 282d
Megasteel pile
a. rammed down to solid ground
b. with poured concrete foot

283 Pressed or driven concrete piles

There are two types of pressed or driven concrete piles: normal, joinable, prefabricated piles, and special piles.

Normal, joinable, prefabricated piles can be adjusted for refoundation work. They are useful when there is room to ram piles down on the outer perimeter of the building. Such piles can also be rammed or pressed down inside buildings. Because they have joints, the length of the pile element and the stress capacity of each pile must be calculated in each individual case.

An example of a special pile is the megapile which is rammed into place by hydraulic jacks. The building itself can be used as a counter balance. This method is often used on large buildings built on easily penetrable soil masses. The pile is usually square with a cross-section of about 300 mm. The length is about 1 m, but many lengths are available. The pile has a sentry hole, which makes it possible to control its direction during the placement process (see Figure 283).

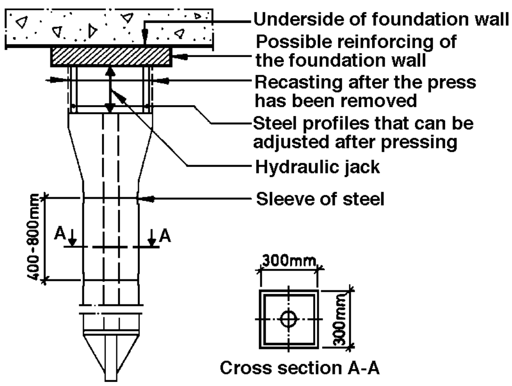


Figure 283
Megapile

Splicing can be carried out in several ways. A single sleeve around the joint will prevent twisting and eccentricity between the piles; a threaded steel pipe along the center of the piles with the joint will give adequate bending capacity; and rigidly mounted steel plates that can be welded together at the ends of the piles will give a joint that is resistant to movements, but they are quite expensive.

In silt or sandy soil the center hole can be flushed through with water or air pressure to aid in the driving process. There is also equipment available for predrilling in areas where there are large rocks and other obstacles in the ground. Downshafting underneath the foundation of the building normally provides resistance for pushing down of the piles. Normal excavation depth under the foundation is about 1.5 m.

284 Board piles

Two types of board piles are used, steel core piles and injected concrete piles. Steelcore piles are used in solid rock. The Lindo pile is an example. Because of its high price, it should be used only where large rocks and other obstacles in the ground make it difficult to press down piles without predrilling. The pile consists of a round steel core which is surrounded by concrete and covered by a sleeve (see Figure 284). The diameter of the steel core varies between 50 and 100 mm with a steel cross-section between about 19.60 and 78.50 mm square. The steel quality is ST50 enabling the load capacity to cover a wide area. An eccentric drill bit is used to drill the steel pile down to solid ground. The pipe is drilled down into bedrock a small distance so it will have a good seat. Pipe length can be 1 to 3 m, depending on how much height one has to work with. Different pipe lengths can be screwed or welded together.

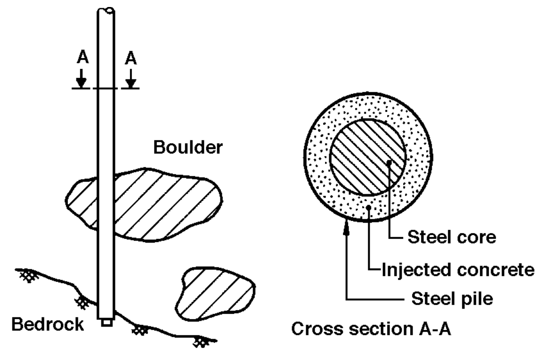


Figure 284
Lindo pile

After the pipe is in place is filled with concrete mortar. The concrete will corrosion-proof the bearing element in the pile. The core consists of massive steel rods in suitable length which are being spliced together with welds or threaded sleeves. The rods are placed immediately after pouring of the concrete. There are special machines for boring in narrow and low rooms.

Injected concrete piles are used as friction piles in circumstances where the load is carried down to bearing soil layers. An example of such a pile is the so-called root pile, which is used in Sweden and elsewhere in Europe. This pile uses an aggregate with a 1.8 m work height and is drilled down 1 m using spliceable steel piles. The bottom pipe is connected with a large powerful shear ring. Loose material is transported upwards while the pipe is being bored by a spray of bentonite or water under high pressure. When the desired pile depth has been reached, prefabricated reinforcing baskets are sunk and welded as they come down into the tube. An aerated concrete is then poured down into the pipe through a hose, as with conventional underwater pouring. A closed lid is mounted on the top of the pile and the concrete is pressurized. Finally, the pipe is pulled up in sections as the tube pile is locked and the concrete is pressurized. This assures that the pile will adhere well with the surrounding soil and provide a high carrying capacity.

285 Other piles. Wooden piles and wing piles are also useful with refoundation work

Unfortunately, wooden piles must be completely submerged to keep from rotting. If wood is exposed to variable humidity above the groundwater table, it will rot very quickly. However, for certain kinds of buildings such as piers and houses that are next to the sea, wooden piles are still the best type of foundation. Wooden piles are inexpensive, but they should be straight and they must be prepared well. The bark must be removed and branches cut off close to the trunk. The top diameter must not be less than 150 mm. The pile is driven with the top down. It is important to use piles impregnated with preservative, such as creosote. (See Figure 285a).

In Sweden, a cohesion pile has been developed which consists of a relatively thin steel pipe with long longitudinal ribs. The length of the piles joined with the sleeve can vary according to building conditions. Figure 285b. The advantage of a cohesion pile lies in its great bending resistance and its cohesive surface qualities with respect to the displaced soil material. Driving is done with a light air hammer or vibration hammers. There is, however, little experience with this system.

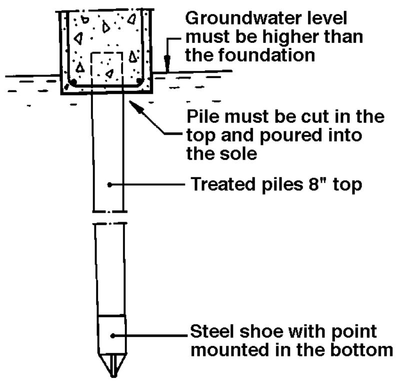


Figure 285a
Example of wooden pile

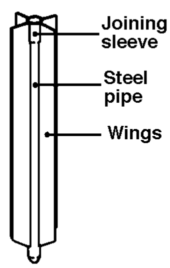


Figure 285b
Wingpile

286 Load transmission

Load transmission from pile to structure can be arranged in several ways. One method is to dig under the foundation wall and place the pile directly under the foundation wall. The forces from the structure to the pile will then be transmitted directly or via a board cap on top of the pile. (Figure 286a). Another method of load transmission is through slits in the foundation wall and/or the foundation. The pile is placed inside the slit and concrete poured around it. The forces from the building are transmitted to the pile by cohesion forces. The same principle can be used with piles installed in bored holes using heavy construction foundation plates. (Figure 286b).

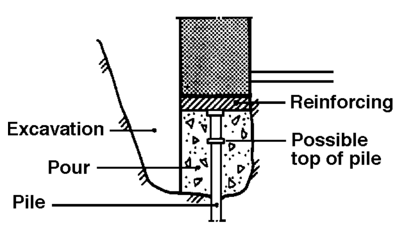


Figure 286a
Direct load transmission under foundation wall

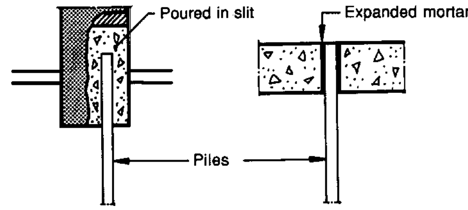


Figure 286b
Load transfer by slit in foundation

Load transmission can also be accomplished by a pile, or piles, placed on either side of the foundation wall. A beam (i.e. a steel beam with concrete) placed over the piles and in direct contact with the lower portion of the foundation establish a beam which will transmit the load to the pile (Figure 286c).

Piles can be driven on either side of the foundation wall for load transmission. A beam is poured on either side of the foundation wall over the piles. The load from the foundation wall to the concrete beam is transferred by cross beams (i.e. poured steel beams or ties). The force in the ties should be checked to be sure that the friction is sufficient (Figure 286d).

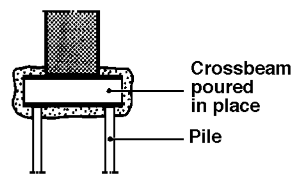


Figure 286c
Load transmission
via cross beam

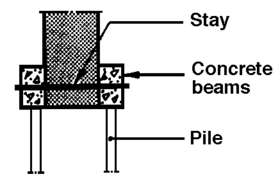


Figure 286d
Load transfer via
longitudinal beams

29 Replacement of material

Around buildings where there is consolidation settling, it is possible to replace existing fills with lighter fills such as lightweight concrete or sawdust.

3 REFERENCES

31 This bulletin has been developed by Knut I. Edvardsen, Norwegian Building Research Institute. Svein Bjorberg, Multiconsult A/S and Arne Nesje, Mur-sentret. Rolf Hauan, Engineers Bonde & Co. and Bjorn Finborud, NOTEBY have been consultants.

The editing was completed September 1981.

32 Literature

321 Translated into English by Nils Johanson and Richard D. Seifert, University of Alaska Fairbanks, 1989.

Chapter 5
Walls

Key Points to Learn

Some of the considerations for designing and building walls are:

- Walls can be made from lumber, logs, steel studs, even straw bales.
- Walls must hold up the roof even in an earthquake, with snow on the roof.
- Walls keep the weather out and heated air in.
- A continuous vapor retarder is very important to prevent moisture damage inside walls.

Exterior walls are usually the most visible component of a house. As such, walls have been the subject of considerable study by architects, building scientists, contractors, and designers. Walls perform many important functions: they hold up the roof, keep the weather outside, and hold conditioned air inside. Walls also serve to tie the roof to the foundation to resist wind uplift and earthquakes. Design and build your walls to survive an earthquake in a windstorm with tons of snow on the roof.

Better Walls

In the 1970s, some visionaries saw oil reaching $1.00 a gallon and began to explore ways to superinsulate a home. Many homes were built with double stud walls 18 to 24 inches thick (Figure 5.1), filled with cellulose or fiberglass or even sawdust. The roofs and floors were also superinsulated to R-60 or more. The pros of this wall are that any thickness of wall can be built, they are very strong, and they have good nailers for siding and drywall. The cons are that they use much more labor and materials to build.

Some of these homes continue to work well today, but many failed because of inattention to airtightness and to inadequate ventilation. Today's better-built homes don't rely on such massive amounts of insulation. Instead, safe, healthy, durable, energy-efficient homes are constructed as a system, employing optimal insulation combined with highly efficient space and water heating devices and effective ventilation equipment within an airtight thermal envelope. Walls are an important part of this system.

All six sides of a house—the floor, four walls, and the roof—must work together as a system to prevent the flow of heat, air, and moisture into or out of the building. A wall must be designed and constructed to keep all wood, insulation, and inside and outside sheathing dry. If any of these building components do get wet, they must be able to dry out quickly to avoid problems with mold, rot, or lowered insulation values. Wet insulation will allow studs and sheathing to cool below the dew point temperature and result in water vapor in the air condensing in the wall. Liquid water increases in the wall cavity in the winter and freezes on the backside of the exterior sheathing. When outside temperatures warm up, the ice or frost melts and liquid water runs down the

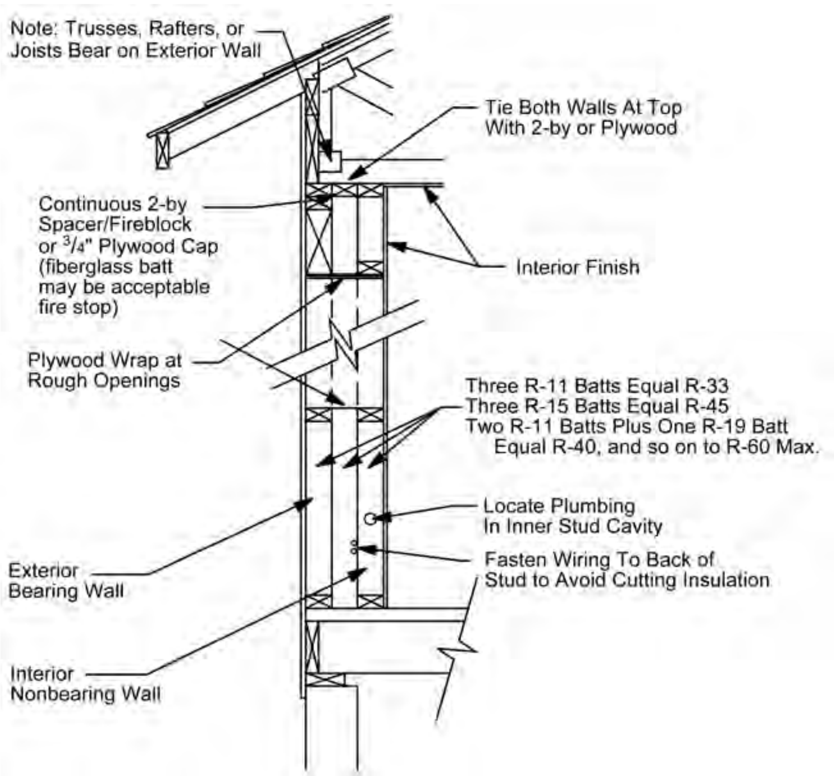


Figure 5.1: The double-stud wall option is returning to the list of desirable options for highly insulated walls. It had been less popular in the late 1990s because it is more labor intensive than a single stud wall, and cross-hatch framing with 2x6 walls can yield R-values in excess of 30 (see CES publication EEM-00954, "Effects of Studs on the Heat Loss and Insulation Value of a Wall," included as an appendix of this "Walls" chapter.)

wall to the bottom plate where it begins to rot the wall from the bottom up. At the same time mold may be blooming on the backside of the Sheetrock and also on the inside surface where structural components were cooled to below the dewpoint temperature (Figure 5.2). This is often manifested as vertical black lines on 16 or 24-inch centers on the wall sheetrock or in corners that aren't perfectly insulated. Parallel lines are often seen on the ceiling Sheetrock where rafters have cooled and promoted condensation and mold growth. So how do we build a wall that is durable, resource efficient, and mold free?

Figure 5.2: Mold on interior walls on an outside corner of the house.

First The Transitions

Making the connections between floor framing and walls, as shown in Figure 5.3 (also in Figures 4.30 and 4.31 in the Foundations chapter) is an often poorly executed detail. Shown in Figure 5.3 is a meticulous solution that is advised for all situations. Commonly plastic foam is sprayed onto the rim joist in most new construction as this option is fast and covers the area easily. This is shown in Figure 4.30 (previous chapter). Use of any combustible foams in this location requires that the surface be protected with gypsum board fire protection or other adequate fire resistant surface.

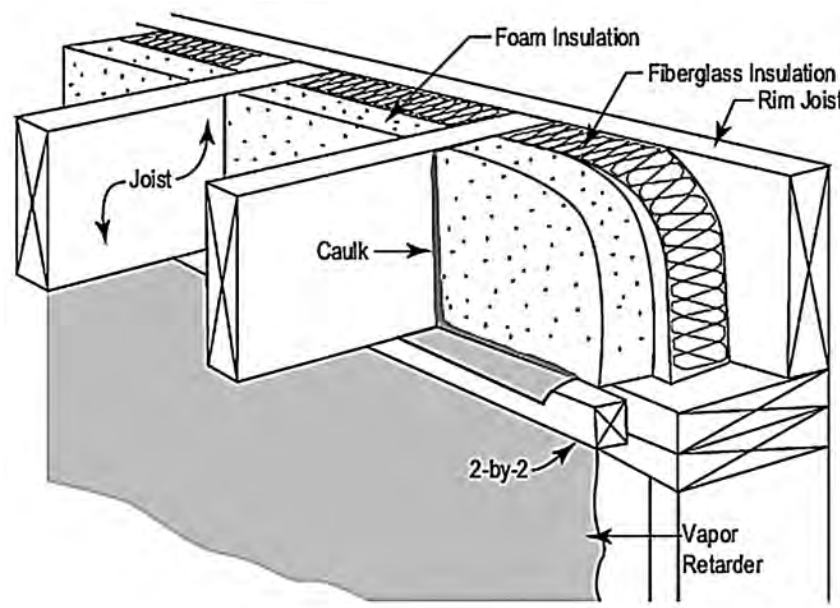
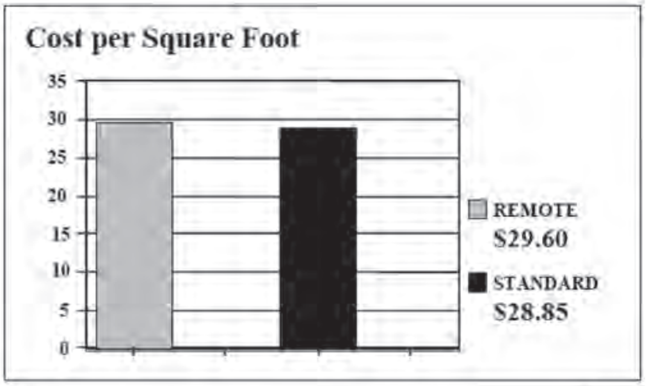


Figure 5.3: Sealing the Rim Joist.

REMOTE Walls

In the 1970s we made our walls thicker either by building double-stud walls or by using 2 x 6 or 2 x 8 studs on 24-inch centers to accept thicker fiberglass batts to achieve higher R-values. At the turn of the 21st century, a few builders in Alaska modified the PERSIST wall design developed by Canadian building scientists and came up with the REMOTE wall system (Residential Exterior Membrane Outside insulation TEchnique). In the REMOTE wall system, all wood sheathing, 2 x 4 studs and 2 x 4 plates, rim joists, and headers are on the warm side of the thermal envelope (Figures 5.4 through 5.6). All of the wood components in the REMOTE wall system remain warm and dry and never reach dew point temperature. Since the vapor barrier and most of the insulation is on the



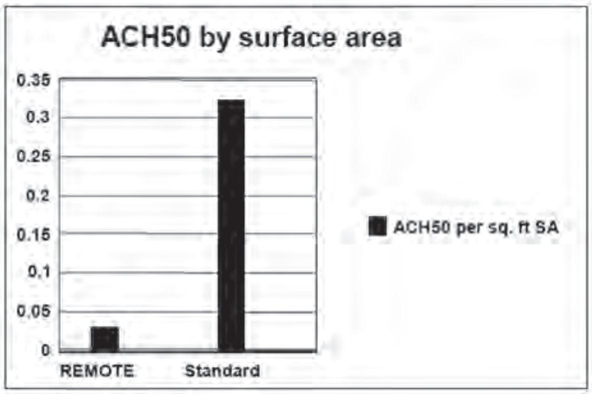


Figure 5.4: Source for above graphics: Maxwell, Robert. "The REMOTE Wall System." Published by Cold-Climate Housing Research Center, October, 2005.
Note: ACH50 is air changes per hour at 50 pascal pressure difference. This is a standard way of measuring air infiltration.

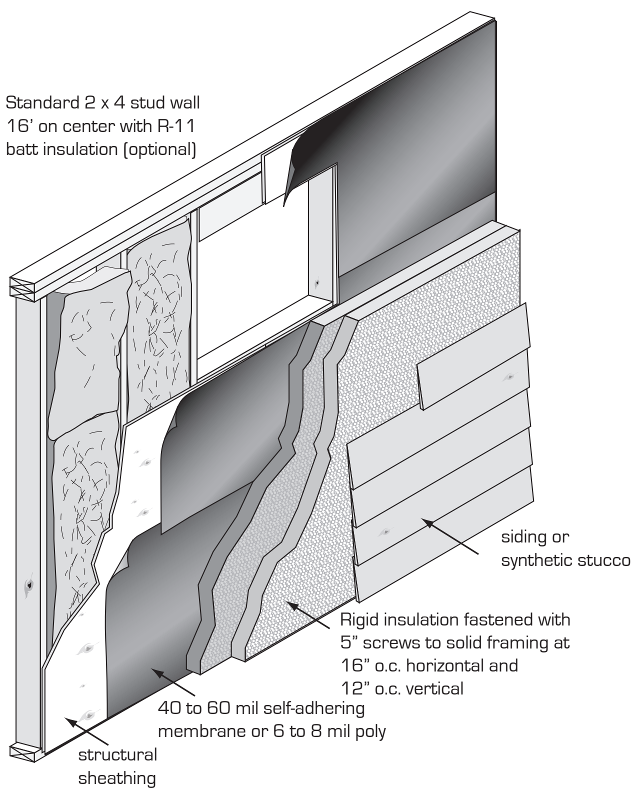


Figure 5.5: A REMOTE wall cutaway view

outside of the structural sheathing, 2 x 4 wall studs are usually sufficient to hold up a standard-sized residential house.

The REMOTE wall construction sequence is as follows: Snap a chalk line on the sub floor 4 inches in from the edge. Lay out the top and bottom 2 x 4 plates on either 16 or 24 inch centers as required. Consider advanced framing or optimum value engineering framing techniques to reduce the amount of materials used in the wall system. Toenail the bottom plate to the sub floor with the bottom, outside corner of the plate just touching the chalk line. Nail the 2 x 4 studs to the top and bottom plates. Square the framed wall with identical diagonal measurements from corner to corner. Tack the top plate to the subfloor to hold it while attaching structural sheathing. Cut out window openings 3 inches larger than factory-specified rough openings. Install 2-x window bucks ripped to flush out with the anticipated exterior insulation thickness. For example, if two layers of 2-inch-thick rigid foam insulation are specified, the window bucks must extend 4 inches beyond the sheathing plus the thickness of the exterior siding system. For a synthetic stucco system, 4 ¼ inch is added to the 4-inch wall thickness of ½-inch siding and 2 x 4 studs, resulting in window bucks 8 ¼ inches thick. If furring strips are part of the wall siding system, the total thickness must be added to the rough window bucks.

With the framed and sheathed wall still lying on the floor, carefully apply 40 to 60 mil thick peel and stick membrane to the sheathing. Leave several inches of membrane sticking below the bottom plate with the protective paper still attached. Tack it up to the wall to later be folded down to attach to the membrane covering the foundation and rim joist. Leave a similar tab of membrane at the top of the wall to later fold over and down the inside face of the top plate. The ceiling vapor barrier will be attached to this tab. Start with short pieces of peel and stick membrane because it takes practice to get it on the wall straight without sticking to itself or to your body. Wrap the entire wall including up, over, and into the window bucks. Start at the bottom and work your way to the top, overlapping shingle-like to promote drainage of any water that makes its way through the siding and insulation system.

After the membrane is on, the wall is lifted up and nailed in place. The first layer of 2-inch EPS rigid foam insulation is attached by special 3" win lock screws with plastic washers into the studs. A second layer of foam is attached with appropriate length screws with all horizontal and vertical joints staggered. At this point furring strips are attached through the foam into the studs with long screws. Siding is then attached to the furring strips. Another option is to finish with a synthetic stucco system per manufacturer's instructions. Proper flashing is a critical component of any wall system. Drain the rain quickly away from the house or into the cistern.

There are dozens of wall systems that have been built to code and found wanting in one aspect or another. The Cold Climate Housing Research Center, in cooperation with the University of Alaska Southeast Construction Technology Center in Juneau, is currently testing the performance of wall systems. The first year of monitoring data suggest that the REMOTE wall system is ideally suited to southeast Alaska. The REMOTE wall panel was the only one of nine test wall panels to show a drying trend over the year of data logging. Eight of the nine panels increased moisture accumulation. Further tests of several different REMOTE wall systems are under way in the CCHRC Mobile Test Lab operated by UAS. The Tlingit-Haida Housing Authority is building several single family and multifamily homes in Southeast Alaska. Preliminary results indicate that these homes are performing well. Several homes have been built in the Fairbanks area using the REMOTE system with positive monitoring results.

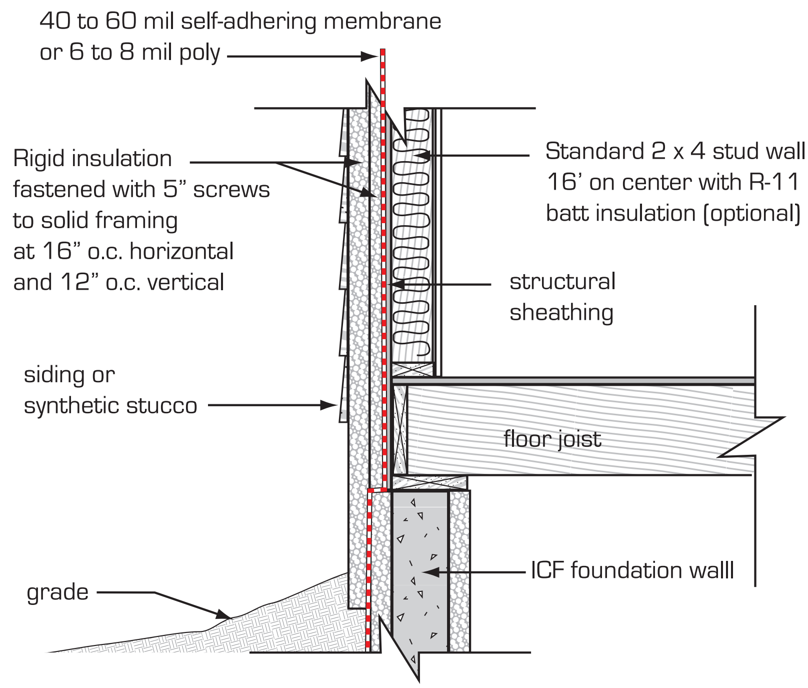


Figure 5.6: REMOTE wall construction and connections to the foundation.

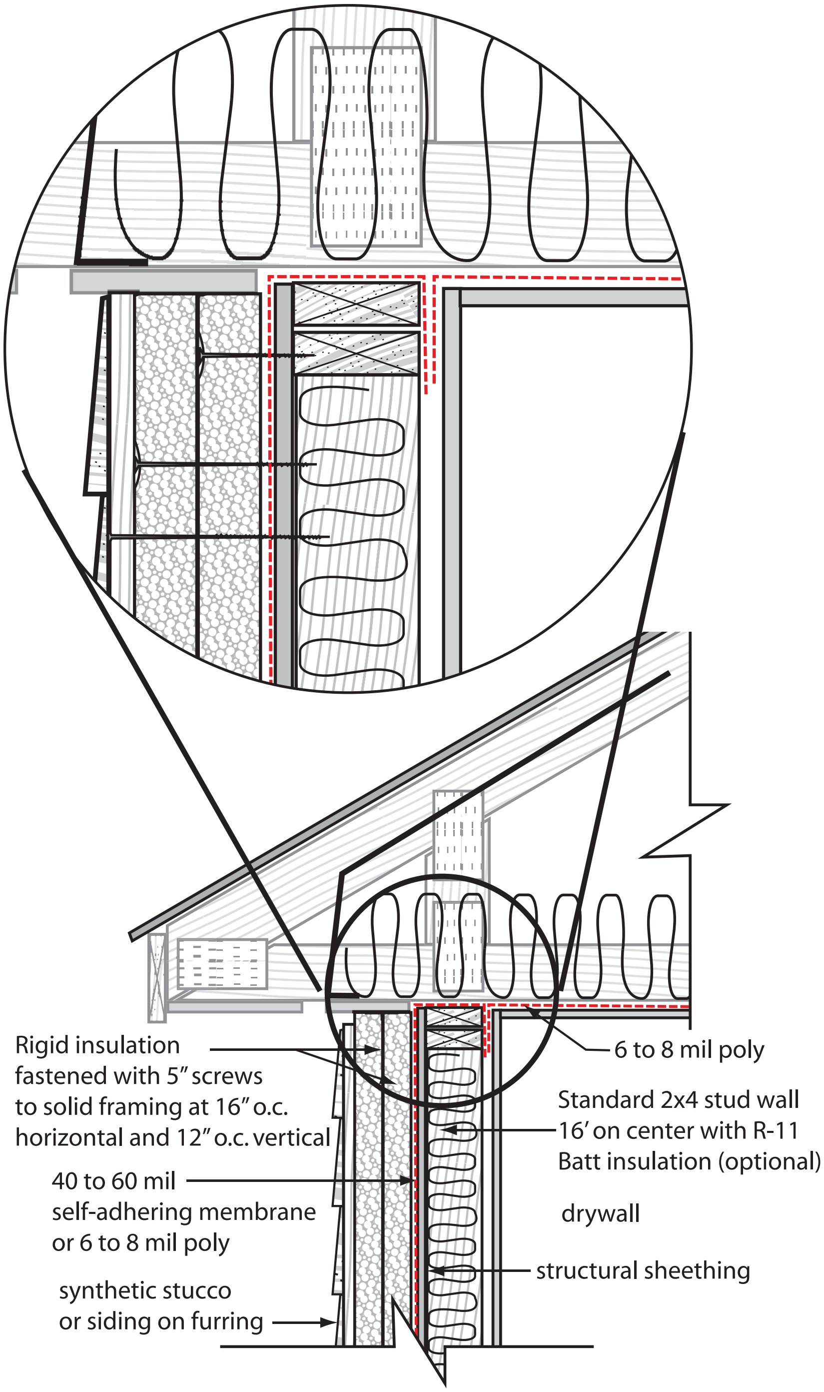


Figure 5.7: The top of a REMOTE wall. Top shows detail of wall-to-roof connection.

Advanced framing techniques or Optimum Value Engineering (OVE)

Framing a house represents about 15 to 20% of the total cost of a typical home. In most home building projects, little or no thought is given to efficiency during the wall framing process beyond the selection of the width of the lumber used. Wood stud walls are typically designed only to serve the basic needs of a wall, including supporting the roof, providing openings for doors and windows, and making a space to house insulation. However, with an eye to efficiency, waste can be reduced, total amount of buildings materials can be decreased, thermal bridging to the outside can be reduced, framing can go quicker, and the strength of the walls can be improved.

Much research has been done to try to make walls more efficient in a number of ways. Optimum Value Engineering or Advanced Framing takes into account many issues that builders face when constructing a wall, and tries to make a more efficient wall that takes less materials and less time to build. Advanced framing has been tested and proven to improve cost and efficiency in building projects. The typical advanced framing project can result in materials cost savings of about $500 or $1000 (for a 1,200-and 2,400-square-foot house, respectively), labor savings of 3-5%, and heating cost savings of around 5%. Not all of these techniques may be available to you. Check your local building codes for requirements before making use of these techniques. High seismic areas or high wind loading may necessitate greater structure than some of these techniques allow.

Cost Comparison - Fairbanks

Cost Comparison of Conventional Construction for the walls of a 32’ x 56’ single story house			
Conventional Construction		REMOTE Construction	
Component	Cost	Component	Cost
2x6 stud* (175 @ $4.55)	796	2x4 stud* (175 @ $2.93)	513
R-21 batt insulation (effective R-18)	964	4.5” EPS foam sheathing (effective R-18)	993
6 mil polyethylene	58	Bituthane	861
2x6 plates	295	2x4 plates	197
Tyvek	186	Furring	132
TOTAL - conventional	2299	**TOTAL** - REMOTE	2696
*Vert. lumber est. at 1/ft		Incremental	397

Cost Comparison - Juneau

Cost Comparison of Conventional Construction for the walls of a 32’ x 56’ single story house			
Conventional Construction		REMOTE Construction	
Component	Cost	Component	Cost
2x6 stud* (175 @ $4.59)	803	2x4 stud* (175 @ $3.19)	558
R-21 batt insulation	893	3” EPS foam sheathing	662
6 mil polyethylene	64	Bituthane	1152
2x6 plates	295	2x4 plates	197
Tyvek	184	none	0
TOTAL - conventional	1944	**TOTAL** - REMOTE	2534
*Vert. lumber est. at 1/ft		Incremental	590

Figure 5.8 & 5.9: Cost comparisons are provided from Robert Maxwell’s report on REMOTE walls. Comparisons are a rough guide only, and are merely provided to show that building using REMOTE is more expensive than standard construction. Whether the benefits of REMOTE are worth the extra cost is left up to the reader.

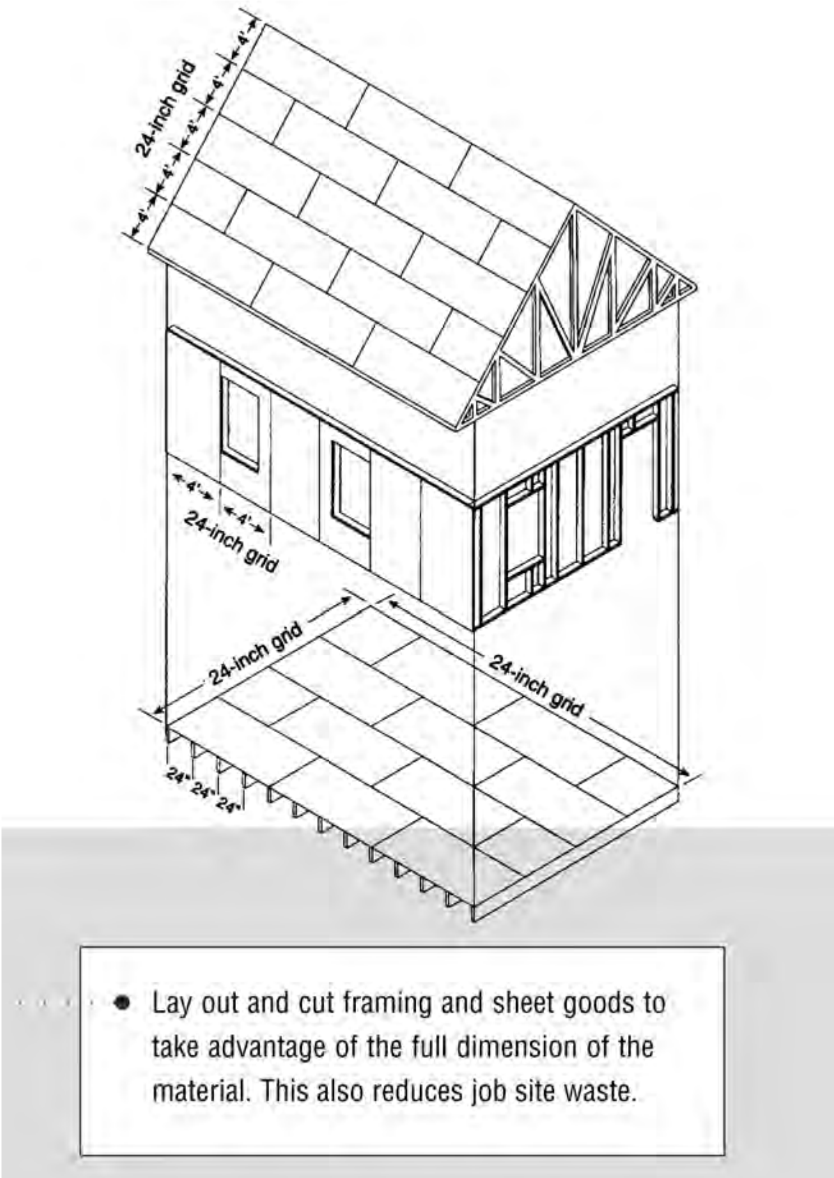


Figure 5.10: Modular design. Above image adapted from Building Science Corporation's Guide to Cold Climates.

OVE will be discussed in this section with an eye to a do-it-yourselfer who wants to build more efficiently. If the builder is experienced in standard wall framing, however, one or more projects may be needed to get used to the techniques of OVE framing and realize the full time savings benefit of these techniques.

Design homes on 2-foot modules

When building a house, it is faster and easier if you can use standard lumber sizes without having to make a lot of cuts. Since most building materials come in even sizes, it will save many scraps of lumber, plywood, drywall, etc. if the house is designed with building materials in mind.

Increased stud spacing and stack framing

Increased stud spacing is a good way to reduce the amount of wood in your walls. Increasing 2x4 stud spacing to 24" is acceptable in most cases, except when using #3 (utility grade) studs. When a wall is supporting both a roof and a floor, a 2x6 minimum stud width on 24" centers is required. Reduced wood in walls makes more room for insulation (wood is NOT good insulation!). See the CES publication Thermal Properties of Typical Wall Sections at the end of this chapter.

Wider stud spacing comes with some responsibilities, however. Since there are less studs in the wall, more care must be taken to line up the studs in the wall with the roof rafters or trusses or the floor joists. This introduces the idea of stack framing.

The picture in Figure 5.11 shows the basic idea of stack framing. That is, rafters or trusses should sit directly over the studs in the wall. Additionally, a structural rim joist must be used (e.g., rim board, not a TJI, BCI, or any wooden I-beam) in order to transfer the point loads from the rafters to all of the studs in the wall.

Lining up studs with load-bearing members above them means that a single top plate may be used because the header will not be relied upon to distribute the load to other studs. This means more insulation can be used at the critical wall/ceiling/floor transitions, and reduces the possibility of icing, mold, and damage to the building. However, a special top-plate connector must be used for wall stability.

Headers are not typically needed in non load-bearing walls. Using headers should be reserved for load bearing walls, and should not be oversized. A table on the approximate headers needed for a specified opening (including doors) is included below. The IRC (international residential code) supplies a more detailed explanation of headers necessary for a given wall opening. However, for most houses with window openings of two feet or smaller in width, a double 2x4 header is sufficient. In all header situations, rigid insulation (foam) should be used to insulate between headers, where possible.

Studs as attachment for drywall

Many builders add extra studs for drywall nailers. For the reasons described above, 2x2 nailers may be used instead of 2x4 studs, and inexpensive drywall clips may be used to support drywall edges instead of expensive, space-consuming studs. See diagrams in Figure 5.14 for proper drywall management.

Note on energy-efficient building in Alaska

Unless foam is to be used on the inside or outside of the wall enclosure, a stud wider than 2x4 should be used. 2x6 studs are a good option, and 2x6 framing on 24" centers uses roughly the same number of board-feet of lumber as 2x4 framing on 16" centers. For most projects, if you decide on 2x4 framing for your walls, it is possible to increase the spacing between studs to 24". In almost

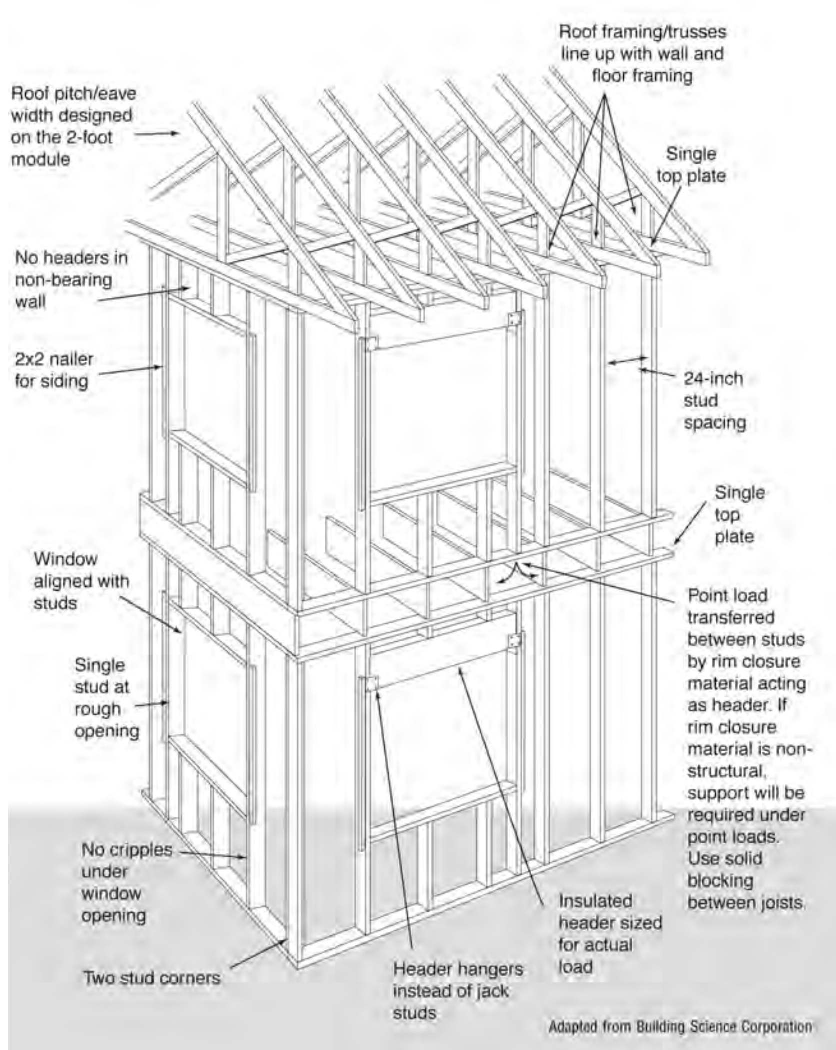


Figure 5.11: Single wall 2x4 stack framing. Notice how the entire structure is aligned. Using this technique, less lumber can be used while maintaining the structural integrity of the building.

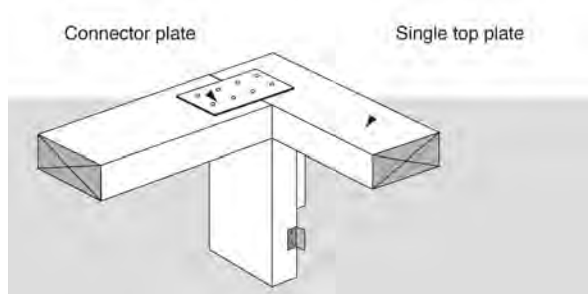


Figure 5.12: Single top plate connector detail. Note that a metal inline connector must be used. Picture adapted from Building Science Corporation.

Maximum Spans For Two-Inch Double Headers (in feet)[a]				
(Derived from Table 602.6 of the 1995 International Code Council's One- and Two-Family Dwelling Code)				
Header Size	Supporting Roof Only	Supporting One Story Above	Supporting Two Stories Above	Not Supporting Walls Or Roofs
2x4	4	0	0	b
2x6	6	4	0	b
2x8	8	6	0	10
2x10	10	8	6	12
2x12	12	10	8	16
a Also applies to nominal 4-inch single headers. Based on No. 2 lumber with 10-foot tributary loads. Not to be used where concentrated loads are supported by headers.				
b Load-bearing headers are not required in interior or exterior walls. Single flat 2-inch-by-4-inch members may be used as headers in interior or exterior nonbearing walls for openings up to 8 feet in width if the vertical distance to the parallel nailing surface above is not more than 24 inches. For such nonbearing headers, no cripples or blocking are required above the header.				

Figure 5.13: Span table for sizing window and door headers. Sizing headers correctly leaves sufficient room for insulation and saves lumber.

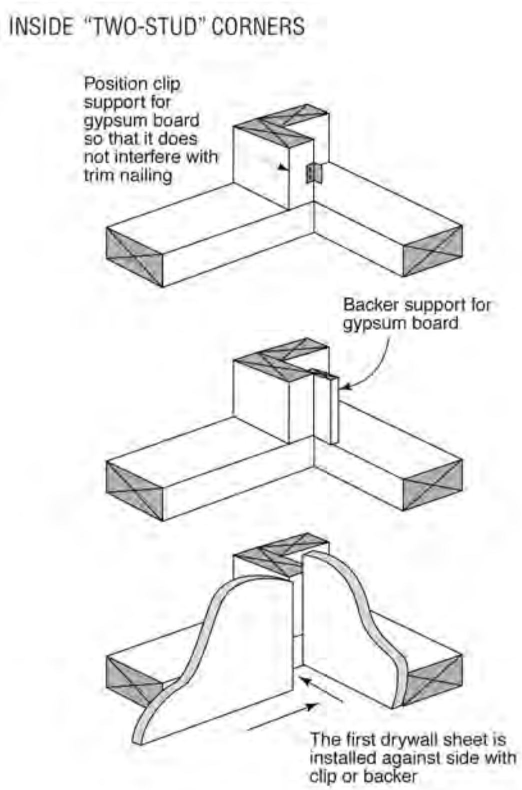


Figure 5.14: Inside two-stud corners are just as easy for hanging drywall, and they use less lumber. Drawing adapted from Building Science Corporation.

all cases 24" centers are possible with 2x6 construction. Again, be sure to consult local building codes and/or an engineer before starting your house project.

Log Walls

Other wall systems to consider are log or timber-frame construction. Large, natural logs of one to two foot diameter, grown locally and sustainably harvested make comfortable, healthy, durable, affordable homes (Figures 5.15 & 5.16).

There are a number of good books on timber framing. A remote wall system would work well with timber-frame or post-and-beam structures.

Structural Insulated Panels

Many good homes are being constructed with structural insulated panels (SIPs) some of which are made in Alaska (Figure 5.17). The main issue to address with SIPs in Alaska is to prevent interior moisture from migrating into the joints of the structural insulated panels. Seal all joints in the floor, walls, and especially the ceiling absolutely water-vapor tight. Use a polyethylene vapor retarder on the warm side or do a perfect job of air sealing the panel joints with sealants and gaskets recommended by the manufacturer. Remember, if a blower door test can pull outside air through the joints between panels, then warm moist air will travel via convection into the roof assembly first and eventually into the walls and floors. Then OSB sheathing on both sides of the rigid insulation panels will compost into mush in the ideal moisture conditions of a leaky hot roof.

Foam Panel Construction

Foam panel construction is an attractive alternative to "stickbuilding" a structure on site. Panels up to 40 by 10 feet can be barged to the building location, but the usual wall panels are four by eight feet. Floor and roof panels are sized according to span requirements and available lifting equipment in the field. R-values range from a low of about R-13 for a 3 ½-inch thick panel insulated with expanded polystyrene to more than R-60 for a 10-inch thick panel filled with urethane foam.

Foam panels are manufactured by several companies, and each has its own proprietary glues and foam insulation, resulting in different structural and insulating properties. Some panels are structural in the sense that they do not require additional framing to carry design loads. Other panels are nonstructural and are meant for sheathing post-and-beam or similar structures.

Each panel company has a system of joining panels that must be sealed with caulk, glue, or gaskets. Of the 15 or so panel structures blower-door tested by the authors, only one did not have some air leakage between panels. This one

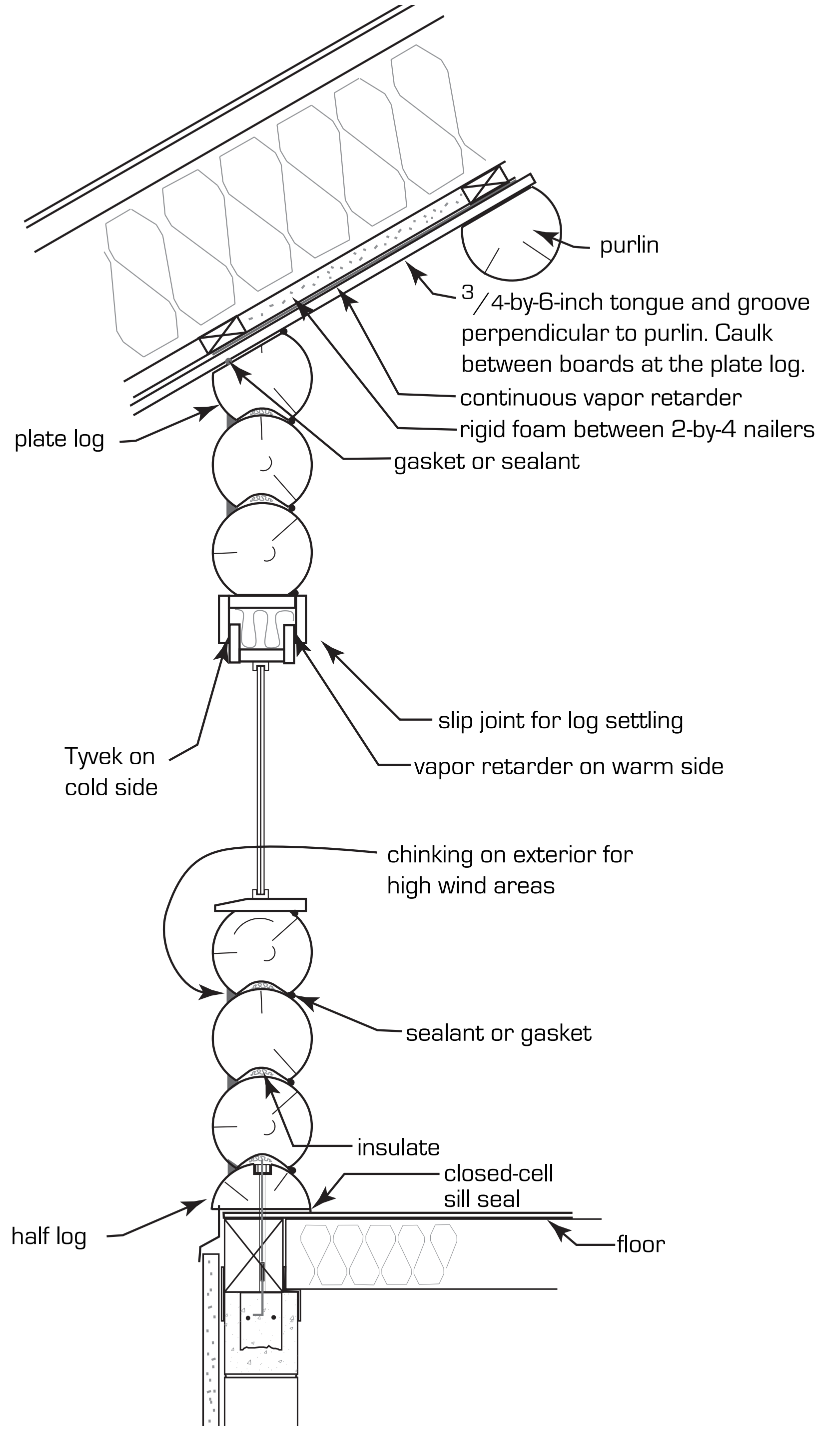


Figure 5.15: Important air sealing details for a round log wall.

super-tight panel structure had a continuous six-mil air/vapor retarder, and the walls were strapped with two-by-threes to provide a chase for electrical wiring on the warm side of the vapor retarder. Another foam panel house tested, which had the electrical wiring run in chaseways provided by the manufacturer, had considerable air leakage through all of the outside wall electrical outlets. The wires were run up through the rim joist space, which was not sealed tightly to the exterior.

Most panel manufacturers do not require a separate air/vapor retarder, since the foam and sheathing used in their products are resistant to moisture damage. However, we recommend that you install an airtight six-mil polyethylene vapor retarder on the warm side of the panels to keep all moisture out of the exterior walls and ceiling. Water freezing between panel joints could lead to premature failure of the structure.

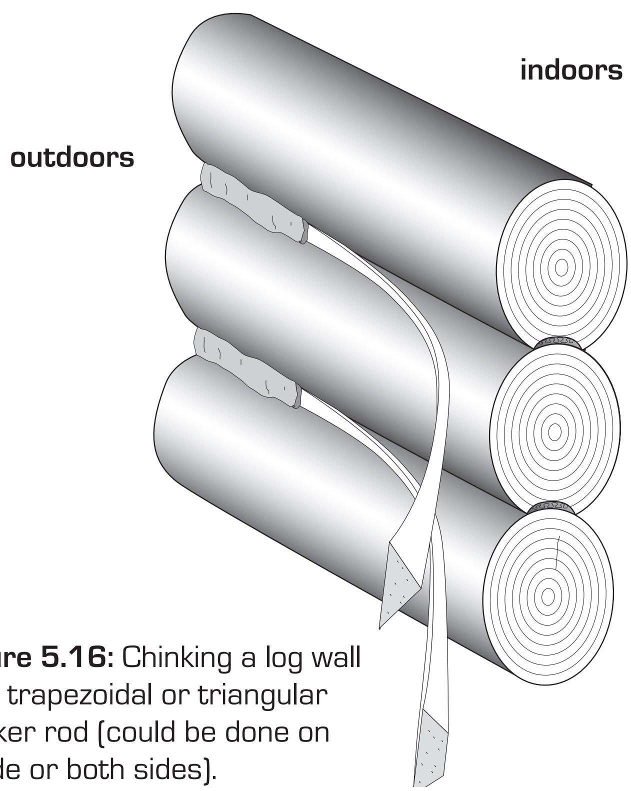


Figure 5.16: Chinking a log wall with trapezoidal or triangular backer rod (could be done on inside or both sides).

One of the problems with closed floor systems like foam panels is there is no room to easily run plumbing, heating, ventilation, and electrical systems. Some designers have gotten around this by installing nonstructural joists on top of the foam panel floor system to provide space for utilities and for additional insulation if necessary. Put an insulated arctic chase or insulated corrugated pipe beneath the floor to protect incoming water and outgoing waste water.

Alternative Wall Systems

A number of straw bale structures have been built in Southcentral and the Interior. Some were built REMOTE style with the straw bales outside of the vapor barrier membrane. Long eave overhangs are essential for keeping the straw bales dry.

A green builder in Palmer built a sturdy post and beam structure of locally harvested spruce poles and sawed spruce timbers. He insulated with straw bales harvested locally. This beautiful, hand-crafted home is constructed mostly of locally harvested materials. Photovoltaic panels, a small portable gas generator, and a wind generator power the house entirely.

A single stud wall with interior foam added is yet another wall option. Further details on this option are shown in the CES publication, EEM-954, "Effects of Studs on the Heat Loss Value of aWall," which is included at the end of this chapter. An example of this wall type is shown in Figure 5.19.

Advantages are: – less lumber used than in a double frame wall, – less consequent labor to assemble, – reasonably good R-values of insulation are achievable (~R30).

Disadvantages are: – some limit to insulation levels, – protection of vapor barrier integrity is slight harder, – some

Figure 5.17: This house is being built using structural insulated panels on both walls and roof. The panels are test fitted (top) then laid back on the ground (bottom) and the drywall is placed against the timber frame, then the polyethelene vapor retarder is hung outside of this. Finally the SIPs are replaced. This makes it much easier to install interior drywall against the outside of the timber frame.

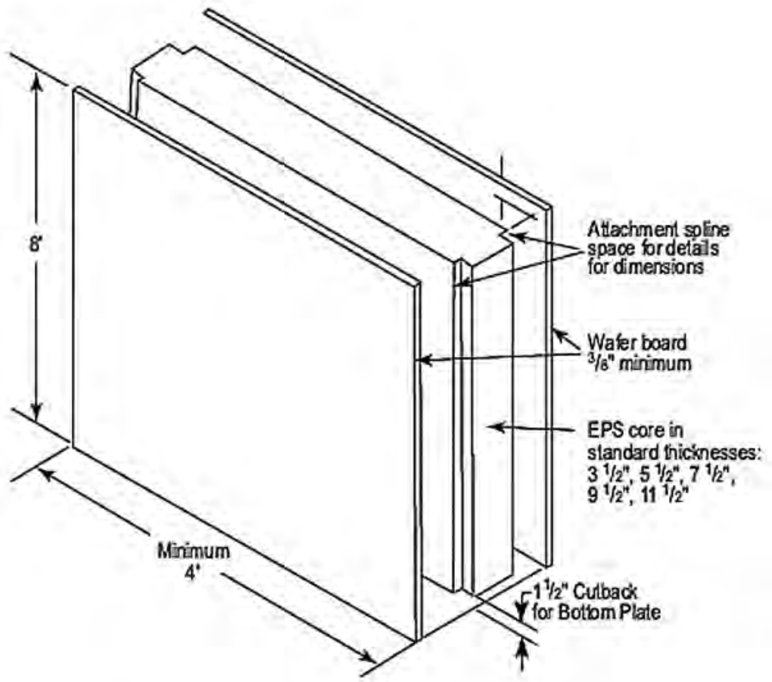


Figure 5.18: EPS Panel for Use as Structural Wall.

through-the-wall thermal bridging is more likely.

Construction Sequencing

Subfloors above unheated crawl spaces or in buildings constructed on pilings should be airtight with all joints in the sheathing sealed with waterproof adhesive. The underside of insulation should be protected from wind intrusion with a weather retarder house wrap of spun-bonded polyolefin or polyester or microperforated polyethelyne (Tyvek®, Barricade®, Typar®, or other brands). Where beams support the floor joist system, house-wrap tabs should be placed over the beams and later integrated into the building weather retarder to provide continuous coverage. The underside of the insulation and the house wrap should also be protected from physical damage with plywood attached to the underside of the floor joists.

Vapor Retarder Installation

Bottom plates of exterior walls should be caulked or gasketed. The framing contractor must be sure that all exterior wall corners and partition intersections are fully insulated and maintain the vapor retarder system. The framers should install insulation and polyethylene behind stair framing, tub enclosures, and other areas that will be very difficult or impossible to get to later. Plumbers must be sure that water pipes are installed on the warm side of the vapor retarder and that all penetrations pass through solid backing so that an EPDM gasket can be installed and caulked to the vapor retarder to minimize the flow of heat, air, and moisture into attics or crawl spaces. Electricians should install the distribution panel on an interior partition. This results in only one hole through the thermal envelope and will not compromise the exterior wall insulation. All switch boxes, wall outlet boxes, and ceiling light boxes must provide for continuity of the vapor retarder.

Some builders complete the entire shell, including insulation, vapor retarder, and ceiling drywall, before installing interior partitions. In Alaska where it is always a race to get heat in a building as quickly as possible, this actually makes sense. This will call for close coordination between all subcontractors since it means that they may have to come back twice.

Installing a nearly airtight minimum six-mil polyethylene or cross-laminated vapor retarder (such as Visqueen®, Ruffco®, or Tutuf®) is critical to the long-term success of a building. The most effective way to accomplish this is to plan ahead to provide for a continuous vapor retarder system. This means that strips of polyethylene must be in place over the top plates of interior partitions and behind partition wall junctions with the outside wall. Once the roof is on and all of the wiring and insulation are finished in a single-stud frame wall, it is time to install the vapor retarder in as large as possible sheets to reduce the need for lapping and sealing. Wall vapor retarder materials should be a few inches taller and longer than the wall so that even if the installation is not perfectly straight it can still be sealed to the floor and to the ceiling polyethylene, with the plates providing solid backing at top and bottom and the drywall nailer or last stud in a partition wall providing solid backing for the ends. The large sheets of polyethylene should be tacked in place with as few staples as possible, stopping just short of lapping another sheet of polyethylene. Now and only now should you take out the caulk gun to apply a continuous bead of acoustical sealant to the junction of the bottom plate and the floor and to the partition polyethylene tabs. This avoids much mess!!

Now that we have the wall vapor retarder sealed on two ends and the bottom, it is time to put down the caulk guns and install the ceiling polyethylene. Once again, staple sparingly and stop just short of where you have to join the ceiling polyethylene to the wall polyethylene. Now take out the caulk gun and apply a continuous bead of acoustical sealant to the wall polyethylene, at least an inch down from the top so that when the wall drywall is installed it will compress the joint to provide an airtight seal. All vapor retarder lap joints must be made over solid backing so that a positive compression joint can be accomplished. Lap joints made without solid backing will come apart during the first wind storm or the first time someone slams a door in a tight structure. The sequencing of detailing the vapor retarder system will vary depending on the wall system used. For example, furred wall systems and double-stud walls require very few penetrations and are easier to make airtight than a singlestud wall.

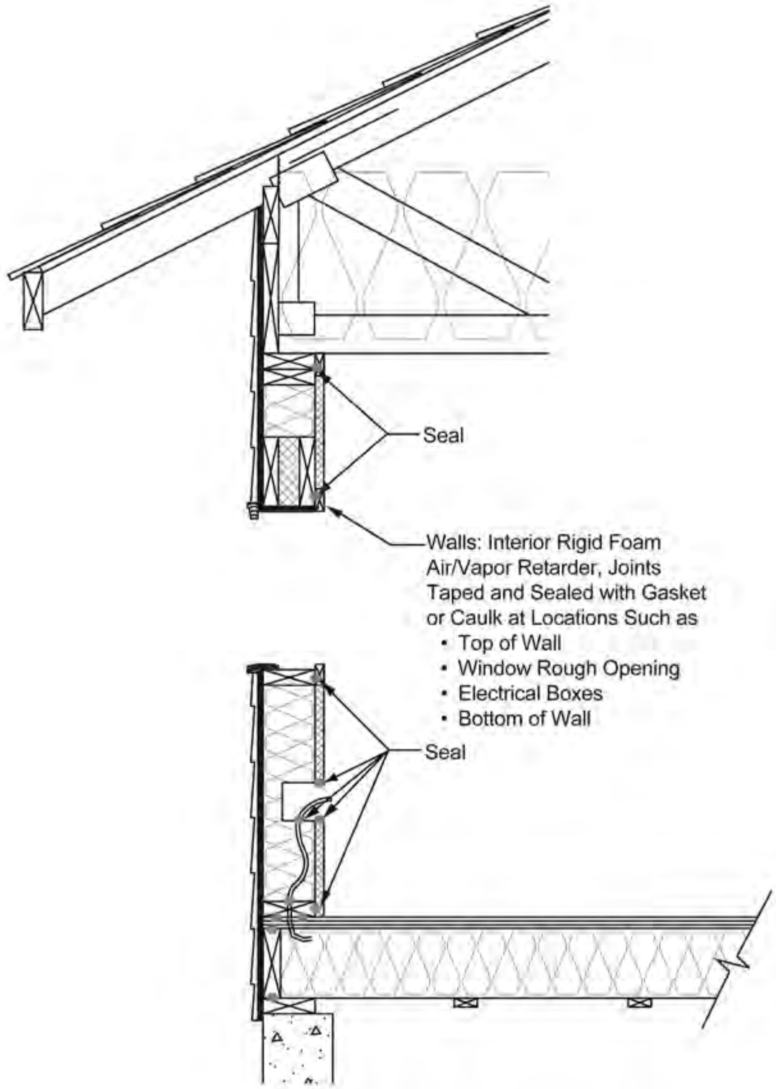


Figure 5.19: Single Wall With Interior Foam Insulation Used as a Vapor Retarder.

An exterior weather retarder such as Tyvek® or Typar® or Barricade® is a modern substitute for tarpaper on walls. It is especially appropriate in high wind areas.

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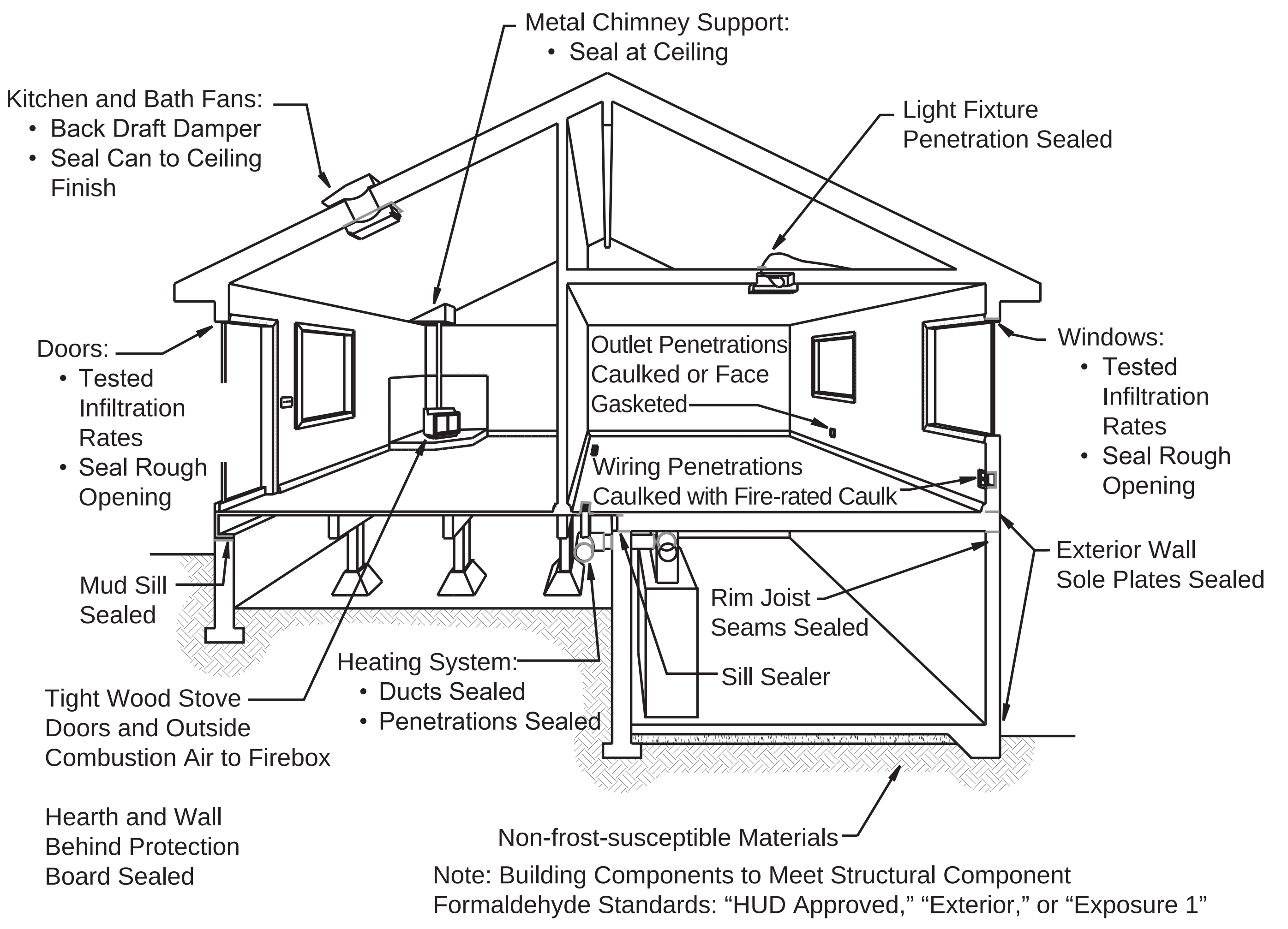

Figure 5.20: Air Leakage Control: Places to Seal..

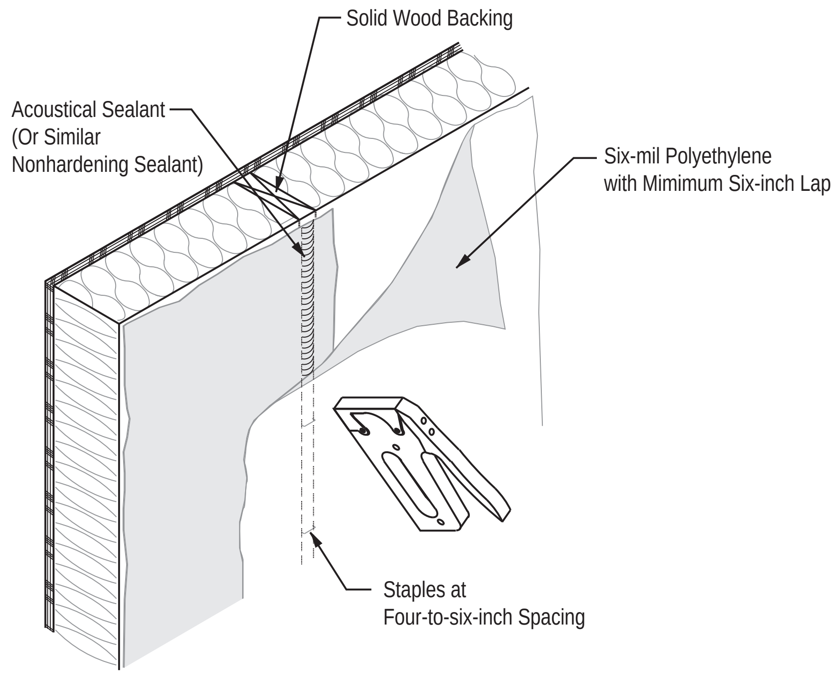

Figure 5.21: Installing the Air/Vapor Retarder

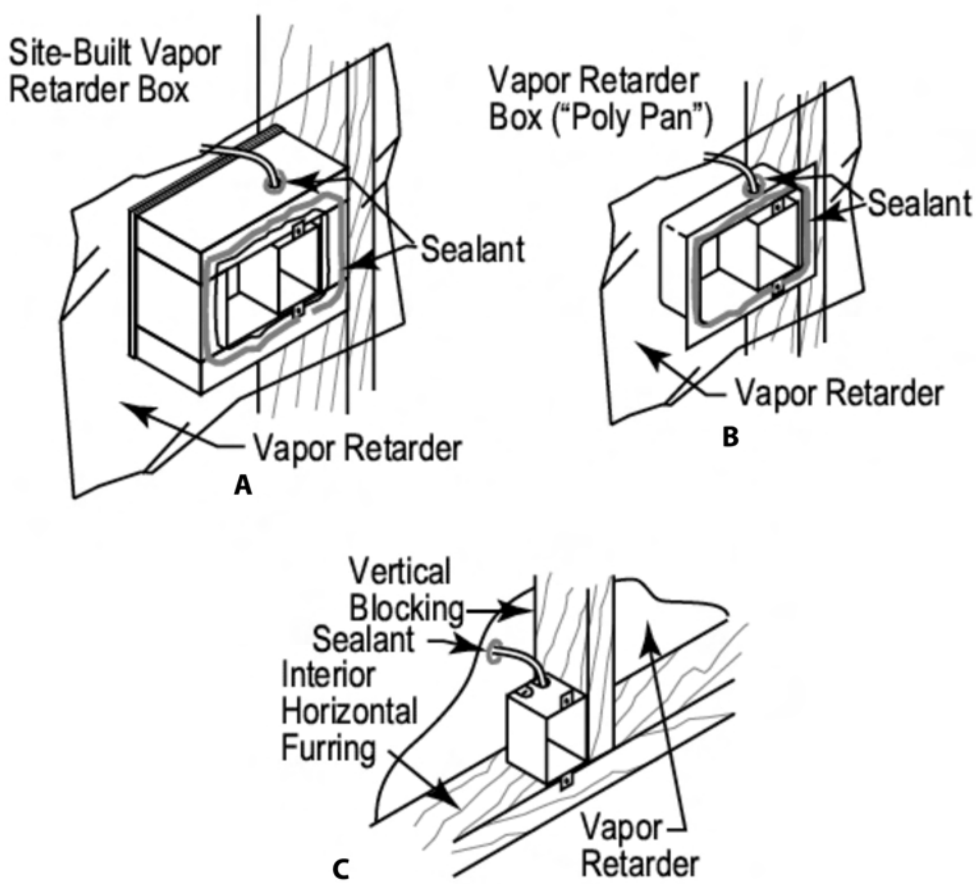

Figure 5.22: Sealing Electrical Penetrations. These figures show various on-site ways to ensure good air vapor retarder sealing in a wall. The site-built option (Figure 5.22A) uses lumber pieces to build a vapor-tight electrical outlet box enclosure.

BUILDING IN ALASKA

EEM-04255

Thermal Coefficients of Typical Sections

Richard Seifert
Energy and Housing Specialist

This publication gives a comparative evaluation of how stud spacing affects wall and roof insulation values, and heat loss. It is intended as an aid in deciding which wall design achieves the desired insulation level sought.

The insulation value of a floor, wall or roof section may be rated as conductance of heat or resistance to heat flow. Conductance (U) of heat is measured in British Thermal Units (BTU) per hour per square foot per degree Fahrenheit. Resistance (R) to heat flow is simply the reciprocal of conductance, such that R=l/U. The larger the R-value or smaller the U-value, the lower the heat loss or heating cost becomes. Various section insulation values for wall, floor and truss roof sections are given in the following pages of this publication.

Normally, framing members are not included in the heat loss calculations. For example, a 2×6 stud wall insulated with 6 inches of fiberglass has a theoretical insulation R-value of 21.08 (U=0.0765), if framing members are excluded, Table 7. If studs are included, the wall would have an average R-value of 18.43 (U=0.0543) at a stud spacing of 24 inches or an R-value of 17.80 (U=0.0562) at a 16-inch stud spacing. However, in counting double studs around windows, doors, etc., the average stud spacing becomes 10 inches, resulting in an average R-value of 16.77 (U=0.596) or less.

Many builders today are considering double 2×4 stud walls with two 3½ inch fiberglass batts for an average R-value of 19.95 (U=0.0501) at an average stud spacing of 10 inches, Table 6.

A 2×4 stud wall insulated with 3½ inches of fiberglass at average spacing 10 inches and 2×4 horizontal nailers at 16-inch centers insulated with 1½ inches of fiberglass would have an average R-value of 15.42 (U=0.0649), Tables 4a and 4c.

Visit the Cooperative Extension Service energy and housing homepage at www.uaf.edu/ces/faculty/seifert/

452/5-78/RDS/1400 Reprinted August 2000

Abbreviations Used in Tables

BTUHF = BTU/HR/°F, an abbreviation of the transfer rate for heat

DStud = Depth of stud, (widest dimension) in inches

FG = Fiberglass

GYP BD = Gypsum board, more commonly know as "sheet rock"

GYP = Same as above

HWall = Height of wall in inches

PLY = Plywood

RInsulation = R-value of insulation of example wall section described in each table

RSkin = R-value of exterior and interior sheathings and film resistance values, all combined

RWood = R-Value of wood per inch

WStud = Width of stud, usually 1.50, or 1.5 inches

WWall = Width of wall in inches

Table 1. Floor, 2 X 10, 9½ FG, ⅜ & ¾ PLY

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	4.53	4.53	0.0707	14.135
2.0	48.0	48.00	16.00	0.50	3.40	3.89	0.0608	16.445
4.0	24.0	24.00	40.00	1.24	1.70	2.94	0.0459	21.785
6.0	16.0	16.00	48.00	1.49	1.13	2.62	0.0409	24.429
8.0	12.0	12.00	52.00	1.61	0.85	2.46	0.0385	26.007
10.0	9.6	9.60	54.40	1.69	0.68	2.37	0.0370	27.056
12.0	8.0	8.00	56.00	1.74	0.57	2.30	0.0360	27.804
14.0	6.9	6.86	57.14	1.77	0.49	2.26	0.0353	28.363
16.0	6.0	6.00	58.00	1.80	0.42	2.22	0.0347	28.798
18.0	5.3	5.33	58.67	1.82	0.38	2.20	0.0343	29.146
20.0	4.8	4.80	59.20	1.84	0.34	2.17	0.0340	29.430
22.0	4.4	4.36	59.64	1.85	0.31	2.16	0.0337	29.666
24.0	4.0	4.00	60.00	1.86	0.28	2.14	0.0335	29.866
0.	0.	0.	64.00	1.98	0.	1.98	0.0310	32.260

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	30.00	96.00	96.00	9.50	1.50	0.	0.	2.26

Table 2. Floor, 2 X 12, 12 FG, ⅜ & ¾ PLY

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	3.85	3.85	0.0601	16.635
2.0	48.0	48.00	16.00	0.40	2.89	3.28	0.0513	19.495
4.0	24.0	24.00	40.00	0.99	1.44	2.44	0.0381	26.270
6.0	16.0	16.00	48.00	1.19	0.96	2.15	0.0337	29.711
8.0	12.0	12.00	52.00	1.29	0.72	2.01	0.0315	31.794
10.0	9.6	9.60	54.40	1.35	0.58	1.93	0.0301	33.190
12.0	8.0	8.00	56.00	1.39	0.48	1.87	0.0292	34.190
14.0	6.9	6.86	57.14	1.42	0.41	1.83	0.0286	34.943
16.0	6.0	6.00	58.00	1.44	0.36	1.80	0.0281	35.529
18.0	5.3	5.33	58.67	1.46	0.32	1.78	0.0278	35.999
20.0	4.8	4.80	59.20	1.47	0.29	1.76	0.0275	36.385
22.0	4.4	4.36	59.64	1.48	0.26	1.74	0.0272	36.706
24.0	4.0	4.00	60.00	1.49	0.24	1.73	0.0270	36.978
0.	0.	0.	64.00	1.59	0.	1.59	0.0248	40.260

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	38.00	96.00	96.00	11.50	1.50	0.	0.	2.26

Table 3. Wall, 2 X 4, 3½ FG, ½ GYP BD, ⅝ PLY

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	9.91	9.91	0.1549	6.455
2.0	48.0	48.75	15.25	1.17	7.55	8.72	0.1362	7.341
4.0	24.0	25.88	38.13	2.91	4.01	6.92	0.1082	9.244
6.0	16.0	18.25	45.75	3.50	2.83	6.32	0.0988	10.119
8.0	12.0	14.44	49.56	3.79	2.24	6.03	0.0942	10.621
10.0	9.6	12.15	51.85	3.96	1.88	5.85	0.0913	10.947
12.0	8.0	10.63	53.38	4.08	1.65	5.73	0.0895	11.176
14.0	6.9	9.54	54.46	4.16	1.48	5.64	0.0881	11.345
16.0	6.0	8.72	55.28	4.23	1.35	5.58	0.0871	11.476
18.0	5.3	8.08	55.92	4.27	1.25	5.53	0.0864	11.579
20.0	4.8	7.57	56.43	4.31	1.17	5.49	0.0857	11.663
22.0	4.4	7.16	56.84	4.35	1.11	5.45	0.0852	11.733
24.0	4.0	6.81	57.19	4.37	1.06	5.43	0.0848	11.792
0.	0.	0.	64.00	4.89	0.	4.89	0.0765	13.080

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	11.00	96.00	96.00	3.50	1.50	3.00	0.	2.08

Table 4a. Wall, 2 X 4, 3½ FG, ⅝ PLY (Add Nailers)

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	10.66	10.66	0.1665	6.005
2.0	48.0	48.75	15.25	1.21	8.12	9.33	0.1457	6.863
4.0	24.0	25.88	38.13	3.02	4.31	7.33	0.1145	8.734
6.0	16.0	18.25	45.75	3.62	3.04	6.66	0.1041	9.608
8.0	12.0	14.44	49.56	3.92	2.40	6.33	0.0989	10.113
10.0	9.6	12.15	51.85	4.11	2.02	6.13	0.0958	10.443
12.0	8.0	10.63	53.38	4.23	1.77	6.00	0.0937	10.675
14.0	6.9	9.54	54.46	4.31	1.59	5.90	0.0922	10.847
16.0	6.0	8.72	55.28	4.38	1.45	5.83	0.0911	10.980
18.0	5.3	8.08	55.92	4.43	1.35	5.77	0.0902	11.085
20.0	4.8	7.57	56.43	4.47	1.26	5.73	0.0895	11.171
22.0	4.4	7.16	56.84	4.50	1.19	5.69	0.0889	11.243
24.0	4.0	6.81	57.19	4.53	1.13	5.66	0.0885	11.303
0.	0.	0.	64.00	5.07	0.	5.07	0.0792	12.630

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	11.00	96.00	96.00	3.50	1.50	3.00	0.	1.63

Table 4b. Nailers, 2 X 2, No Insulation, ½ GYP

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	27.53	27.53	0.4301	2.325
2.0	48.0	48.75	15.25	11.21	20.97	32.18	0.5028	1.989
4.0	24.0	25.88	38.13	28.03	11.13	39.16	0.6119	1.634
6.0	16.0	18.25	45.75	33.64	7.85	41.49	0.6483	1.543
8.0	12.0	14.44	49.56	36.44	6.21	42.65	0.6664	1.500
10.0	9.6	12.15	51.85	38.13	5.23	43.35	0.6774	1.476
12.0	8.0	10.63	53.38	39.25	4.57	43.82	0.6846	1.461
14.0	6.9	9.54	54.46	40.05	4.10	44.15	0.6898	1.450
16.0	6.0	8.72	55.28	40.65	3.75	44.40	0.6937	1.442
18.0	5.3	8.08	55.92	41.12	3.48	44.59	0.6967	1.435
20.0	4.8	7.57	56.43	41.49	3.26	44.75	0.6992	1.430
22.0	4.4	7.16	56.84	41.79	3.08	44.87	0.7012	1.426
24.0	4.0	6.81	57.19	42.05	2.93	44.98	0.7028	1.423
0.	0.	0.	64.00	47.06	0.	47.06	0.7353	1.360

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	0.91	96.00	96.00	1.50	1.50	3.00	0.	0.45

Table 4c. Nailers, 2 X 2, 1½ FG, ½ GYP

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	27.53	27.53	0.4301	2.325
2.0	48.0	48.75	15.25	2.54	20.97	23.51	0.3673	2.722
4.0	24.0	25.88	38.13	6.35	11.13	17.48	0.2732	3.661
6.0	16.0	18.25	45.75	7.62	7.85	15.47	0.2418	4.136
8.0	12.0	14.44	49.56	8.26	6.21	14.47	0.2261	4.423
10.0	9.6	12.15	51.85	8.64	5.23	13.87	0.2167	4.615
12.0	8.0	10.63	53.38	8.90	4.57	13.47	0.2104	4.753
14.0	6.9	9.54	54.46	9.08	4.10	13.18	0.2059	4.856
16.0	6.0	8.72	55.28	9.21	3.75	12.96	0.2026	4.937
18.0	5.3	8.08	55.92	9.32	3.48	12.80	0.1999	5.002
20.0	4.8	7.57	56.43	9.40	3.26	12.66	0.1978	5.054
22.0	4.4	7.16	56.84	9.47	3.08	12.55	0.1961	5.099
24.0	4.0	6.81	57.19	9.53	2.93	12.46	0.1947	5.136
0.	0.	0.	64.00	10.67	0.	10.67	0.1667	6.000

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	5.55	96.00	96.00	1.50	1.50	3.00	0.	0.45

Table 5. Wall, Double, 2 X 4, 7 FG, ½ GYP, ⅝ PLY

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	5.91	5.91	0.0923	10.830
2.0	48.0	48.75	15.25	0.63	4.50	5.13	0.0802	12.464
4.0	24.0	25.88	38.13	1.58	2.39	3.97	0.0621	16.111
6.0	16.0	18.25	45.75	1.90	1.69	3.59	0.0560	17.852
8.0	12.0	14.44	49.56	2.06	1.33	3.39	0.0530	18.872
10.0	9.6	12.15	51.85	2.15	1.12	3.28	0.0512	19.541
12.0	8.0	10.63	53.38	2.22	0.98	3.20	0.0500	20.015
14.0	6.9	9.54	54.46	2.26	0.88	3.14	0.0491	20.367
16.0	6.0	8.72	55.28	2.30	0.81	3.10	0.0484	20.640
18.0	5.3	8.08	55.92	2.32	0.75	3.07	0.0479	20.857
20.0	4.8	7.57	56.43	2.34	0.70	3.04	0.0475	21.034
22.0	4.4	7.16	56.84	2.36	0.66	3.02	0.0472	21.181
24.0	4.0	6.81	57.19	2.37	0.63	3.00	0.0469	21.305
0.	0.	0.	64.00	2.66	0.	2.66	0.0415	24.080

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	22.00	96.00	96.00	7.00	1.50	3.00	0.	2.08

Table 6. Wall, 2 X 4, 3½ FG, ⅝ PLY, ½ GYP, Interior Shell.

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	11.63	11.63	0.1817	5.505
2.0	48.0	48.75	15.25	1.26	8.86	10.11	0.1580	6.329
4.0	24.0	25.88	38.13	3.14	4.70	7.84	0.1226	8.160
6.0	16.0	18.25	45.75	3.77	3.32	7.09	0.1107	9.031
8.0	12.0	14.44	49.56	4.09	2.62	6.71	0.1048	9.540
10.0	9.6	12.15	51.85	4.27	2.21	6.48	0.1013	9.874
12.0	8.0	10.63	53.38	4.40	1.93	6.33	0.0989	10.110
14.0	6.9	9.54	54.46	4.49	1.73	6.22	0.0972	10.286
16.0	6.0	8.72	55.28	4.56	1.58	6.14	0.0960	10.421
18.0	5.3	8.08	55.92	4.61	1.47	6.08	0.0950	10.530
20.0	4.8	7.57	56.43	4.65	1.38	6.03	0.0942	10.618
22.0	4.4	7.16	56.84	4.69	1.30	5.99	0.0935	10.691
24.0	4.0	6.81	57.19	4.71	1.24	5.95	0.0930	10.753
0.	0.	0.	64.00	5.28	0.	5.28	0.0824	12.130

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	11.00	96.00	96.00	3.50	1.50	3.00	0.	1.13

Table 7. Wall, 2 X 6, ½ GYP, 5½ FG, ⅝ PLY

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	7.15	7.15	0.1117	8.955
2.0	48.0	48.75	15.25	0.72	5.44	6.17	0.0964	10.377
4.0	24.0	25.88	38.13	1.81	2.89	4.70	0.0734	13.623
6.0	16.0	18.25	45.75	2.17	2.04	4.21	0.0658	15.208
8.0	12.0	14.44	49.56	2.35	1.61	3.96	0.0619	16.148
10.0	9.6	12.15	51.85	2.46	1.36	3.82	0.0596	16.769
12.0	8.0	10.63	53.38	2.53	1.19	3.72	0.0581	17.211
14.0	6.9	9.54	54.46	2.58	1.06	3.65	0.0570	17.541
16.0	6.0	8.72	55.28	2.62	0.97	3.60	0.0562	17.797
18.0	5.3	8.08	55.92	2.65	0.90	3.56	0.0556	18.002
20.0	4.8	7.57	56.43	2.68	0.85	3.52	0.0550	18.168
22.0	4.4	7.16	56.84	2.70	0.80	3.50	0.0546	18.307
24.0	4.0	6.81	57.19	2.71	0.76	3.47	0.0543	18.425
0.	0.	0.	64.00	3.04	0.	3.04	0.0474	21.080

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	19.00	96.00	96.00	5.50	1.50	3.00	0.	2.08

Table 8. Truss Roof, 6 FG, ½ GYP

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	7.49	7.49	0.1170	8.545
2.0	48.0	48.00	16.00	0.77	5.62	6.39	0.0999	10.013
4.0	24.0	24.00	40.00	1.94	2.81	4.74	0.0741	13.491
6.0	16.0	16.00	48.00	2.32	1.87	4.19	0.0655	15.258
8.0	12.0	12.00	52.00	2.52	1.40	3.92	0.0613	16.326
10.0	9.6	9.60	54.40	2.63	1.12	3.76	0.0587	17.043
12.0	8.0	8.00	56.00	2.71	0.94	3.65	0.0570	17.556
14.0	6.9	6.86	57.14	2.76	0.80	3.57	0.0557	17.942
16.0	6.0	6.00	58.00	2.81	0.70	3.51	0.0548	18.243
18.0	5.3	5.33	58.67	2.84	0.62	3.46	0.0541	18.484
20.0	4.8	4.80	59.20	2.86	0.56	3.43	0.0535	18.682
22.0	4.4	4.36	59.64	2.89	0.51	3.40	0.0531	18.847
24.0	4.0	4.00	60.00	2.90	0.47	3.37	0.0527	18.986
0.	0.	0.	64.00	3.10	0.	3.10	0.0484	20.670

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	19.00	96.00	96.00	5.50	1.50	0.	0.	1.67

Table 9. Truss Roof, 9½ FG, ½ GYP

Spacing Inches	Members	Frame Sq Ft	Insulation Sq Ft	BTUHF Insulation	BTUHF Frame	BTUHF Total	Average U-Value	Average R-Value
1.5	64.0	64.00	0.	0.	3.27	3.27	0.0512	19.545
2.0	48.0	48.00	16.00	0.51	2.46	2.96	0.0463	21.614
4.0	24.0	24.00	40.00	1.26	1.23	2.49	0.0389	25.693
6.0	16.0	16.00	48.00	1.52	0.82	2.33	0.0365	27.418
8.0	12.0	12.00	52.00	1.64	0.61	2.26	0.0352	28.370
10.0	9.6	9.60	54.40	1.72	0.49	2.21	0.0345	28.974
12.0	8.0	8.00	56.00	1.77	0.41	2.18	0.0340	29.391
14.0	6.9	6.86	57.14	1.80	0.35	2.16	0.0337	29.696
16.0	6.0	6.00	58.00	1.83	0.31	2.14	0.0334	29.929
18.0	5.3	5.33	58.67	1.85	0.27	2.13	0.0332	30.113
20.0	4.8	4.80	59.20	1.87	0.25	2.11	0.0330	30.262
22.0	4.4	4.36	59.64	1.88	0.22	2.11	0.0329	30.385
24.0	4.0	4.00	60.00	1.89	0.20	2.10	0.0328	30.488
0.	0.	0.	64.00	2.02	0.	2.02	0.0316	31.670

RWood	RInsulation	HWall	WWall	DStud	WStud	Plate	Extra	RSkin
1.25	19.00	96.00	96.00	5.50	1.50	0.	0.	12.67

BUILDING IN ALASKA

EEM-00954

Effect of Studs on the Heat Loss and Insulation Value of a Wall

by
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A considerable amount of heat is lost through the wall sections of frame buildings where studs are located. Depending on the size of the wall (2' × 4', 2' × 6', etc.) and the spacing of the studs, the heat loss through framing can vary from 33 percent to 49 percent of the total. Some of these calculated values are shown in Table 1. These calculations are based on a typical section of wall, 8' × 8' in area, to provide a comparison of the effects that studs have on the heat loss through a wall. The comparison of different stud spacings for a 2' × 4' stud wall is given in Table 1 along with the percentage of total heat loss due to the studs. The effect is quite significant.

As shown in this example calculation in Table 1, as much as 44 percent of a wall's heat loss can be through the studs. This results in some common problems in Alaska buildings.

Condensation is a very common problem in Alaskan houses. It often occurs on windows, at cold corners or at the top or bottom of a wall, and on sheet rock nail heads. This is because the nail shank penetrates the framing members and cools more rapidly than the adjacent sheet rock. The tip of the shank is exposed to a lower temperature (and greater temperature difference) within the stud. With an outdoor temperature of minus 40°F and an indoor temperature of 70.0°F, it is estimated that a 1½-inch nail would have a temperature of 54.8°F, while the surface of the sheet rock would be 58.7°F. Condensation on the nail heads would occur at relative humidities greater than 56 percent.

Condensation of soot often becomes visible as painted surfaces darken over framing members because the framing members are cooler than adjacent insulated surfaces.

Table 1. PERCENTAGE OF HEAT LOSS THROUGH A STUD WALL
(8' × 8' Example Section)[1]

	Heat Loss Through Studs		Heat Loss Through Insulated Section		TOTALS	
STUD SPACING	BTU/HR/°F	Percent of Total	BTU/HR/°F	Percent of Total	BTU/HR/°F	Average R-value
——[2]	—	—	4.89	100%	4.89	13.1
24 inches o.c.	2.03	32%	4.37	68%	6.40	10.0
16 inches o.c.	2.61	38%	4.23	62%	6.83	9.35
12 inches o.c.	3.17	44%	4.08	56%	7.25	8.82

1 The example section is a 2" × 4" stud wall, with 3½ inches of fiberglass insulation (R11), ½ inch gypsum dry wall and ⅝ inch plywood sheathing on the exterior, 64 square feet in area.
2 This is an example showing the wall heat loss if studs are not present.

The insulated portion of the wall between the studs (R=13.1) would have an interior surface temperature of 64.3°F. The sheet rock directly over the framing members (R=6.61) would have a surface temperature of 58.7°F, such that condensation would occur at around 66 percent relative humidity.

In order to minimize the staining of nail heads and soiling of painted surfaces due to temperature differentials, it is suggested that exposed walls be framed (in new construction) with either 2" × 4" (or better — 2" × 6") studs, 24 inches on center.

In addition, the wall should be insulated with fiberglass batts and a 1½-inch foil-faced insulating board placed on the **inside** of the new wall. This has several advantages. 1) It utilizes the vapor barrier properties of the foil-faced insulation on the warm side of the wall. 2) It will completely cover the studs and shield them from direct contact to the inside of the wall adding a rated value of ~R-10* (commercial rating information) to the wall insulation which is dependent of the thickness of the insulation used. In the case of a 2" × 4" wall with 3½ inches of fiberglass and studs 16 inches on center, this would result in a wall with an R-value of 19.35 instead of the average R-value of 9.35 for a 2" × 4" stud wall.

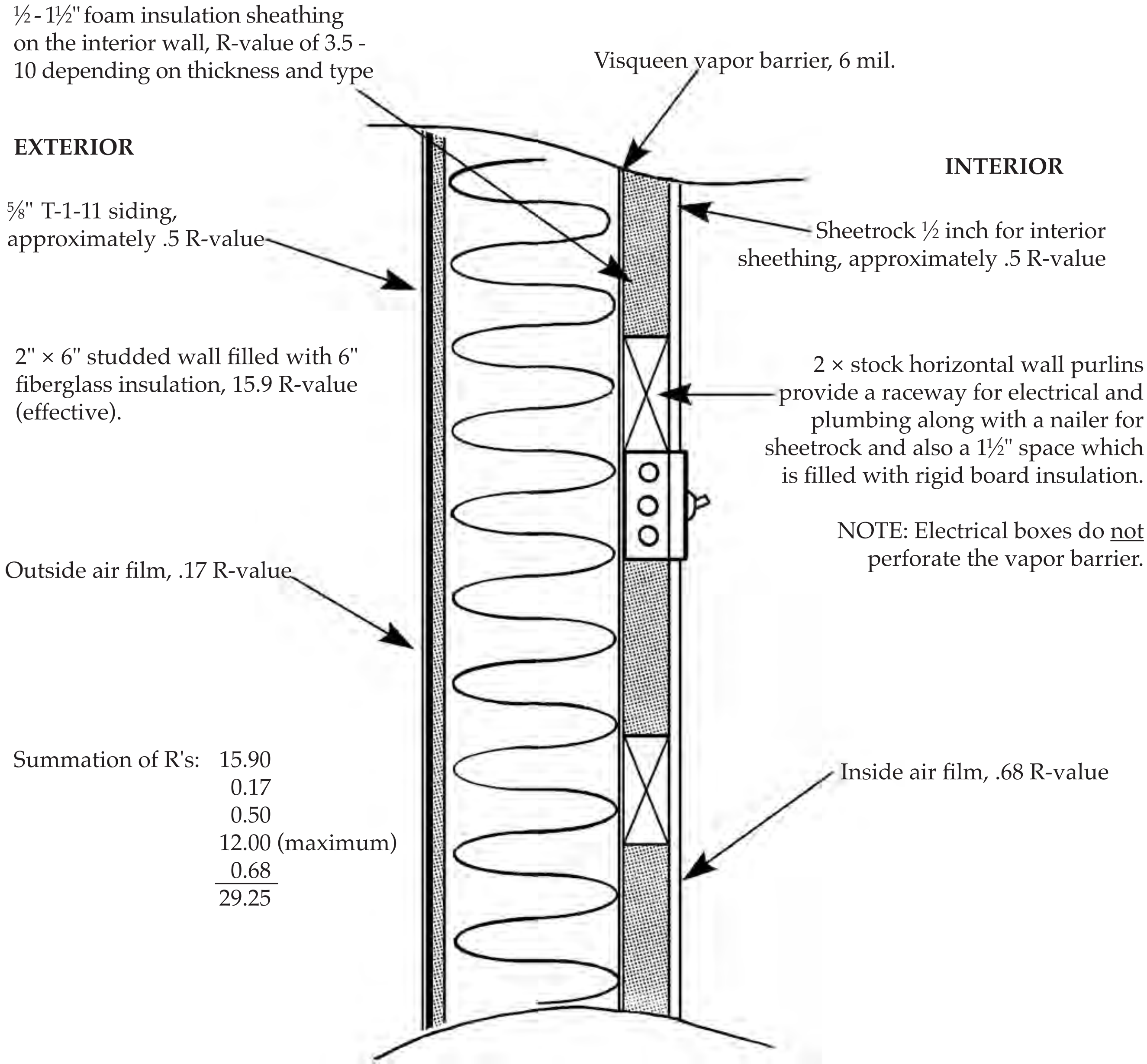
The installation of boardstock insulations is preceded by a 6-mil vapor barrier and then crosshatched by either 2" × 3" or 2" × 4" nailers onto which the sheet rock will eventually be screwed. These nailers are screwed directly onto the face of the 2" × 6" framing stud with long screws, typically sheet rock screws, and then the installation of boardstock in-between these horizontal nailers as shown in Figure 1. This allows for electrical runs to be made in the nailer space and prevents perforating the vapor barrier when these electrical runs are made. The nailer should not be set over the top and bottom plates. An indication on how this might be accomplished to insulate the plates, is shown in the second figure, Figure 2.

This wall type (2" × 6" stud base) yields a finished wall R-value of approximately R30. While this wall has some disadvantages — mainly the slight decrease in interior space

*These are maximum board stock rigid insulation numbers (R-values). Use of polystyrene insulation boards will result in less insulation value per inch.

continued on page 4

Figure 1. Cross-Section of a Well-Insulated, 2" × 6" Stud Framed Wall



A well-insulated, 2" × 6" stud-framed wall which minimizes the effect of studs by covering the stud wall with a continuous layer of insulation on the inside. An R-value of ~29.25 is achieved using this design.

and the nailing difficulties — it is still a top contender for the most efficient home wall both thermally and economically. This is especially true since the new Alaska State Thermal Standards are in place and many regions of the state which have a cold climate, require a wall which exceeds the standard R-value R-19 of a 2" × 6" stud wall to meet the minimum thermal efficiency standards. The easist way to achieve a wall such as R-24 or R-26, would be to use a cross-hatched wall such as shown in Figures 1 and 2.

Note: These thermal efficiency standards for the State of Alaska are given in Cooperative Extension Service publication entitled *Special Considerations for Building in Alaska*, HCM-00952.

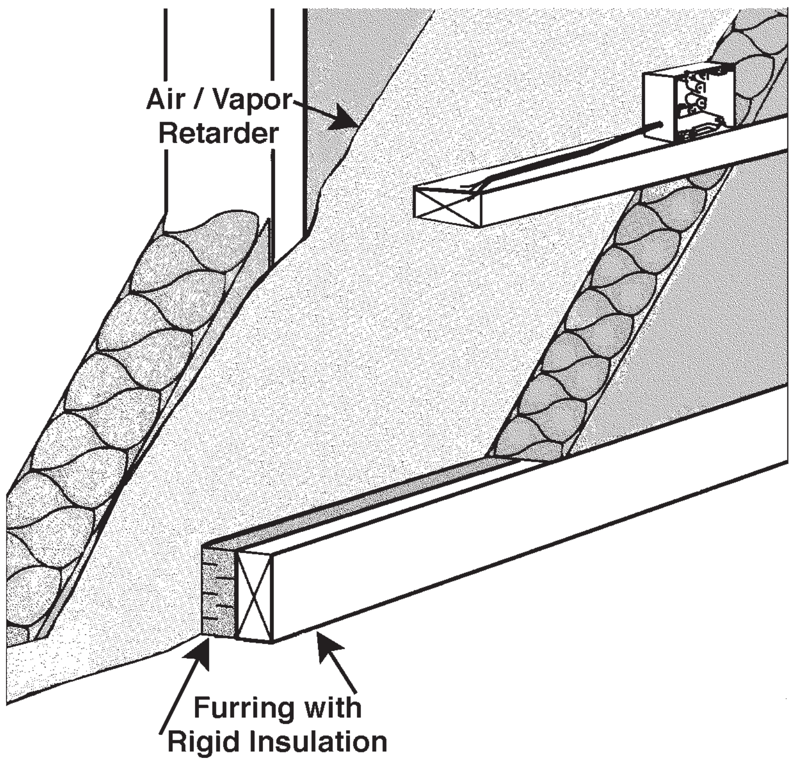


Figure 2. An Alternative Cross-hatch Framing Detail Using 2"×4" Lumber

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EXTERIOR VENTILATED CLADDING

ALASKA BUILDING RESEARCH SERIES
HCM-01558

Introduction
This publication is one of nine that has been translated from Norwegian. They are taken from a series of publications produced by the Norwegian Building Research Institute (NBI) series, "Byggdetaljer," which literally translated means "building details." It is hoped that Alaskan builders will be able to glean useful ideas from these publications. The translations were done by Dr. Nils Johanson and Richard D. Seifert of the University of Alaska Fairbanks with the cooperation and permission of NBI, Oslo, Norway. The financial support for the translations and printing came through the Alaska Department of Community and Regional Affairs, from USDOE Grant DE-FG06-80CS6908. The publications use the original index code of the Norwegian "Byggdetaljer" series so that specific translations can be directly cited. All questions on these translations should be directed to Richard D. Seifert, Alaska Cooperative Extension, P.O. Box 756180, University of Alaska Fairbanks, Fairbanks, Alaska 99775-6180. Phone: 907-474-7201.

01 This publication deals with principles for ventilated claddings on exterior walls. This is a general survey and pertains to various types of cladding material and wood framing construction techniques. Details of the construction of ventilated cladding are given in this paper, particularly in the photographs.

02 It is the purpose of this pamphlet to show the general performance and mechanics of the cladding system and also to give the necessary background for the construction and use of ventilated cladding.

03 Ventilated cladding has been used in Norway for hundreds of years and mainly consisted of wood paneling that was not watertight. The panels themselves were often loose, and abundant ventilation occurred through cracks and joints in the paneling. This provided for a satisfactory wall cladding. External cladding used in connection with modern exterior wall construction has led to greater demands on the cladding due to increasing amounts of thermal insulation and air tightness requirements (tightness against air penetration). This has led in turn to a two-tiered approach to tightening the wall, and has furthered the understanding of the dynamics of ventilated claddings. The two surfaces on the exterior wall each have a different purpose: one protects against rain and the other against wind.

04 It is wind and rain that create the greatest problems in deterioration of exterior walls. If rain occurs simultaneously with strong wind, we get driving rain against the wall. This driving rain is often the cause for leakage. Causes of inward water movement are: capillary action, the force of gravity, and kinetic energy. Strong wind creates a pressure over the wall which can be extremely high. With a single barrier against both rain and wind the water film which is formed on the outside of the wall will be very strongly influenced by the pressure over the outermost layer of the wall. This is the main reason that walls with a single layer barrier are so often damaged by driving rain.

05 In the ventilated wall system, the rain and wind barriers are separated from each other by an air space which is ventilated outward as in Figure 05. This column of air has many functions. It evens out the pressure in such a way that no pressure drop is created over the rain barrier. It also can drain away water which has come

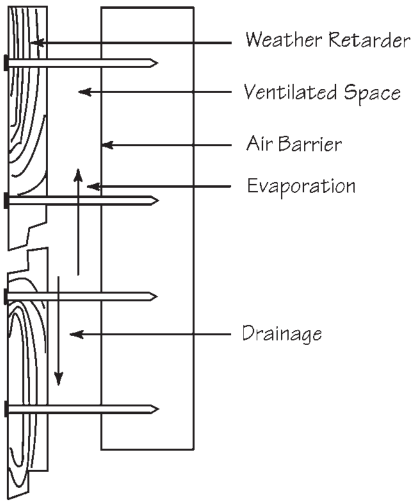


Figure 05. Design schematic for ventilated cladding on exterior walls.

through the barrier and direct it out of the wall. It can allow the escape of moisture which has found its way from the inner parts of the wall and allow it to evaporate in the ambient air.

1 FUNCTION

In addition to giving the wall the desired appearance, the cladding must withstand the stresses to which it is exposed, and also must protect the enclosed structure against the local climate. These functions include: stopping rain which is driven against the facade and to direct it downward and away from the underlying construction. It must endure the wind stresses and be able to take up and absorb the changes in expansion and contraction which can occur because of temperature and moisture changes without causing damage to the cladding. Deformations due to these stresses must not exceed the expansion and contraction allowable with the fastening mechanisms. It must withstand shock and abuse, and chemical attack from possible air pollution, salt air, or unusually bad weather. Be very attentive to potential for corrosion of hardware mountings and fastenings associated with the cladding. They must endure solar radiation without discoloration, bleaching or other damage. And the cladding must also limit the spread of fire (meet code requirements).

2 DRIVING RAIN

21 Cladding as Rain Protection

211 Rain is first halted at the wall's outermost surface. If the surface is porous, water penetrates straight inward and can, in massive construction (concrete) penetrate deep inward and eventually to the inner wall surface. In compressed walls with many layers of material, one surface can direct water and carry it laterally a long distance both into and from the outer wall. In walls with loose cladding such as walls with an air space behind the outer layer of surface material, water which has been absorbed will run down along the cladding's backside and can be directed out again, such as in Figure 05. The surface of the backwall (the wind barrier) can thereby be kept free of water. That surface must consist of permeable material such that humidity which needs to get from within this wall to the outside through the air barrier surface can be ventilated away. It is important that there is some air change between the outside air and the air space behind the cladding.

212 Rainwater not absorbed into the wall will stream down the wall. Over holes, cracks or faults larger than 5 millimeters in diameter, hanging water drops would create a bridge or a film of water which can be blown in against the back wall. The pressure difference over the cladding in turn causes air movement through this opening which eventually pushes and bursts the film as shown in Figure 212.

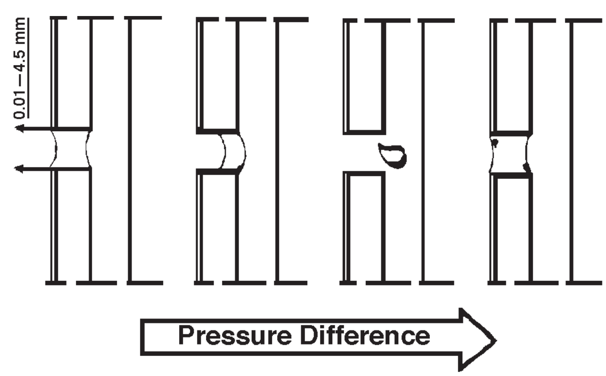


Figure 212. Water penetration in small openings and cracks is caused by pressure differences over the cladding.

213 Ventilation of the air space behind the cladding contributes to the elimination of any pressure difference present. This is especially necessary during wind storms and high wind events when the wall must prevent the air stream from carrying water into the wall. This is a great advantage of covered joints.

214 The back of the wall, especially its outer surface, must be airtight. If there are breaks or perforations in the wall it is possible to get powerful local airflow into the walls and water drops could be carried into them, such as in Figure 214. Concentrated air leakage can often convey water leakage and distribute it over a large area. For this back wall surface an air barrier material such as Tyvek® or equivalent is highly recommended.

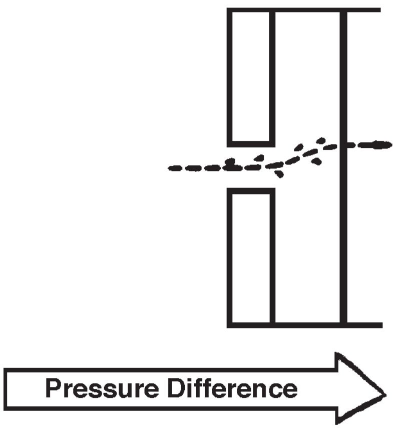


Figure 214. Water penetration due to leaky cladding and faulty construction.

215 Wind always yields an uneven pressure on a wall. Pressure variations in the plane of the wall can create lively air movements behind the cladding, such as in Figure 215 a and b. Air movement through the cladding can move water into the wall. On large facades the air space is divided up into compartments. It is important to seal the air space at the corners of the house such as in Figure 215 c, d, and e. See also Figures 218 - 223.

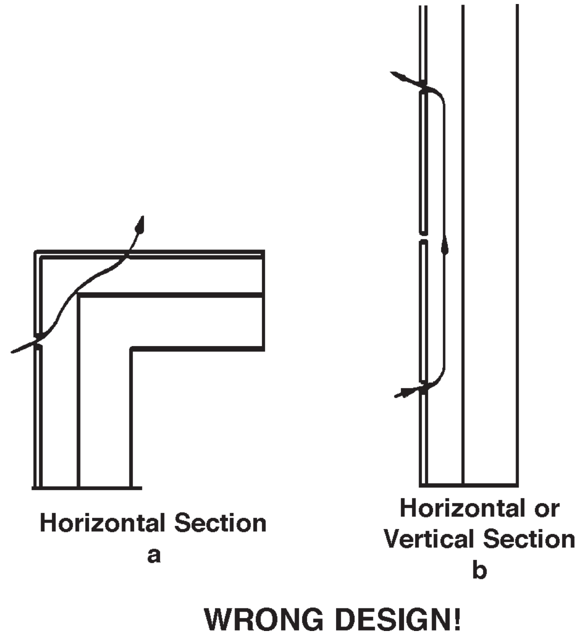


Figure 215 a and b
a. Airflow in the airspace around the corner.
b. Vertical or horizontal airflow in the airspace.

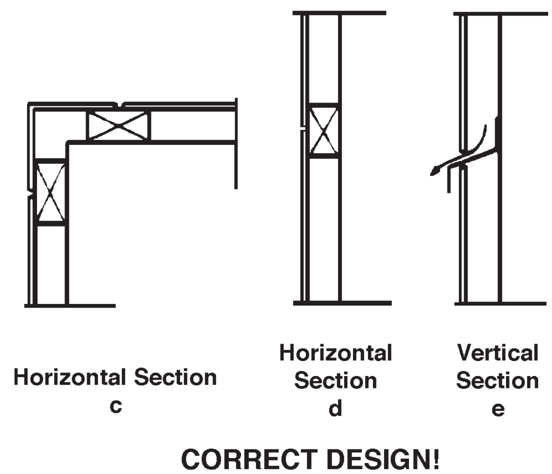


Figure 215 c, d and e
c. Barrier to airflow around corner.
d. Air is blocked in stud spaces.
e. Drainage with horizontal air blocks.

216 During driving rain the kinetic energy of water droplets can be large enough so that they can penetrate through open joints in walls. The width of the joints, the thickness of the cladding and the direction of the drops all combine such that they can pass through whole or split up against the side of the joint, such as in Figure 216. Whether or not water reaches the back wall is dependent upon the air space thickness.

217 Much water can run into the wall if the joints have an inward slant such as in Figure 217. How much depends upon the amount of driving rain

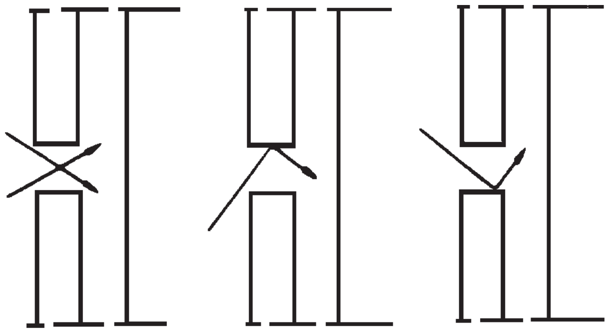


Figure 216. Water spray reaches the backside (air barrier) if joint openings are too large.

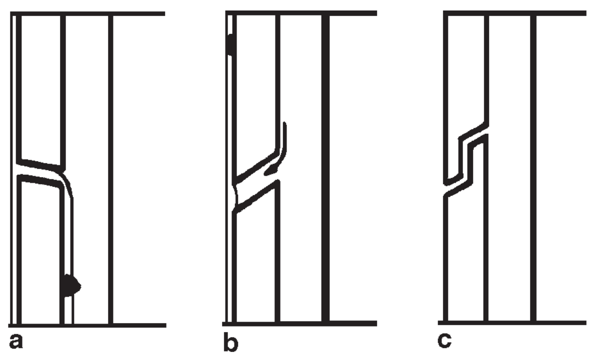


Figure 217 a, b and c
a. Joints with inward sloping drainage. Water will pass through badly constructed joints in the claddings.
b-c. Joints with an outward sloping drain. This method provides drainage and protection from rain penetration simultaneously.

and the height of the wall. If the climate isn't too rigorous, one can use horizontal joint surfaces, but the surfaces must have an outward slant. However, when there's a large wind pressure against the facade and especially when the wind is blowing water upward, such joints will allow water to penetrate the exterior cladding.

22 Principle recommendations for types of joints.

221 There are in principle two types of joints, an open joint: a joint without a rain protection; and a closed joint: a joint with rain protection.

222 The joints can also be classified as to how they allow for movement of the cladding.
— Butt joints: In these joints the stresses, due to compression and tension, are handled by the fastening mechanisms.
— Lap joints: in which the fastening hardware is mostly provided for countervailing the sheer stresses.
— Open joints: in cladding which is not leak tight. These provide no stress function on the surface of the back wall because of movements in the joints.

223 Basically a joint system between the elements of the wall can be divided into three parts: the vertical joints, the horizontal joints and the cross joints. Because weather stresses are different on different parts of the joints, they often deform in different ways simultaneously, such that one must take great care in the structure and design of those areas where the joints meet each other.

23 Vertical Joints

Water which runs downward over the facade collects in back along the vertical joint, and in inlaid joints and at connections with pilastres, or columns. Strains on the joints at these particular points are very great but can be curtained at the ribs and thereby limit the passage of water from the sides.

231 Closed joints are made according to the same principle as ventilated cladding. It consists of the outermost rain shield, then a pressure equalization chamber (with drainage), then bounded on the inward side by an air barrier. An opening is provided in the back of the rain protection for pressure equalization and a drain in each cross joint. Cover the top of the drainage channel on the back side. During episodes of wind pressure the stresses on the rain shield can be reduced with the help of small holes or drainage channels in the sides of the joints.

232 When using open joints, only the best fastening hardware must be used because of the great stresses from the sun, humidity, cleaning materials, environmental weathering and general movement. This type of joint must not be used in areas of extreme weather or where they can be destroyed by vandalism. Stresses can be reduced by utilizing narrow joint openings on the outside. Three millimeter joint openings can prevent water from reaching the air barrier if that barrier lies at least 45 millimeters behind the surface.

Figure 218. A framed example of backing side of exterior ventilated cladding.

Figure 219. Shows the installation of insect-proof mesh vent screening installed over the bottom opening of the ventilated wall. This allows air and water drainage to easily occur behind the exterior rain-shield sheathing.

Figure 220. This figure indicates a sequential step from figure 218. The battens have been carried up to the soffit. As the finished siding approaches the top of the wall a single or double vent can be used. The choice is only determined by the desired “look” and/or performance. Only experience will tell how much ventilation is necessary or appropriate. Cut a strip of fiberglass insect screen to be stapled to the top leading edge for the last “common” siding course above the reveal line of the existing course of siding. This sequence is then followed by using cutoffs of the furring material. Use $\frac{1}{2}$ inch pressure treated plywood, ripped to a width of 2 $\frac{7}{8}$ inches. A wide strip is used to increase the width of the nailing base. Keep the nails at least 1 inch away from any end of a board to decrease the likelihood of splitting the siding.

Figure 221. The stand-off furring blocks are attached over the sandwiched screen and original furring. The corner boards have only the original furring underneath them. This gives a nailing base for the corner board and the siding that will butt into the corner board. As the stand-off blocks at the top of the wall are installed, do not install a furring block where the siding is going to marry to the corner board, as this will result in the siding standing out proud of the corner board. The siding is formed, faired, and bent from the corner board plane to the next stud-furring spacer so the air space goes from nothing to the $\frac{1}{2}$ inch space depending on the stud spacing. This holds true when a deck or other mid-wall penetration occurs. Visually it is quite undetectable.

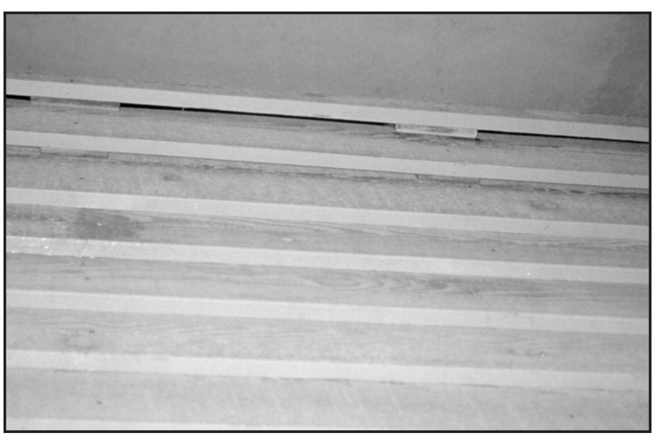


Figure 222. This is similar to figure 221. The top-most spacer is cut to not lay on the siding, but over the existing furring and insect screen. One stand-off is probably more than adequate.

Figure 223. This figure is a view of a finish exterior cladding wall. Note that it is difficult to see that the wall is vented, and it is esthetically pleasing. The biggest problem with a ventilated wall is probably a correct flashing detail over the top of the windows. A two-piece flashing system has been used by Marquam George in Juneau. The first goes on before the furring is attached and the windows have been installed. The final goes on after the window has been installed. This creates a counter-flashed system.

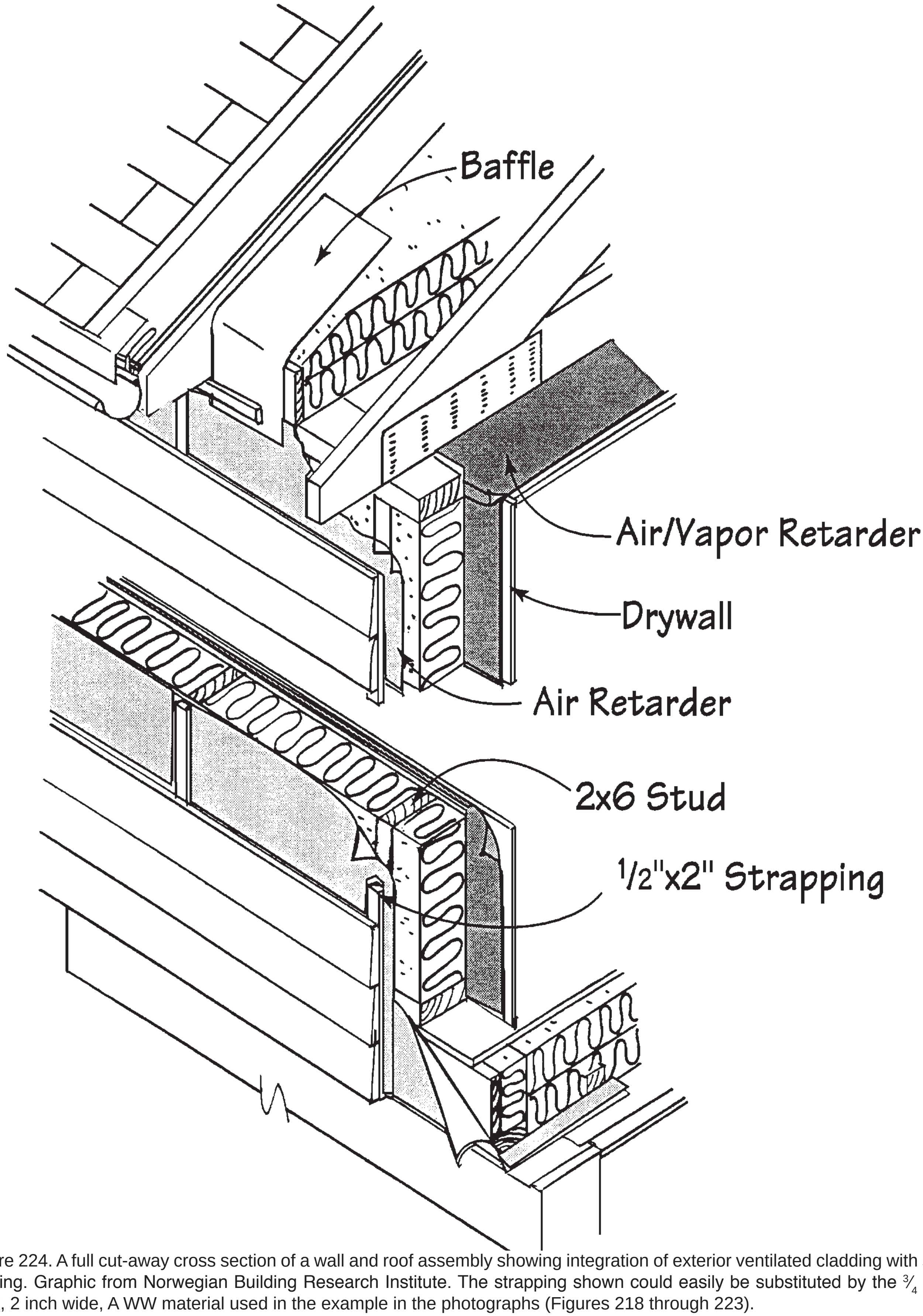
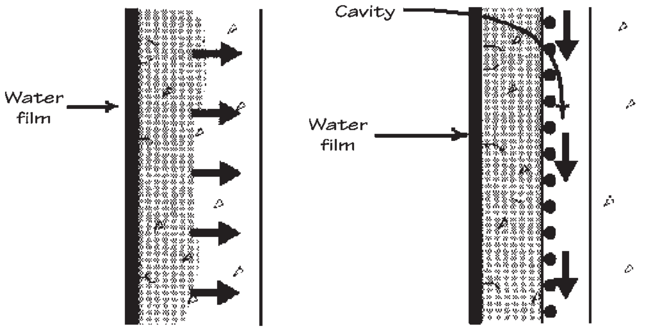


Figure 224. A full cut-away cross section of a wall and roof assembly showing integration of exterior ventilated cladding with stud framing. Graphic from Norwegian Building Research Institute. The strapping shown could easily be substituted by the $^{3}/_{4}$ inch thick, 2 inch wide, A WW material used in the example in the photographs (Figures 218 through 223).



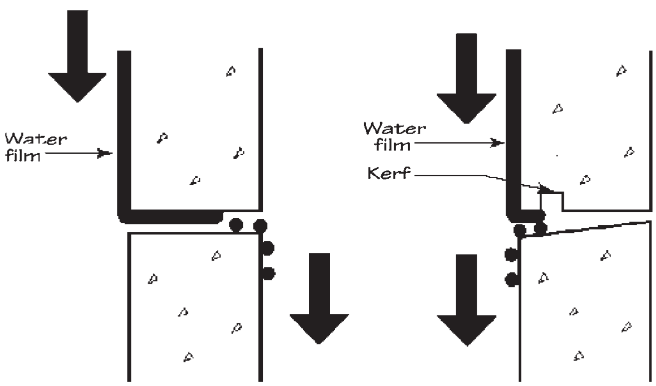
Capillary suction draws water into porous material and tiny cracks

a

Cavity acts as capillary break and receptor for capillary water interrupting flow

b

Figure 225 a and b. Capillarity effects in exterior cladding. This effect provides the "strategy" for design of a ventilated wall to stop water penetration. The air cavity in figure 225b is backed by Tyvek or equivalent providing a drainage path, drying and limiting water penetration into the wall.



Rainwater can flow around a surface as a result of surface tension

a

Providing a kerf or drip edge will promote the formation of a water droplet and interrupt flow

b

Figure 226 a and b. Flashing to eliminate water penetration around an edge. Some crucial flashing details and kerfs should be made to ensure droplet formation and drainage to the exterior.

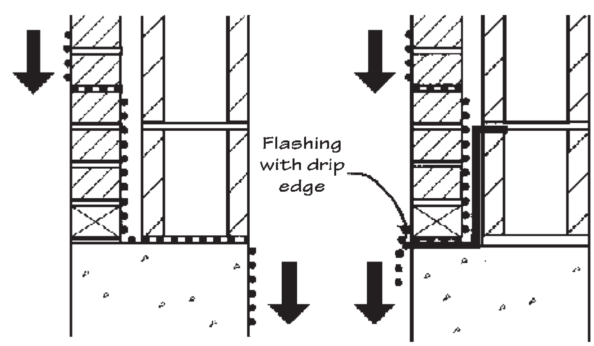
233 Open joints in loose cladding must be as narrow as possible, at the most not over 3 millimeters. The back wall (air barrier) must be able to withstand water and wetting. The vertical joints are covered on the back side with lathwork. This must be done in locations where the weather is severe.

Figures 225-227 are from the EEBA Manual by Joe Lstiburek, Cold Climate Version, Appendix I: Rain and Drainage Planes.

3 STRESSES

31 Rain

The amount of rain which is allowed to impact against the wall is dependent, among other things, upon the intensity of precipitation and the simultaneous wind strength and direction. From measurements it is desirable to find out where the most precipitation will occur on the wall. Conditions are complicated by the fact that driving rain's effect is influenced strongly by the size of the building, the orientation and condition with respect to the predominant wind direction and the width and height conditions, building shell responses to rain, neighborhood buildings and so forth. Small changes in the environment can cause marked changes in the effects of driving rain on a building. The same conditions also apply to precipitation and wind conditions in general, such that the data from a meteorological station is not relevant for other than measurements in the general vicinity. Experience and measurements show that areas near corners and high on top of walls get more driving rain on the facade under most conditions. Tall houses are much more exposed than low houses. Water has a tendency to collect itself along vertical cracks or openings in facades. Stresses are especially great where the cladding is smooth because wind can cause the water film to be driven sideways. Joints with vertical openings must always be covered. Along coastal areas driving rain occurs more



Rainwater can flow down surfaces and enter through openings and cavities

a

Flashings direct gravity flow rainwater back toward the exterior

b

Figure 227 a and b. Rainwater flow down surfaces and flashing with drip edge. Two additional flashing details also ensure drainage to the outside away from wall.

often. Conditions are generally more difficult and severe than inland. The following are estimates of maximum rain intensity. One can estimate the maximum rain intensity as the following: one to two liters per meter squared per ten minutes in the general coast areas of Norway[1], rain can achieve rates of 5 to 6 liters per meter squared per ten minutes or about 30 to 36 liters per meter squared per hour (8-10 gals/hr).

32 Wind

321 Wind pressure operates on walls as a pressure or a suction. Wind pressure varies with the wind's velocity and the height over the terrain and the stresses on a building are therefore dependent on the site and form.

322 It is somewhat unclear just exactly how a ventilated cladding transfers the power of the wind to the other construction. With complete pressure equalization the wind pressure is transmitted to the surface behind the air space and the cladding will be unloaded. In practice the cladding always must absorb some loading. The wind must not be allowed to set the building elements or cladding into vibration.

323 The cladding must be fastened such that its own weight and the loads it is designed for can be transmitted to the bearing portions of the building. Placing of the fastening points must be related to the size of the deformations of the building elements and to what extent vibrations will occur. The fastening points must be designed such that the minimum deformation in the building is anticipated and such that the cladding will not suffer damage because of deformation.

33 Temperature Changes

All materials change dimensions with variations in humidity. Cladding and the underlying construction to a lesser degree deforms such that the movements can be significant normal to the plane of the wall. Simple materials will become bent or bowed. Wall design must take this into consideration. For example, the sealing materials in joints must be appropriate to handle the stresses they will be exposed to. Tremco® acoustical sealant or its equivalent should be used to seal the air barrier on the backside of the ventilated space.

34 Shocks

The cladding, especially the lower part of the facade, will be exposed to shocks and general rough treatment. Fragile or delicate materials must not be used where they can contact the terrain. If these materials are in fact desired for use, it is appropriate, especially in exposed places, to provide framing which is stronger and more supportive than normal. One can also limit the rough handling of claddings through the use of excavation of terrain, with forethought as to how it will affect the exposure of the cladding. Clever and well thought out use of shrubbery can also be effective. Openings through joints can also enable damage to the back wall, for example through the use of a knife. It is especially important to cover the joint's exposed parts, by providing a backwall that is robust enough to handle any shocks. Parts of the jointing system can be damaged if it can come in contact with the backing material.

35 Chemical Action and Corrosion

Practically all the chemical action which strongly affects materials is associated with water. This makes it imperative that rain water must be carried away from the facade as fast as possible to avoid any possibility that stagnant water can come in contact with the structural materials. Strong chemical attack can occur because of air pollution in industrial regions and because of salt in the coastal regions. This is especially the case for some types of acids which attack materials. It is doubtful you will be able to determine which pollutants are present in the local air. Material suppliers are required to give information on dangers from chemical attack for materials. Nearly all metals corrode when they come into contact with other metals. This can be a serious problem, and also a security problem with cladding and

[1]Comparisons of these areas correspond roughly to the outer coasts of Kodiak Island, Yakobi, Chichagof, Baranof, and Prince of Wales Island in Alaska

curtain walls. Many unlike metals are used in construction. Corrosion can be prevented in building by isolating materials from one another or by choosing metals which corrode very little in contact with one another. Corrosion products, rust, etc. can discolor facades when water carries them with it. Impregnation materials can be found for wood which can be used to keep corrosion from occurring on simple metals.

36 Sunlight

Cladding materials are exposed to the physical action from the sunlight, especially ultraviolet and thermal radiation. Materials which from experience have been shown to age rapidly must (if it's necessary to use them) be mounted in such a way that they are easy to replace. Sealing materials age more rapidly when they are exposed to solar radiation and therefore require as much shielding and shading as possible.

37 Fire Protection and Considerations

371 The demands of fire protection vary with the building's size and type. They can also vary from place to place dependent upon the local fire protection equipment available. Regulations require that the outer wall in large buildings must be constructed for the most part of fire proof materials. Lath made of wood can be used, but protection against the spread of fire must be provided because of the presence of tiers of beams and burnable wall materials.

372 Nonbearing outer walls can be made of wood with a fire authority's permission. However, the exterior cladding must be of fireproof materials (in buildings with a maximum of 8 floors, a smaller portion of the cladding can be burnable). Internal wood construction must be protected by a fire proof cladding. Outer walls must be provided with a barrier such that the tiers of beams and burnable walls can be protected from the spread of fire.

373 The air space behind the cladding must be blocked at each beam and at each burnable wall interface. One can construct the wall such that the beam or the burnable wall portion can penetrate the facade cladding. If a smooth or sheer facade is desired, it is possible to satisfy the necessity for protection of the burnable section of the wall or the beams with fire protective cladding. If it is not possible to place fittings and mountings outside the layer which is ventilated, they can be mounted vertically, as long as they are bounded by a fireproof flat strip. This is adequate if there is ventilation of the ventilated surface downward when the building the wall surface does not exceed one floor in height.

BUILDING IN ALASKA

EEM-04550

THERMAL AND VAPOR BARRIERS FOR 1½ STORY HOUSES

10-79/ARC-RS/1000 Reprinted September 2000

COOPERATIVE EXTENSION SERVICE

UNIVERSITY OF ALASKA FAIRBANKS

INTRODUCTION

The 1½-story house has long been a popular Northern building. Its main attraction seems to be economic: on a dollar-per-square-foot-of-livable-floor-area basis, the 1½ story is less expensive to construct and heat than either a 1-story ranch style house (Figure 1). Structurally, the only way in which a 1½-story house differs from a 1-story is that it has a slightly larger roof on it, and the first floor ceiling joists are sized slightly larger so that they will serve as floor joists for the newly created living space. It should be noted, however that this second floor living space is inexpensive by virtue of being enclosed on top and sides by a sharply pitched roof (usually 45° to horizontal, which is a 12:12 pitch). This roof type is easy to construct because it has no doors, windows or other irregularities in it. The resultant space, however, is long, narrow, and naturally lighted only by the windows in the end walls.

To let light into the middle of the upstairs and to make more of the floor space useful as living space, it is very common to build dormers onto 1½-story houses, either at the time of new construction or at some later date. Installing dormers improves the quality of the space, but also adds to the expense of construction. Instead of the relatively simple job of building a long,

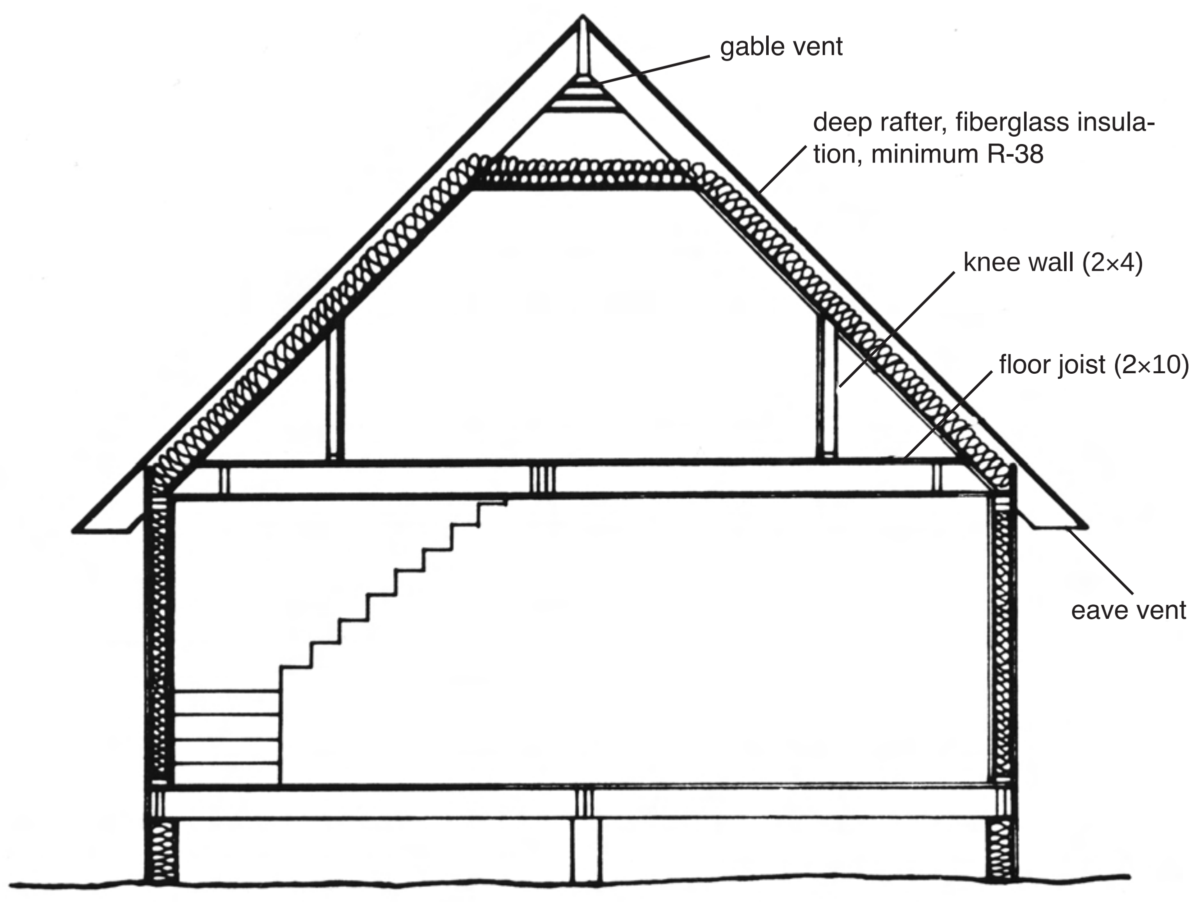


Figure 1. Schematic of 1½-story house with dimensions of lumber used in conventional frame.

uninterrupted expanse of roof section, the installation of dormers involves custom carpentry, glazing and control hardware. The more dormer space is added, the more a 1½-story house becomes like a 2-story, and costs vary proportionately. It is also possible, however, to install openable skylights in gable roofs, and thus admit light without adding dormers.

Another factor which contributes to the economy of the 1½-story is that the upper floor is most commonly used as bedroom space, and is usually constructed without plumbing and with minimum wiring. Obviously, the more second floor amenities are added, the greater the cost will be.

PROBLEMS

When built to minimum structural standards, as many existing Alaskan 1½-stories are, this house type has more than its share of heat loss and condensation problems. These problems result from a combination of inadequate insulation, air and vapor leaks through an improperly installed vapor barrier, and insufficient (or nonexistent) ventilation over the top of the insulation. Figure 2 points out the thermal and vapor barrier deficiencies, and attendant condensation problems, which are often encountered in conventionally constructed 1½-story residences.

AIR/VAPOR LEAKS

The first source of difficulties is the water vapor that migrates through holes in the vapor barrier. Because many older 1½-story houses were constructed as shown in Figure 2, with insulation in the knee wall and ceiling joists, there are many resulting air and vapor leaks. Electrical wiring and recessed light fixtures allow large amounts of water vapor to migrate into the cold roof cavity. In practice, the ceiling vapor barrier has often been omitted entirely in the ceiling joists, and even if installed, is seldom sealed to the vapor barriers covering the knee wall and the first floor wall. Access openings into the knee wall for storage or other purposes also violate the vapor barrier, unless arrangements are made for a door with an effective air/vapor seal. Another problem area is recessed light fixtures. Installed as required for fire safety, with a 3-inch gap between them and the insulation and vapor barrier, they will obviously allow air and vapor leaks. The only way that recessed fixtures can be used, while still maintaining the integrity of the vapor barrier, is to put them into a drop ceiling.

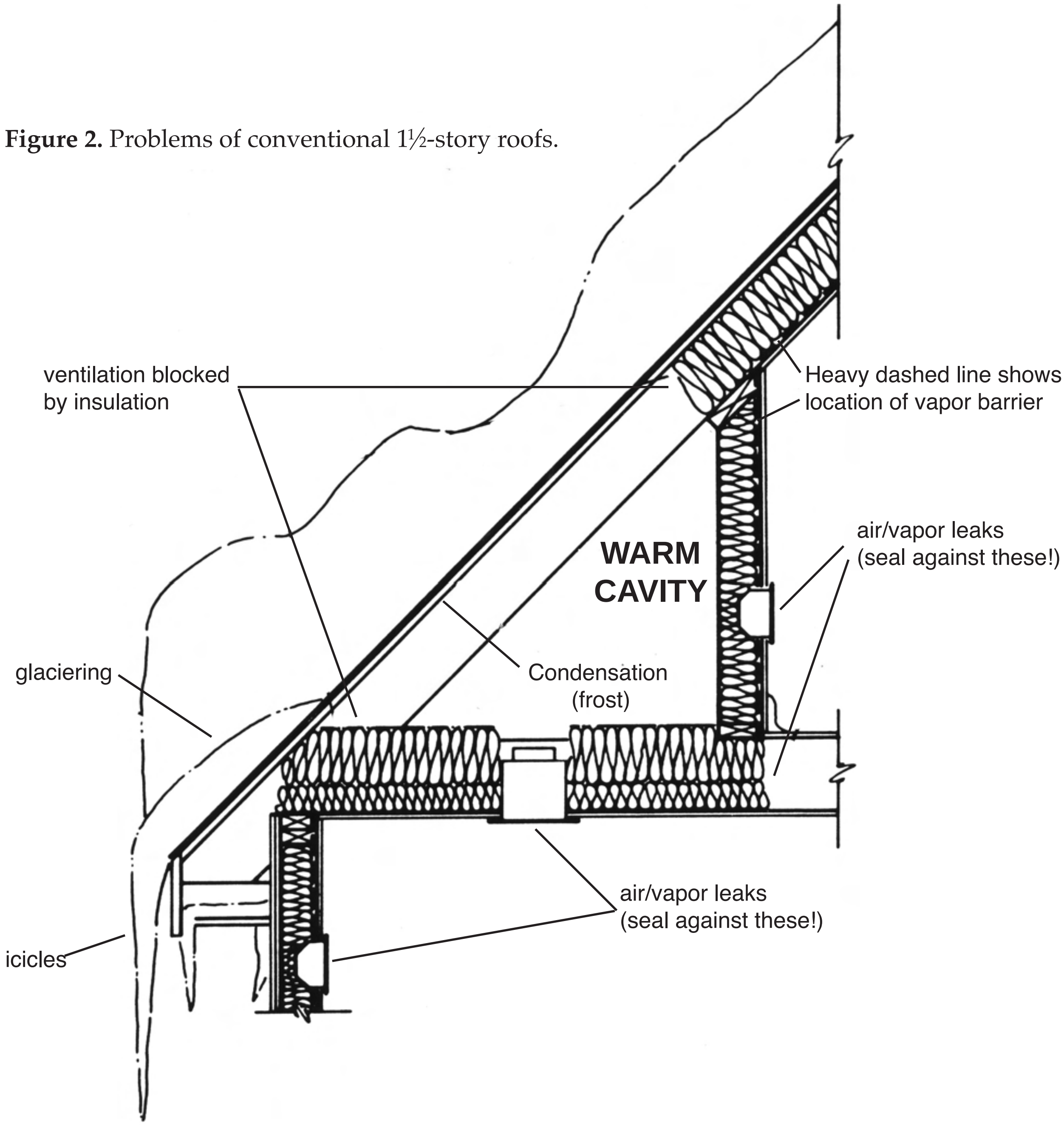
VENTILATION BLOCKAGE

All the water vapor that enters the roof cavity should be carried away by a stream of dry, outside air flowing constantly over the top of the insulation. In practice, however, this ventilation space is often blocked by installing more insulation than the rafters can hold. If the roof rafters are 2×6, then installing nominal 6 inch fiberglass batts will result in ventilation blockage. Nominal 6 inch insulation between 2×8 rafters will leave 2 inches of space over the top of the insulation, which is adequate (although there is no Alaskan climate so warm that 6 inches of roof insulation is adequate). See Figures 3-6 for solutions to this problem.

CONDENSATION AND ICE

When water vapor enters the roof cavity and has no way out, it collects during cold weather as frost on the underside of the roof deck. As the weather warms up, the ice melts. Water then drips onto the insulation, and runs through any available hole back into the house, staining sheetrock and causing all the problems associated with a leak in the roof.

Figure 2. Problems of conventional 1½-story roofs.



GLACIERING

With ventilation blocked, and warm moist air flooding up into the roof cavity, the surface of the roof will, in mild weather, become warm enough to melt snow. This water then runs down the roof to the eaves which, being out in the cold air, are cool enough to freeze the water, creating ice dams and eventual leaks. Icicles hanging off the eaves or gutters are a related phenomenon.

RETROFITTING

Solving the condensation problems of an improperly constructed 1½-story house is no easy task. In order to fix the vapor barrier leaks, it is generally necessary to pull down the ceiling covering on both sides of the house in the area under the knee wall. Since there is not room enough for both adequate insulation and adequate ventilation, it is imperative that the vapor barrier be of high quality with minimum leaks, or the condensation-freezing-melting cycle will occur. If a retrofit is to be done on a 1½-story that has an insulated knee wall, it may be best to move the insulation out to the rafters, and thus avoid all the problems of electrical wiring and access openings.

THE CRUCIAL DETAILS!!

THERMAL AND VAPOR BARRIERS

Figure 3 shows an improved version of the conventionally framed 1½-story house. It is essentially like the 2×4 wall and 2×6 rafter construction, but larger dimension lumber is used allowing for more insulation and ventilation space. This design also makes provisions to ensure a leak-free vapor barrier.

Note that instead of insulating the knee wall and ceiling joists, the insulation is carried all the way down the roof rafter to meet the wall insulation. Not only will this avoid all the problems of recessed lighting fixtures, access openings, and knee wall wiring, but it is actually a more economical use of insulation: since the length of the hypotenuse is less than the length of the other two sides, this method requires less insulation and displays less area for heat loss.

The blocking which is shown installed between the ceiling joists is meant to provide a surface against which to seal the roof vapor barrier to the wall vapor barrier. In this scheme, the blocking is sealed to the joists with sealant, and then the polythylene is sealed to the top and bottom of the blocking. This technique probably will not yield a perfect vapor seal, but given minimum ventilation, it should be adequate.

In order to make a good vapor barrier in the wall, this design shows 2×3 nailers installed perpendicular to the 2×6 stud walls. The electrical wiring is then installed on the warm side of the vapor barrier, thus assuring that there will be no leaks. If electrical wiring is required in the attic ceiling, then nailers may be placed perpendicular to the roof rafters, as well.

The design shown in Figure 3 represents the maximum insulation value achievable using dimension framing lumber and fiberglass insulation. If one wishes to use more than 10 inches of fiberglass in the roof and 6 inches in the walls, then it is necessary to employ other techniques.

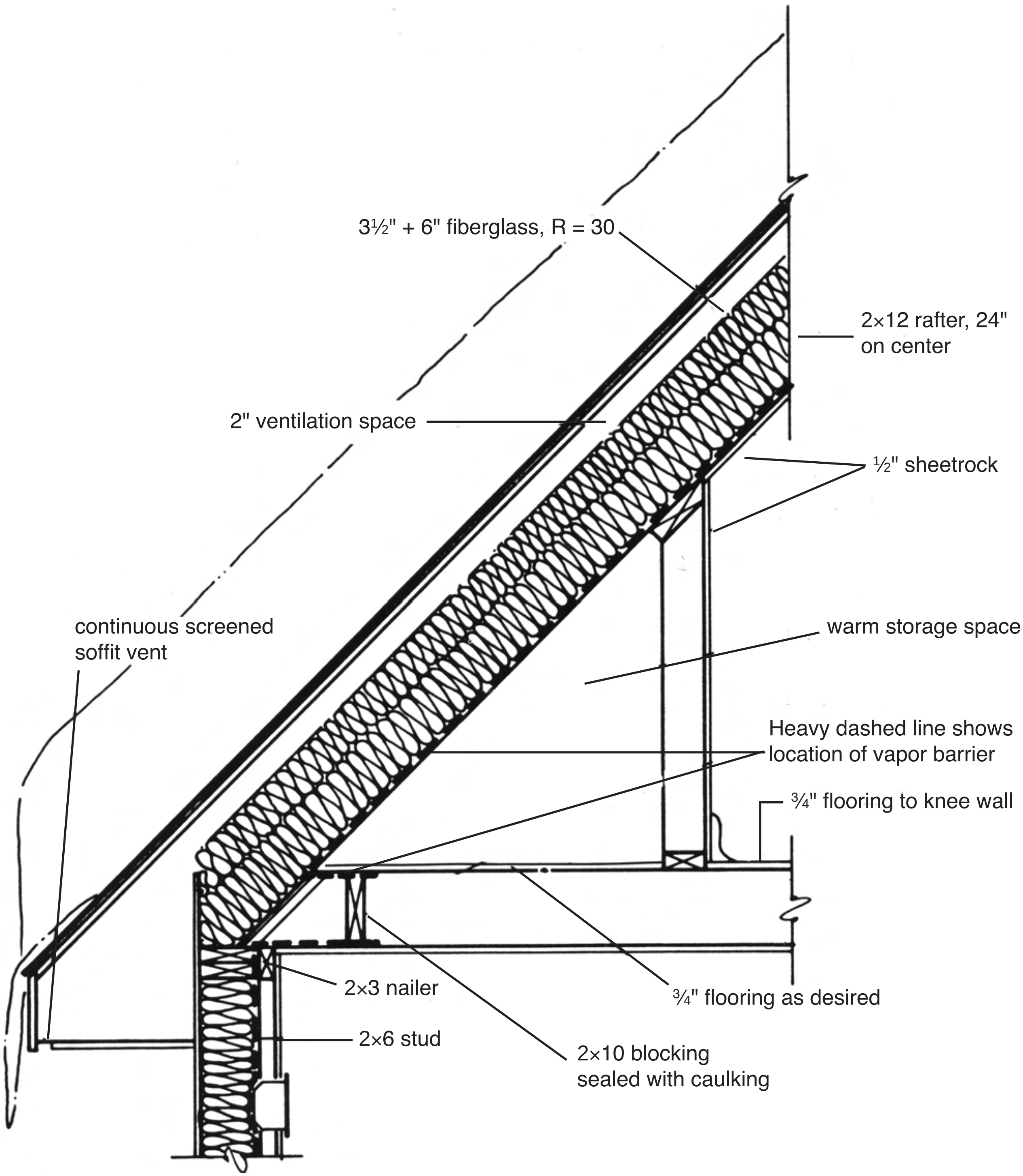
A SUPERINSULATED 1½-STORY

The design shown in Figure 4 is adapted from techniques used in Scandinavian residential construction, as well as in agricultural production buildings in the United States. Instead of using dimension lumber for rafters, this design employs glued and nailed lumber-plywood joists known as “channel beams” (see Figure 6 for construction details).

These beams are commonly built to a depth of either 16 or 24 inches, depending on requirements. Using a 16-inch deep beam involves ripping sheets of plywood in thirds, and the 24-inch beam uses half sheets, ripped lengthwise. Because the strength of a beam varies with the cube of its depth, the deep joints are much stronger than standard dimension lumber, and may be set on 48-inch centers (48 inches on center).

Since neither sheetrock nor most commonly used exterior sheathing will span 48 inches, 2×4 nailers are installed, 16 or 24 inches on center, on both sides of the channel beams. On the inside, the vapor barrier is placed between the rafters and the nailers, thus insuring a virtually perfect vapor seal. Polyethylene apparently seals itself around nails that are driven through it.

Figure 3. Improved thermal and vapor barriers.



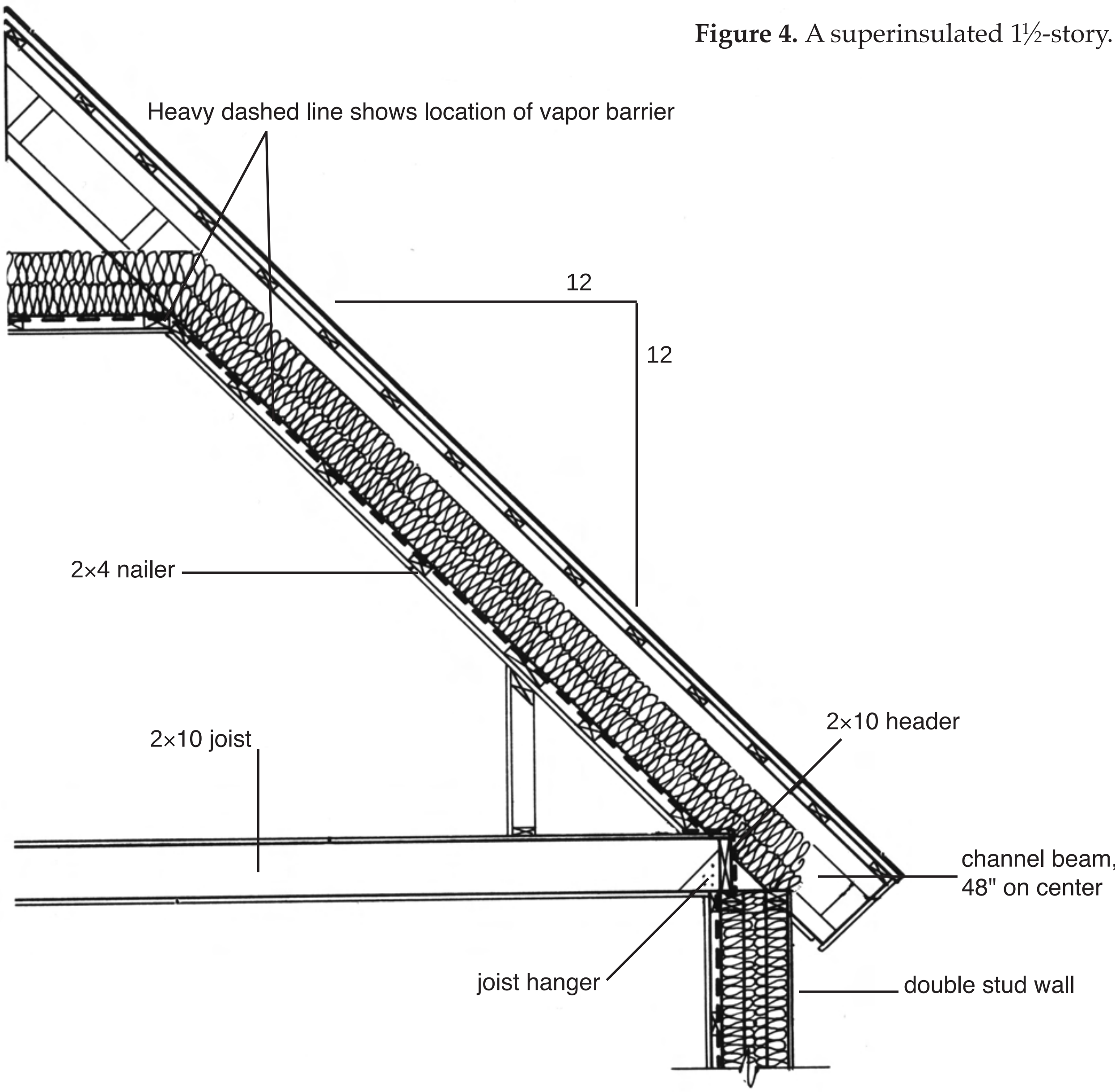


Figure 4. A superinsulated 1½-story.

VAPOR BARRIER DETAILS

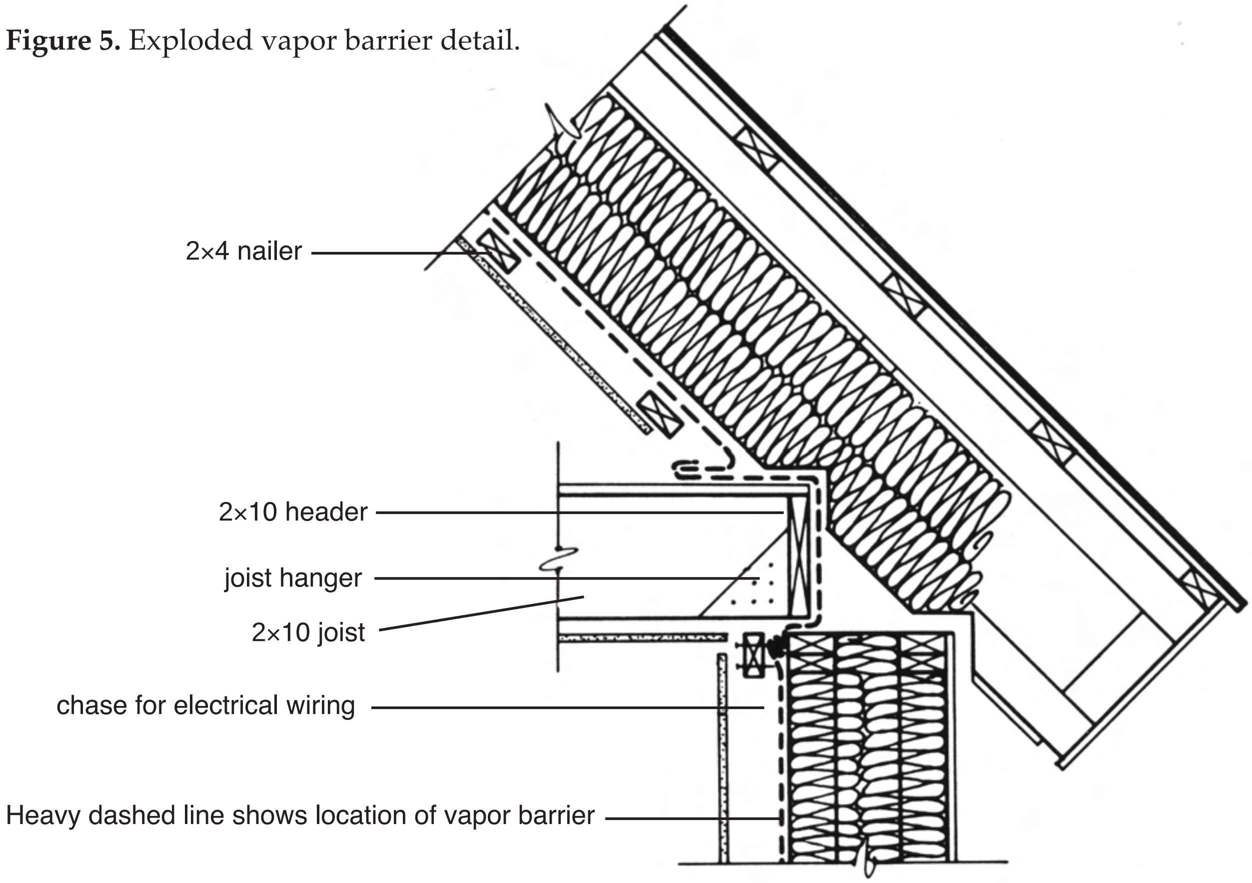
Figure 5 shows details for installing a continuous vapor barrier at a point where conventionally framed 1½-story buildings generally have massive vapor leaks. The trick is somehow to join the wall vapor barrier with the roof vapor barrier. This design accomplishes that objective, which is not to say that there might not be easier, cheaper and better ways of doing the same thing. Construction procedure is as follows:

Step 1: Frame up the double walls, including double top plates. Do not yet install nailers on walls.

Step 2: Cut a 24-inch wide strip of 6 mil polyethylene and lay it over the top plates, allowing it to dangle 4-5 inches on the inside. This will later be joined to the wall vapor barrier.

Step 3: Set the 2×10 headers (assuming the joists are 2×10s) on the inside of

Figure 5. Exploded vapor barrier detail.



the inside wall, over the top of the poly strip. Place header with wood screws.

Step 4: Set floor joists in place, attaching with joist hangers to the header installed in Step 3.

Step 5: Install plywood subfloor.

Step 6: Pull the poly strip up and tack it to the plywood of the subfloor.

Step 7: Set the channel beams, notched as shown, 48 inches on center. Since downward thrust on the beam translates itself into outward thrust at the walls, it is essential that a good connection be made between the rafters and the floor, which acts as a tension member to keep the walls from spreading. The easiest connection might be steel angles, nailed into the sides of the beam and the subfloor and underlying framing. There is, however, an abundance of nailing surface, and toenailing with 16 or 20d nails should provide necessary holding power.

Step 8: With rafters temporarily braced in place, install the roof vapor barrier and perpendicular 2×4 nailers. The seal between the roof vapor barrier and the previously attached 24-inch wide poly strip is made with a bead of Tremco® acoustical sealant joining both laps of polyethylene.

Step 9: With the vapor barrier and nailers in place on the inside, unbacked fiberglass insulation may now be dropped into the roof cavity from above. This procedure is called for because of the difficulty of holding 24-inch wide fiberglass batts in place while installing from below. If one went to the trouble of ordering 48-inch wide backed fiberglass, then it would be possible to install the roof deck first and add the fiberglass from the bottom, as is the more common procedure.

Step 10: Install exterior 2×4 nailers and roof decking. This design shows ply-wood sheathing and asphalt roofing, but corrugated metal is also a popular covering for the 1½-story. If metal roofing is to be used and plywood sheathing omitted, diagonals must be installed to triangulate the roof. Wide steel banding material works well for this purpose. If one is stuffing the roof cavity from above with fiberglass batts, it might be wise to install the nailers first, so as to give better footing while working on the roof.

Step 11: After the roof is under cover, the walls in the lower floor may be filled with insulation, the vapor barrier hung, and the nailers installed. The original 24-inch wide strip of poly is now folder with the wall vapor barrier, and a nailer placed over the fold, with a bead of Tremco® sealant in the joint lap.

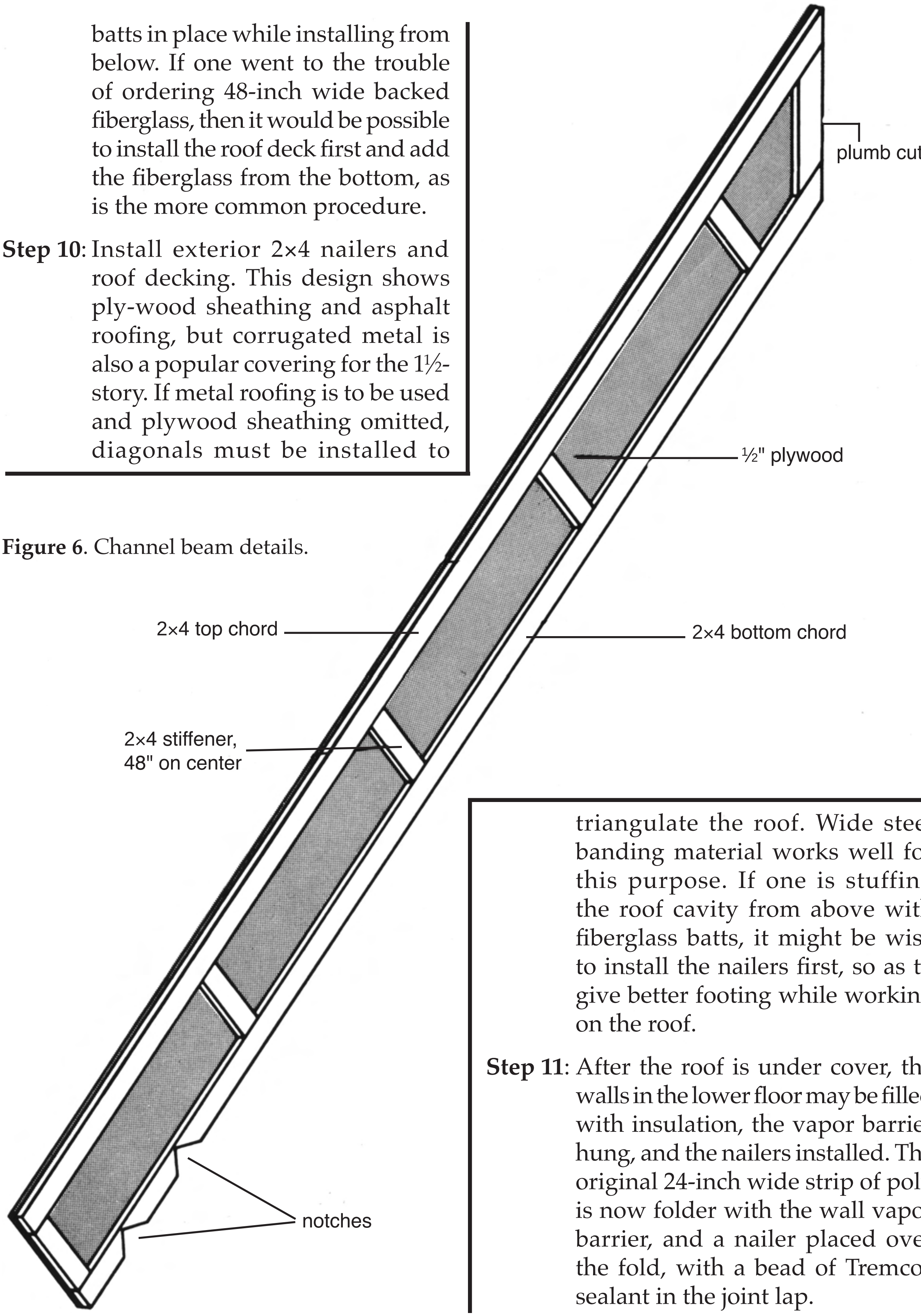


Figure 6. Channel beam details.

INSULATION THICKNESS

Table 1 below shows maximum possible thicknesses of three insulating materials when they are placed in the cavities formed by common framing lumber, and by beams and trusses of standard depths. It is assumed in all cases that there is a 2-inch air space between the top of the insulation and the bottom of the roof deck. Note further that conductance through the framing members is not taken into account in the figures given as R-values. Heat lost through framing members is not so serious a problem in roofs as in walls, because the percentage of surface area made up by framing members is much less. In shallow roofs, however, with framing members 16 inches on center, there will be some drop in performance due to conductance. Some-times in the winter it is possible to see the lines of all the joists or rafters in the roof, because the snow over them has melted more than the snow lying on insulated sections. With deep trusses and beams the conductance is less significant.

Please note that the R-values used for these calculations are approximate. Fiberglass batts and rolls vary from about R3 to R4 per inch, depending on who made them, and to what density. Cellulose may vary 10% from the figure given here. Sawdust, of course, is subject to no quality control whatsoever, and will vary in insulative value with density, moisture content, kind of wood, and consistency of material.

LOOSEFILL INSULATION

For various reasons, a builder may wish to use blown-in cellulose or fiberglass, or sawdust insulation, instead of fiberglass batts. Any of these materials will work in a 1½-story roof, but because of the steep pitch, special provisions must be made to keep the loosefill insulation from settling to the bottom of the rafter cavities and plugging up the ventilation system. For this purpose, it is customary to install a baffle between the rafters, 2 inches or so below the roof deck. According to a local cellulose manufacturer and installer, the best available material for the baffle is nylon-reinforced polyethylene with holes poked in it. Other materials are of course possible, but any material used for this purpose must meet three basic design criteria:

1) The material should be pervious to water vapor. Any vapor that gets through the vapor barrier needs to pass easily through the baffle.
2) The material should be strong enough to take the force of the insulation being blown in against it, and must not be forced up against the roof deck.
3) The material should be cheap and easy to install.

TABLE 1
MAXIMUM POSSIBLE INSULATION, DEPENDING ON FRAMING

		DIMENSION LUMBER				PLYWOOD-LUMBER JOISTS BEAMS AND TRUSSES		
		2×6	2×8	2×10	2×12	16"	20"	24"
FIBERGLASS	Thickness	3.5"	6"	6"	9"	12"	18"	21.5"
Batts, rolls	R value	11	19	19	30	38	60	71
CELLULOSE	Thickness	3.5"	5.5"	7.5"	9.5"	14"	18"	22"
R3.7/inch	R value	13	20	28	35	52	68	81
SAWDUST	Thickness	3.5"	5.5"	7.5"	9.5"	14"	18"	22"
R2.6/inch	R value	8	14	19	25	36	47	57

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This publication incorporates materials developed between 1971 and 1979 by Axel R. Carlson, Extension Engineer, Cooperative Extension Service, University of Alaska, Fairbanks. Under the direction of Mr. Carlson, the manuscript was prepared by Ed McGrath and illustrations done by Clay Pankratz. The employment of McGrath and Pankratz was funded by the Comprehensive Employment Training Act (CETA) Title VI.

Axel R. Carlson is now Extension Engineer Emeritus, Cooperative Extension Service, University of Alaska Fairbanks.

This publication reviewed by Richard D. Seifert, Energy and Housing Specialist, Cooperative Extension Service, University of Alaska Fairbanks.

Chapter 6
Windows

Key Points to Learn

- Windows are the greatest source of energy loss in a modern home.
- It pays to install the best windows you can afford.
- Windows are the primary areas in buildings where radiative heat loss (and gain from the sun) are dominant.

Introduction

Since people want to see the world outside and allow sunlight inside, the walls of homes are fitted with windows. Windows are the greatest source of energy loss in a modern home. It pays to install the best windows you can afford. Today's best windows, when installed properly, lose less energy than the walls of homes built before the energy crisis of the 1970s. Even so, windows must be placed thoughtfully, with the majority facing south to receive natural light and passive solar heat. North windows should be restricted to minimum building code requirements for egress and natural lighting. East-facing windows may be oriented to catch the morning sun, while west windows should be designed carefully to avoid seriously overheating the house in summer.

The importance of windows can be traced back to dark wintry days in Scandinavian fjords where the word originated. Window ("*vindu*" in Norwegian) comes from the old Norse words *vindr auga*, which literally mean "wind eye." One can imagine a small round portal of glass on the windward side of coastal farmsteads that allowed these seafaring people to keep an eye to the wind. Thus a wind eye became the name for our modern window, because it was a direct view of the weather.

Windows ideally provide opportune lighting, security, protection from weather and prevent air leakage. At the same time they are often operable and may be relied upon for ventilation. In Alaskan conditions, they must function as transparent insulation. Their sizing and orientation is a crucial element of thermal design in our climate zone. Windows are very important to obtaining a quality, durable energy-efficient home. They also have marketing importance: they are an important aesthetic feature for homes. Who wants a home with inadequate natural lighting and poorly planned windows? Windows have developed into modern, high-tech building elements that continue to move to higher energy efficiency and durability.

Figure 6.1: This window is weeping moisture because condensation is thawing inside, running out the weep holes, and refreezing outside.

Selecting the Proper Window

Window Styles

Casement

Window styles are many and varied. One of the most popular in the U.S. is the crank-operated casement window. The casement can enhance ventilation by scooping air from the exterior in poorly insulated buildings, where ventilation is necessary for temperature control. Another advantage is that casement windows compress the weatherstrip at a 90-degree angle that helps to seal against high wind conditions. Multiple locking points on the leading edge have become quite popular in cold climates.

Shortcomings of the casement style window include the relatively short life of the crank-operated hardware. In commercial applications such as hotels, apartment buildings, school buildings and rental property, the crank is often missing. All outward-opening windows have another problem in cold climates. The problem is the requirement to have a weep system (method to get rid of condensation and water infiltration) to weep over the sill. This phenomenon causes moisture to refreeze as it weeps over the sill to the outside and it frequently freezes and glaciates under the sash, freezing the sash shut or open (Figure 6.1). The design of the operating system limits the size of the operable sash and frequently requires an egress window to have disconnect links to meet egress codes. Many occupants don't know of or understand the egress window disconnects.

Sliders

Whether they are side sliders, single or double hung (Figures 6.3, 6.4), this style window has minimal or no hardware

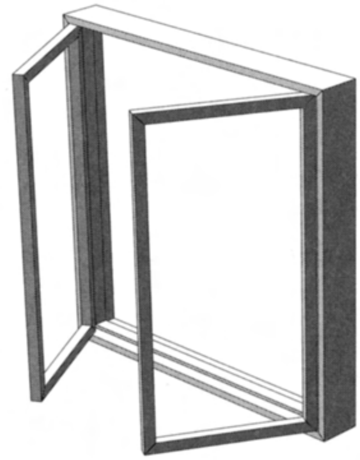


Figure 6.2: Casement window

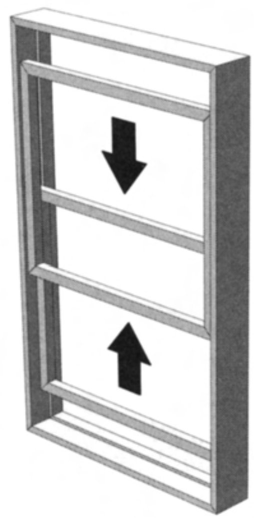


Figure 6.3: Double-hung slider

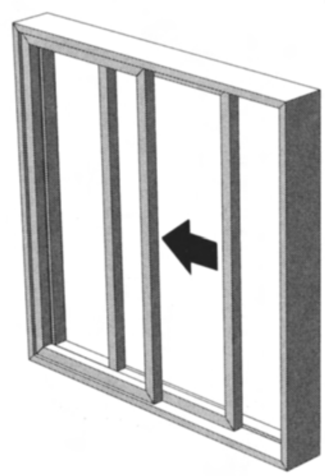


Figure 6.4: Horizontal slider

to malfunction or maintain. The initial cost is reasonable.

Shortcomings of slider windows include the necessity of keeping the sliding track clean and lubricated. The pile-type weather stripping must be replaced frequently, depending on frequency of operation. A minimal amount of frost and ice will render the slider style windows inoperable. Sliding windows that meet egress standards (5.7 square feet of net clear opening) require a significant amount of force to operate. The force required to operate this style window could be a factor when selecting windows for a senior center, hospital, or childcare center.

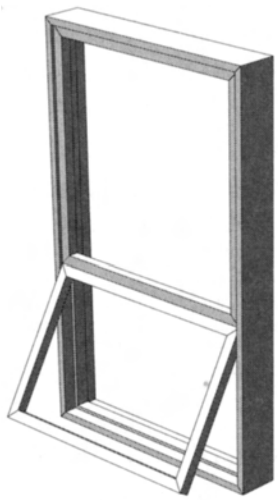


Figure 6.5: Awning below fixed window

Awning

As with all projection windows, the awning-style weather-strip is compressed at a 90-degree angle and can be made to seal relatively well. One of the best features of the awning window (Figure 6.5) is the ability to ventilate during inclement weather and not have an abundance of rain or snow enter the building.

A problem with awning style windows, as with all outward opening windows, is the necessity to weep over the sill, increasing the probability of freezing open or shut. This problem is the most serious where there is high occupancy resulting in high relative humidity. As with all outward opening windows, the insect screen must be mounted inside the operable sash. This usually requires a wicket (small operable screen door) be included in the screen to allow access to the operator.

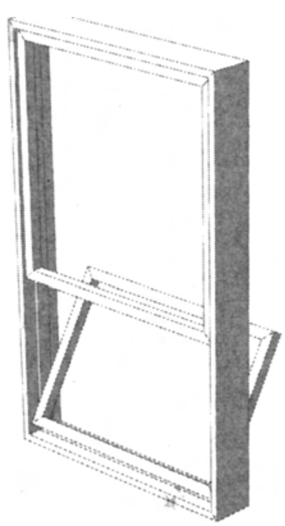


Figure 6.6: Hopper below fixed window

Hopper

As an inward projecting window, the hopper or trough-style window (Figure 6.6) has the advantage of properly compressing the weather-strip material and frequently has more than one locking point to distribute pressure around the sash. Like the awning style, the hopper may be used for ventilation during rainy weather. The sash and frame weep through the frame and will not tend to freeze shut under any condition. Another attribute is this window can usually be opened far enough to clean the outside of the window from the interior of the building. Installing the insect screen on the exterior of the window helps break up air currents and actually enhances the thermal performance of the window.

The disadvantage of the hopper is that they don't readily conform to egress requirements.

H-window

The revolutionary H-window was developed in Norway in the late 1950s to solve a specific Scandinavian window problem. Window washing is a very routine activity in the Nordic countries, and sitting out on a window sill or swinging on staging to accomplish the task is not acceptable. The H-window solved the problem by allowing routine window washing from the safety of the inside of the building.

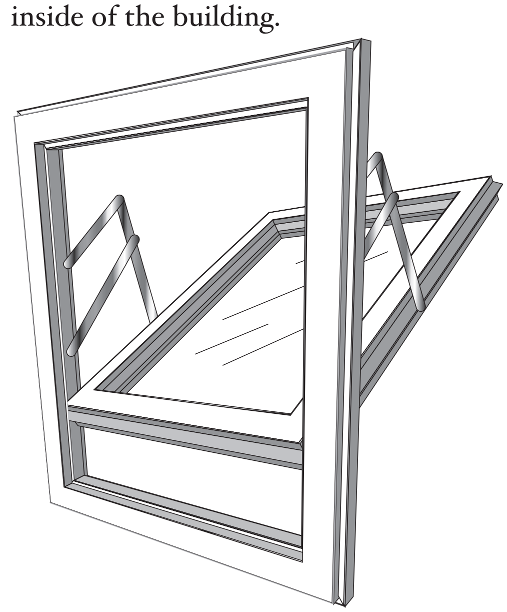


Figure 6.7: H-window

The H-window is not presently widely used in cold, high-wind applications because most systems available are of aluminum or wood. The operating mechanism is expensive and not conducive to rough use. Occasional cleaning and lubrication is essential to enhance longevity.

Turn-Tilt

The Turn-Tilt (officially known as dual action due to copyright) window was developed in Germany before World War II and was produced of wooden mill work. This style window has one operator that unlocks and opens the window, swinging inward from the side to allow emergency egress and for cleaning. By placing the operator in a different position, the window tilts in at the top like a hopper or trough. This position allows for venting in foul weather without having an unhealthy, uncomfortable cold draft on occupants near the window. The glazing pocket and frame are weeped through the frame to the outside. If an abundance of condensation and ice build up on the sash the resultant water cannot enter the frame, making it unlikely to freeze shut. The wrap-around hardware incorporates multiple locking points, compressing the weather-strip on all four sides of the sash. The hardware is fully adjustable and is capable of increasing or decreasing the compression of the weather-strip and raising the sash up and down and rotating it to compensate for any racking, sagging, or settling of the frame.

Drawbacks of the turn-tilt window include the initial cost and the need to lubricate the hardware every two to five years, depending on geographical location and use.

Of the mass-produced European hardware systems that are available, tilt and turn hardware potentially offers the most advantages for the arctic market.

Figure 6.8: A dual-action (tilt-turn) window in the tilt position (top) and in the open or turn position (bottom).

The hardware is now being given a wider introduction into the North American market, mainly in higher-priced urban projects.

The advantages of the tilt-and-turn hardware for arctic windows are:

- multiple locking points for tight air sealing
- on-site adjustable clearances for fine-tuning clearances between the frame and the weather stripping
- no structural loads on the screws holding the hardware in position
- structural loads absorbed by the metal reinforcement of the frame
- capability of supporting heavy triple glazed sealed units
- capability of supporting large sizes of sealed units
- maximum size of about 4 feet by 8 feet so that perimeter heat loss is reduced
- glass is dry mounted and units can be reglazed by homeowner without special tools, materials or training
- cold-weather operation is good, with no reports of freezing shut.

Window hardware should be a primary concern for Alaskan demands. The advantages of superior hardware are numerous, durability is much greater, and judging from the small incremental cost ($30 to $45 per window) we encourage you to select the best available window hardware.

Heat Loss and Solar Gain Through Windows

Knowledge of window terms and technologies is helpful. A few terms that will help understand how energy flows through windows are described below; these are the basic heat flow mechanisms for windows that also apply to all building elements. Familiarity with these terms and concepts will also help you to read labels and talk to building contractors and building supply merchants.

Conduction is the flow of heat through a material. One molecule transfers heat to the molecules next to it. Direct conduction occurs through glass, the window frame, and the edge seals.

Convection is the flow of heat within a fluid. The misunderstanding of convection has led to the phrase "heat rises." Actually, hot air convects upwards because it is lighter (less dense) than cold air. This is relevant to windows because convection occurs as downdrafts—the familiar drafts below windows—from cold window surfaces. Convection currents in the space between the panes transfer heat from the inner peice of glass to the outer one.

Radiation is the transfer of electromagnetic waves (infrared, ultra-violet, visible), from one separate body to another. Heat energy is transferred in the infrared band. This is how the sun heats the earth. Radiant heat transfer makes you feel cold standing in front of a cold window, even if the inside air is warm. Your body radiates heat to the cold window surface. Windows are the primary areas in buildings where radiative heat loss (and gain from the sun) are dominant.

R-value is a measure of the resistance of a material or an assembly of materials to heat flow. It is expressed in English units as hr-ft^2-F/BTU. Window manufacturers and engineers commonly use the R-value to describe the rate of nonsolar heat loss or gain through the window. The higher a window's R-value, the greater the resistance to heat flow and the greater the insulating value.

Solar heat gain coefficient is the fraction of solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater its shading ability. Solar heat gain coefficient can be expressed in terms of the glass alone or can refer to the entire window assembly. (Solar heat gain coefficient or SHGC shown on National Fenestration Rating Council (NFRC) labels are for the entire window.

Reducing Heat Loss From Windows

By understanding the mechanisms for heat loss from windows, people have developed technologies to minimize these heat losses (Figure 6.9). Some examples include:

1. Increasing the air space between the sheets of glass or plastic to at least ½ inch.
2. Increase the number of still air spaces. By going from double or triple pane, to quadruple glazing, the R-value increases by about R-1 for every ½-inch air space that you add. (See Figures 6.10 and 6.11)
3. Reflect heat radiation back into the house. Radiant heat losses, which account for a large component of heat loss through window glass, can be reduced with heat-reflective coatings. Heat-reflective coatings are also known as low emittance or low-E coatings. Heat reflective coatings are placed on glass or plastic sheets, which are then built into double- or triple-glazed windows. A heat-reflective coating on one sheet of glass in a double-glazed window will give that window an R-value approximately equal to that of a typical triple-glazed window. The solar transmission of these windows also is affected. The solar heat gain coefficient is decreased as less solar radiation is allowed to pass through these windows (see Figure 6.11)
4. Using a gas fill between the panes of glass, which is a better insulator than air, will decrease heat loss and will not reduce the shading coefficient of the glazing.

Table 6.1 shows the R-values of various windows and includes a description of the effects of the metal frame of the window. Metal frames are such good conductors of heat that they cannot be recommended for Alaska and

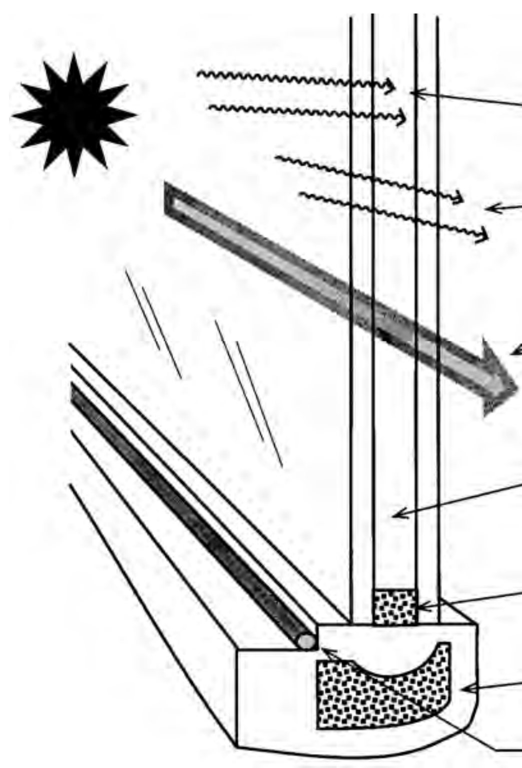


Figure 6.9: Energy-efficient window

Table 6.1: Window R-values and dew points

Type Glazing	Insl. R–val	To, F	−60	−50	−40	−30	−20	−10	0	10	20	30	40	50
		Outside Temperature (To, F), Temperature Gradient (Tg, F), Relative Humidity (Rhi, Pct)												
SINGLE GLAZING	0.85	Tg, F	−34	−26	−18	−10	−2	6	14	22	30	38	46	54
		Rhi, Pct	1	1	2	3	5	7	10	15	22	31	42	57
DOUBLE GLAZING														
center of glazing ½-inch airspace	1.70	Tg, F	18	22	26	30	34	38	42	46	50	54	58	62
		Rhi, Pct	13	15	19	22	26	31	36	42	49	57	66	76
½-inch air space filled with argon	2.10	Tg, F	28	31	34	38	41	44	47	51	54	57	60	64
		Rhi, Pct	20	24	27	31	35	39	44	50	56	63	71	80
½-inch airspace, hard-coat low-emissivity coating	2.66	Tg, F	37	39	42	44	47	50	52	55	57	60	62	65
		Rhi, Pct	30	33	36	40	44	48	53	58	64	70	77	84
½-inch airspace, soft-coat low-emissivity coating	2.90	Tg, F	40	42	44	47	49	51	54	56	58	61	63	65
		Rhi, Pct	33	36	39	43	47	51	56	61	66	72	78	85
¾-inch airspace with low-emissivity coating between i.e., (two spaces of ⅜ inch)	3.29	Tg, F	43	45	47	49	51	53	56	58	60	62	64	66
		Rhi, Pct	38	41	44	48	52	56	60	65	70	75	81	87
¾-inch argon-filled space with low-emissivity coating between (two spaces of ⅜ inch)	4.03	Tg, F	48	50	51	53	55	57	58	60	62	63	65	67
		Rhi, Pct	46	49	52	55	59	62	66	70	75	79	84	89
¼-inch air space														
wood frame	1.79	Tg, F	21	24	28	32	36	40	43	47	51	55	59	62
		Rhi, Pct	14	17	21	24	28	33	38	44	51	59	67	77
metal frame	1.41	Tg, F	7	12	17	22	27	31	36	41	46	51	56	60
		Rhi, Pct	7	10	12	15	19	24	29	35	42	50	60	71
thermally broken metal frame	1.69	Tg, F	18	22	26	30	34	38	42	46	50	54	58	62
		Rhi, Pct	13	15	18	22	26	31	36	42	49	57	66	76
½-inch air space														
wood frame	2.16	Tg, F	29	32	35	39	42	45	48	51	54	57	61	64
		Rhi, Pct	21	25	28	32	36	40	45	51	57	64	72	80
metal frame	1.69	Tg, F	18	22	26	30	34	38	42	46	50	54	58	62
		Rhi, Pct	13	15	18	22	26	31	36	42	49	57	66	76
thermally broken metal frame	2.04	Tg, F	27	30	33	37	40	43	47	50	53	57	60	63
		Rhi, Pct	19	22	26	29	34	38	43	49	55	63	71	79
½-inch air space, low emissivity coating														
wood frame	2.78	Rhi, Pct	38	41	43	46	48	50	53	55	58	60	63	65
		Rh, %	31	34	38	41	45	50	55	60	65	71	78	84
metal frame	2.10	Tg, F	28	31	34	38	41	44	47	51	54	57	60	64
		Rhi, Pct	20	24	27	31	35	39	44	50	56	63	71	80
thermally broken metal frame	2.53	Tg, F	35	38	40	43	46	48	51	54	57	59	62	65
		Rhi, Pct	28	31	34	38	42	46	51	57	62	69	76	83

1. Window R-values taken from Canadian Home Builders Association Builders Manual.
2. Temperature gradient, (Tg, F), Allowable relative humidity, (Rh, %). Temperature gradient and dew point temperature are equal.
3. Developed by Axel R. Carlson, Professor Emeritus, Extension Engineer, Cooperative Extension Service, University of Alaska Fairbanks, Fairbanks, AK 99775-6180.

TABLE 6.1: Window dew point conditions (continued)

		Insl.	To, F	−60	−50	−40	−30	−20	−10	0	10	20	30	40 50
Type Glazing	**R-val**	**Outside Temperature (To, F), Temperature Gradient (Tg, F), Relative Humidity (Rhi, Pct)**												
TRIPLE GLAZING														
½-inch air space	2.79	Tg, F	38	41	43	46	48	51	53	55	58	60	63	65
		Rhi, Pct	31	35	38	42	46	50	55	60	65	71	78	85
TRIPLE GLAZING														
wood frame	3.30	Tg, F	43	45	47	49	51	54	56	58	60	62	64	66
		Rhi, Pct	38	41	44	48	52	56	60	65	70	75	81	87
metal frame	2.32	Tg, F	32	35	38	41	44	47	49	52	55	58	61	64
		Rhi, Pct	24	27	31	34	39	43	48	54	60	66	74	82
metal frame	2.90	Tg, F	40	42	44	47	49	51	54	56	58	61	63	65
		Rhi, Pct	33	36	39	43	47	51	56	61	66	72	78	85
thermally broken	4.34	Tg, F	50	51	53	54	56	57	59	61	62	64	65	67
metal frame		Rhi, Pct	48	51	54	58	61	64	68	72	76	81	85	90
low emissivity	4.34	Tg, F	50	51	53	54	56	57	59	61	62	64	65	67
coating		Rhi, Pct	48	51	54	58	61	64	68	72	76	81	85	90
WALL 2 x 6 STUDS														
6-inch fiberglass	19.97	Tg, F	66	66	66	67	67	67	68	68	68	69	69	69
		Rhi, Pct	86	87	88	89	90	91	92	93	94	95	97	98
Plate & Sole, 2 x 6	6.88	Tg, F	57	58	59	60	61	62	63	64	65	66	67	68
		Rhi, Pct	64	66	68	71	73	76	79	81	84	87	90	93
SUPER-INSULATED,														
DOUBLE STUDS	30.00	Tg, F	67	67	68	68	68	68	68	69	69	69	69	70
		Rhi, Pct	90	91	92	93	93	94	95	95	96	97	98	98
INSIDE CONDITIONS														
Interior film		Ri	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Temperature, Ti, F =		Ti, F	70	70	70	70	70	70	70	70	70	70	70	70
Saturated pressure, PsfPsi, Psf		52.2	52	52	52	52	52	52	52	52	52	52	52	

1. Window R-Values taken from Canadian Home Builders Association Builders Manual.
2. Temperature gradient (Tg, F), Allowable relative humidity (Rh, Pct) Temperature gradient (Tg, F) and dew point temperature (Tdw) are equal.
3. Developed by Axel R. Carlson, Professor Emeritus, Extension Engineer, Cooperative Extension Service, University of Alaska Fairbanks, Fairbanks, AK 99775-6180.

circumpolar conditions. The edge of a single window is worth discussing, because the edge effects were not of great concern before multiple pane, low-E, and gas-filled windows were widely used. As the glass became more insulative, the effect of including frame in the performance of the window became much more important. Today, the window frame and glass edge effects play a critical role in determining overall insulating R-values of windows. One factor to consider related to the edge effect is that a larger window is less impacted by these edge effects, simply because the perimeter is a smaller portion of the whole system.

Window frames are not at a higher stage of technical development, however. Frames are only at the initial stages of improvement, and much potential still remains to develop better window frames. A close inspection of Table 6.1 will show this. Compare the frame R-values between aluminum and wood framing, for instance. Aluminum frames with or without a thermal break are not recommended for Alaska applications.

Improving Window Thermal Performance

Heat losses through the window frame can be reduced in the following ways:

Use an airtight seal between the glazed unit and the sash. This is accomplished with durable, flexible gaskets and glazing boots. Use fixed (nonoperable) units. It is generally easier to ensure an airtight seal.

Provide an airtight seal between opening sashes and the window frame. The airtightness of this joint depends on the type of weather stripping used and the amount of pressure that can be placed on the window frame and opening sash joint. Sliding windows, whether horizontal or vertical, tend to have the highest air leakage rate because positive closure and compression is more difficult. Turn/tilt, casement, awning, and hopper windows tend to be more airtight, since more pressure can be placed on the weather-stripped joint. Any warping of the opening sash will also affect the airtightness of an openable window. Compressible weather-strip made of EPDM (ethylene propylene diene monomer), TPE (thermoplastic elastomer), or silicone compounds is desirable for cold climates. A standard test procedure rates windows on the basis of the volume of air leaking through the window at a standard pressure difference. Air leakage test results (as discussed in the section on air infiltration or air leakage) can be used to compare one window with another, but certain factors must be considered when studying test results: (1) windows that are tested are new; (2) test windows are built to be tested; and (3) during structural testing, the windows are the same temperature on both sides.

Center-of-glass Insulation

In the past, many window manufacturers advertised the thermal performance of their windows as if they were of infinite size, without any edge effect or heat loss through the frame. Increased customer awareness and the formation of the NFRC in 1989 caused a change to this practice. Windows tested under the NFRC procedure are tested for the overall window of a specific size. The center-of-glass R-value can be very impressive but is of little use when calculating heat loss from a building. The actual thermal performance of a window depends on the framing materials used, the edge spacers, the degree of glass inset into the frame, and other characteristics. The thermal performance in the center of the glass is better than the whole unit performance, so in general, larger windows will have a better overall thermal performance than small ones and a fixed window will be better than an opener. When comparing windows, you must know the type of information you are being given.

Gas-filled Air Spaces

The space between the panes of glass can be filled with gases that insulate better than air. Argon, sulfur hexafluoride, and krypton are among the gases that have been used for this purpose. Gas fills add little to the cost of most windows and have proven most effective when used in conjunction with low-E coatings. For these reasons, some manufacturers have made gas fills standard in their low-E windows. Table 6.1 provides R-values for some low-E and gas-filled window configurations. Table 6.2, gas R-values, shows the different insulative values for different gas fills of windows. Note also that in the second column of Table 6.1, the R-Values are for the center of the glass only and do not account for the edge effects.

Table 6.2: Gas R-values (extrapolated from Energy Design Update, Nov. 1991)

Inches	Air	Argon	Krypton
0.250	2.21	2.50	3.68
0.375	2.79	3.31	3.81
0.500	2.90	3.59	3.72
0.625	2.90	3.40	3.61
0.750	2.90	3.40	3.61
1.000	2.90	3.31	3.42

Minimize heat conduction through the window frame by: (1) using a low conductivity material such as wood, fiberglass, or vinyl for the window frame; and (2) using a window frame with air chambers or thermal breaks.

Recently a vacuum technology window glazing system has been introduced in Japan. This is the world's first com-

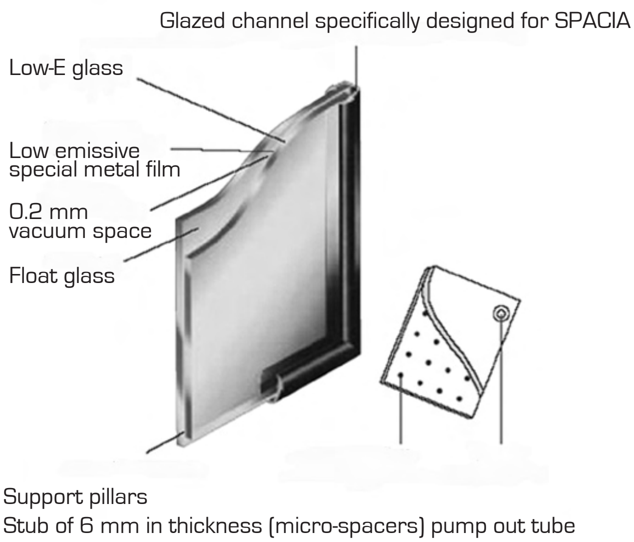


Figure 6.10: Structure of the vacuum glazing unit.

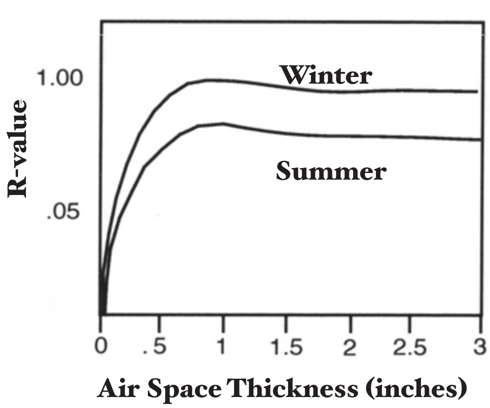


Figure 6.11a: Thermal resistance of air space

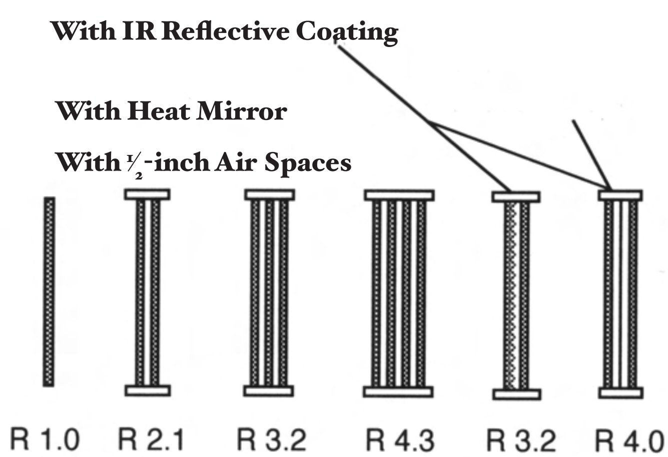


Figure 6.11b: Insulation values of glazings

mercialized vacuum glazing. Figure 6.10 shows how this glazing system is configured. Although this is a wonderful option, it is not available in the North American market and there are no plans for making it available. The vacuum glazing made by Nippon Sheet Glass Co. claims to achieve an R-value of 3.85 in a glazing system lighter than a single pane of North American window glass and only 8 mm thick.

Air Space

The higher the number of air spaces, the higher the R-value and the lower the heat loss through the window. The number and thickness of the air spaces between glazing is the most important factor. Windows with a ¼-inch air space between glazing (even with low-E glazing) have a lower R-value than windows with ½-inch or more air space. In most cases, however, air spaces of more than 1 inch will be less effective than ¾-inch space, due to convective air movement between the panes of glass. Air spaces over ¾-inch allow unrestricted convection, and that transfers heat from the inner pane of glass to the outer pane at a faster rate. The difference in temperature and the height of the window also affect the amount of heat transferred by convection.

Air Space	R-value
¼ inch	R-1.5
½ inch	R-1.8
1 inch	R-1.96

Storm Windows

One practice used to increase the number of air spaces in a cold-weather window is to install a storm window. Storm windows are commonly referred to as RGPs or removable glass panels. Storm windows will improve the performance of a thermal pane window, but a few rules must be followed. The storm window should be within ¾ inch of the main window to keep convection flow between the panes under control. The added pane should never be installed on the inside of the main window. The added-on panel will not have an airtight seal and if it is on the interior, it will allow moisture-laden inside air to come in contact with the cold main window. The resulting frost and ice buildup will eventually melt and cause problems. Figure 6.12 shows an example of this common mistake. Window quilts and interior shutters will have an equally disastrous effect on the window and wall. All of these interior accessories prevent warm air from reaching the main window, but not the moisture.

Low-E

Low-E glazing systems are now widely accepted for all energy efficient buildings. The low-emittance (low-E) surface blocks radiant heat loss and warms up the inner surface of the glazing. The low-E surface is either vacuum

Figure 6.12: Frost has built up between the storm window and the main window. It will eventually melt and cause water damage.

"sputtered" onto finished glass for a .002 inch polyester membrane (the so-called soft coat), or applied hot during glass manufacture (hard coat). When the film is applied to the polyester membrane, the membrane is suspended between the panes of glass, establishing two air spaces as well as the radiant heat reflection. This configuration is trademarked Heat Mirror.

The soft coat surfaces deteriorate when exposed to moisture, so can only be used in sealed units. Hard coat is more durable and can be used for window surfaces exposed to the air. While this durability difference is used to market hard coat low-E windows, it has no significance in sealed unit windows. A second generation hard coat process has been recently developed to reduce the emissivity (increase R-value) and control the solar heat gain coefficient (the ability to transmit solar energy).

Argon and Other Gas Fills for Windows

Argon is an inert gas that is denser than air. An air space properly filled with argon can result in an R-value increase of 1.0. In general, the theoretical R-value of an insulated low-E window will go from R-3.0 to R-4.0 with the addition of the gas. Krypton gas is also now being used for window fills. Table 6.2 shows the various R-values and respective gas layer thicknesses presently used in windows. Care must be taken to optimize spacer thickness for gas filling because heavy gases convect more readily than air.

There is a somewhat hidden issue that needs to be understood when shopping for windows that use a gas other than air between the panes. Both the commonly used inert gas options, argon and krypton, diffuse slowly out of the space between the panes through the edge-spacer sealing compound. This diffusion is very slow, however. Even though it is slowly lost, the gas fill is much better at insulating the window than air. Argon fill for a ½-inch air space (see Table 6.2) is .69 R-value better than air. This is a 27% improvement over air in a simple double-pane glazing with a ½-inch space, over an air-filled space. With a triple-glazed or heat mirror type window the advantage is nearly doubled, since there are two argon-filled spaces.

Although the precise energy savings are difficult to determine, these advantages of argon (or krypton) fill are significant enough and add very little incremental cost to the window. In fact, one retailer of windows in Fairbanks doesn't charge anything extra for the argon, at least when they're selling the top quality (triple glazed, double argon space, double low-E) grades of windows. Homeowners are well advised to purchase argon-filled windows.

Window Edge Insulation

Window edge effect pertains to the thermal short through the glass and glass spacers of an insulated unit. This phenomenon affects the first 2½ inches on the perimeter of an insulated glass unit. The ratio between this 2½ inch band around the perimeter of the unit and the overall window cross-section determines the impact on overall thermal performance. A very small window will have poor overall performance regardless of the enhancements of gas filling and low E coatings.

Figure 6.13 is a good example of heat flow through cold-weather windows. The frost visible on these sunroom windows is on the outside. The high performance insulated glass in this sunroom does not lose enough heat to keep the outer pane of glass above the dew point for the humidity of the night air. Note that the 2½ inches along the edge does transmit enough heat to keep the condensation from forming, even with thermally enhanced spacers. Also note the top 18 inches of the window is frost free. This is due to the overhang of the roof shielding the glass from the night sky. A clear night sky will absorb 100% of the infrared transmitted from exposed surfaces. It would have an emissivity of 1 as a perfect absorber. The roof overhang prevents the glass from "seeing" the night sky.

Most windows use aluminum spacers to separate the panes, an unfortunate choice from a heat loss point-of-view. For windows used in cold climates, some manufacturers have substituted foam spacers and thin metal spacers standing on edge, encapsulated in sealant, to help reduce the edge effect. Southwall's Heat Mirror units must use steel spacers to withstand the drumhead effect of the polyester membrane when it is suspended between the panes. These steel spaces are frequently separated by a foam thermal break. Another approach is to simply recess the spacer deeper in the frame and thereby reduce the conduction of the edges by "sheathing" them in framing and glazing gaskets. This is a common practice in European-designed PVC window systems.

The edge spacer is clearly a weak spot in the thermal performance of windows. To counteract the edge losses of heat, research into suitable material substitutions for edge spacers has been ongoing for more than a decade.

Some materials tested include a corrugated metal spacer, a metal spacer with a polyurethane thermal "break" (an insulated spacer), silicone foam spacers, and vinylm butyl-rubber edge spacers.

Particularly good performance has been achieved with the "warm edge" technologies, both the vinylm butyl-rubber and silicone foam materials. They do cost more than standard metal edges, but the better performance makes this technology suitable for all window systems. It should be consid-

Figure 6.13: There is condensation on the outside of these windows, but the edge effect and a roof overhang make the edges and the top of the windows warm enough to be frost-free.

Figure 6.14: Ice accumulation from condensation on the very bottom of a window: the coldest place on any window surface.

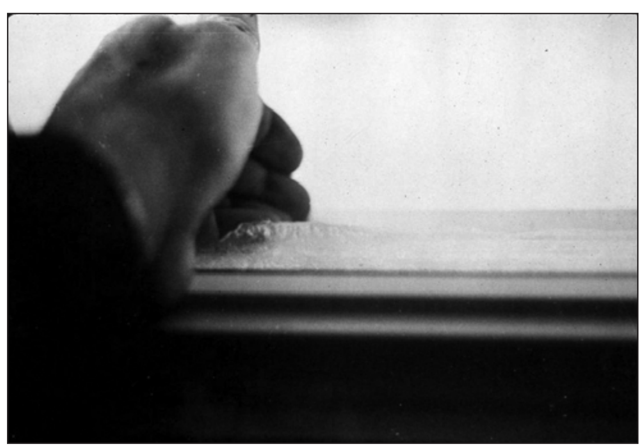


Figure 6.15: Another example of ice accumulation during extreme cold on the bottom of a window pane.

ered mandatory when low-E coatings and inert gas fills are used. If warm-edge technology is not used with these technologies, much of the benefit of these technologies is lost by the poor performance of normal metal edge spacers.

Additional Glazing Options

There are some interesting materials other than glass that are now available for architectural and home applications. Some of the more diverse options are available from Kalwall Corporation (Figure 6.16). Kalwall's products are patented translucent glazings, panels, and flexible fiberglass. A series of products made for applications as either windows or translucent wall sections are available. They are in panel form, typically either in 4 or 5 foot wide choices, and lengths in 1-foot increments from 3 to 20 feet.

Even more of interest is that some of Kalwall's products have substantial insulation value while still maintaining translucence. While the light transmittance decreases as the insulating value of the panel increases, panels with an R-value of 10 (U = .10) are rated at .18 solar heat gain coefficient, and 18% of the light transmission of full sun. This may be the closest option available to translucent insulation. An option with 5% light transmission and an R-value of 20 is also available. This is a product designed for use as a skylight, so light transmission is not its highest positive feature. The R-10 material is perhaps the most interesting because it could find wide application as a translucent shutter. R-10 is more than twice the R-value of heat-mirror type glazings, so this material still has some daylight transmission capability but is effectively an insulating shutter. It also weighs less than 2 pounds per square foot, much less than glass or wooden-framed shutters with insulation.

Figure 6.16: An example of a Kalwall glazing used in an elementary school in Rochester, New Hampshire. This is the R-10 translucent glazing material, a double surface fiberglass with insulation between the fiberglass sheets. The view is from the inside of the building, so that actual light levels are shown. (Photo from www.kalwall.com)

Frame Materials

Wood

Wood has been the most traditional window frame material due to its thermal properties, availability and ability to be milled into complex shapes. The beauty of wood makes it the most desirable of all framing material but it must be well maintained and kept in good condition. It is not intrinsically the most durable window frame material because of susceptibility to rot and mold in cold climates where condensation is likely. They require routine maintenance to have a reasonable longevity.

Aluminum

After World War II, aluminum windows quickly gained popularity in the United States. The aluminum industry had grown to huge proportions supporting the war effort, and extruding techniques and alloys made it possible to extrude strong, complex shapes to the close tolerances required for the window industry. Unfortunately, one of aluminum's attributes is its ability to conduct heat. The very attribute that makes aluminum the material of choice for heat sinks in electronic equipment and fins for fin tube baseboard convectors makes it a very poor choice for window frame material in cool climates. Even with the best thermal break incorporated in the design, aluminum window frames are a poor choice for windows when there is high humidity and low temperatures. Aluminum is used in store fronts and window walls were it is exposed to low relative humidity and there is a requirement for high tensile strength.

Vinyl

Another construction material product that was developed during World War II was plastic. PVC, or polyvinyl chloride, found its way into the war effort because it was impervious to moisture and corrosion. At war's end, some European chemical companies developed extrusions that copied the millwork of the pre-war wood windows. There was a lack of good wood, a great need for replacement windows, and a plastics industry with nothing to do. In the late 1940s and early 1950s a new industry was born. The first PVC windows had many inherent problems. There was brittle fracture due to aging and cold temperatures, ultraviolet bleaching, and problems welding the extrusions in a factory environment. PVC windows had a poor reputation until compounding of the plastic solved those problems and vinyl windows gained popularity. In the 1970s the Scandinavian countries adopted the practice and plastic windows became prevalent throughout Europe and Scandinavia. PVC windows were introduced to North America in the 1980s and gained a strong foothold in the 1990s.

The new vinyl windows solved many window problems. They virtually eliminated the need for preservation, and they have good thermal properties. The frame and sash can be welded, eliminating the need for corner keys and mechanical joints. If the vinyl window is properly designed, properly manufactured, and properly installed, it will last the life of the building.

However, vinyl has some characteristics that are not beneficial, and these must be dealt with or their life expectancy will be limited. This material has a high coefficient of thermal expansion, which becomes an issue in cooler climates. The relative movement between the frame and insulated glass unit creates the need for dry glazing, adequate clearance in the glazing pocket, and a mounting system that allows the window frame to move as necessary during seasonal temperature changes. The second biggest problem with vinyl window frames and sashes is their elasticity. This characteristic causes the plastic to flow when pressure is applied to one area (much like hanging trousers on a plastic coat hanger). Fixtures cannot be screwed to the plastic as they are to wood and aluminum. As torque is applied to a screw, the plastic tends to flow with the threads. Therefore, good quality vinyl windows are reinforced with steel. Load-bearing operating hardware and mounting clips are attached to the steel reinforcement. The need to reinforce the vinyl reduces its thermal performance and increases the cost to manufacture, which is why most North American manufacturers omit the reinforcement.

Fiberglass

Glass-fiber-reinforced polyester or fiberglass windows are slowly capturing a market share (Figure 6.17). Although one of the newest products in the fenestration industry, it has been in development for years. The first patents for pultrusions were issued in 1946. This material offers an alternative to metal, plastic, and wood with most of the advantages and few of the disadvantages. The fiberglass lineal is fabricated using a process known as pultruding. This is a process of pulling fiberglass roving and matting through an impregnation station to coat each fiber with a specially formulated heat-setting resin mixture. The coated fibers are assembled by a forming-shaping guide and drawn or pulled through a die. Under pressure and heat, the resins are cured. The result is a high-strength profile, ready for use as it leaves the pultrusion machine. This process is irreversible. The lineal cannot be melted or reformed, as PVC can. The resin used in fiberglass pultrusions is thermoset, as opposed to thermoplastic as used in PVC-extruded windows. This process produces material that is stable up to 350 degrees F, so it does not suffer from heat buildup from infrared being absorbed in dark-colored frames. Dies have been developed to produce very intricate shaped pultrusions with a thin wall thicknesses. Fiberglass pultrusions are dimensionally stable, have good thermal characteristics, and have a high tensile strength, and the coefficient of thermal expansion is similar to the glass unit it is supporting. The original pultrusions were very expensive, but as the pultruding techniques become refined the cost of manufacture is coming more in line with other window framing material.

Figures 6.17a & b: Two views of fiberglass window frames taken at the Fairbanks Home Show.

Air Infiltration or Air Leakage

Air leakage is sometimes touted as a major parameter in selecting one window over another. Although air leakage is a big factor in the overall energy efficiency of a window, you should fully understand the numbers on the NFRC label before casting your expectations in stone. Leakage of the window will of course increase as the differential pressure acting on it increases. In interior and northern Alaska, the stack effect of a two-story building will induce pressure on the outside of the first-floor windows and on the inside of the second story windows. In Fairbanks, it is not uncommon to observe frost around the sash of second-story windows when the first-floor windows appear frost free (Figures 6.18 and 6.19). In coastal and southeast Alaska, wind pressure will load the outside on the windward side and the corresponding vacuum will load the inside of the windows on the leeward side.

The problem with hanging your hat on the posted infiltration rate is that the procedure used to measure air leakage (ASTM E 238) is somewhat dated and was probably more relevant when not all windows had weather strip or the weather strip used was spring-loaded steel or rigid plastic. The procedure calls for 1.57 pounds per square foot (75 Pascals) applied to the exterior only. Outward-opening windows such as casement and awning could have marginal hard wear and weather stripping, and the test pressure will help seal them. The test specimen is also tested at 69.8 degrees F (21° C) and 50% relative humidity with no differential temperature across the unit. It is important to consider (1) the window used to develop this air infiltration rating was built to be tested, (2) the window tested was new, and (3) the window tested was the same temperature on both sides.

Figure 6.18: This photo shows frost from leaky windows on the top story, while the first and second stories are less frosty.

Figure 6.19: This frost on a second-story window is the result of air being pushed out by the stack effect through a poorly installed seal around the window.

Weather Stripping and Dry Glazing Gaskets

It is a good engineering practice to dry-glaze PVC windows in cold climates due to the high coefficient of thermal expansion of the plastic. Dry-glazing is the practice of sealing the glass with gasket-like material and not a sealing compound and glazing tape. This allows the glass to move in the glazing pocket but remain air and water tight. Glazing with tape and bedding compounds should be reserved for warm climates. At temperatures above 50 degrees F, a lot of resilient weather strips and glazing gasket look and feel the same. Some of the more popular materials are listed here.

- TPR (tampo plastic rubber) is plastic and will become rigid around 10 degrees F . It is coextrudeable and weldable. TPR will test well at 69.8 degrees F, which is required by ASTM E-238.
- EPDM (ethylene porpylene diene monomer) is synthetic rubber and will not freeze at -40°F. It is not weldable or coextrudeable but may be bonded chemically. EPDM's shortfall is its coefficient of thermal expansion, which causes it to contract substantially as the temperature drops. It is necessary to cut EPDM weather strip at least 10 percent long and work it into the weather-strip retainer.
- TPE is a compound of plastic and rubber and does not have the shortfall of TPR or EPDM. TPE is extrudable and weldable and performs very well at low temperatures.
- Pile-type weather strips like those used on double hung and sliding windows will appear suitable when new and tested by the present procedures. One of the best ways to evaluate weather stripping is to examine windows that are three to five years old. A weather-strip is just a gasket. It must be compressed to seal. If it is compressed it will not slide. Another requirement of the air infiltration test is a maximum force to operate. A vertical sliding hung window in a residential Class can require 45 lbs to operate. A more realistic light commercial class can take 50 lbs to operate. Many seniors and children may have trouble operating this kind of window.
- When there is a desire for extremely tight weather strip, silicone base material could be used. Silicone is soft and will not freeze, so it seals very well at all temperatures. A problem with silicone is it is expensive and vulnerable to mechanical damage.

Windows as Solar Collectors

An often-asked question regarding high-performance windows is whether they should be used on south-facing windows. The answer is complex. About 86% of the solar radiation striking a single pane of glass is transmitted through the glass. Double-pane glass allows about 70 to 75% of solar radiation through, triple glazing about 60%. Low-E double glazing will transmit about 50 to 60%. So, there is about a 15% to 20% higher loss in solar gain with high-performance glass (or triple glazing) than with standard double glaze. If solar gain is important, low-E may not be the best choice. Also, Low-E coatings are customized by some producers like Southwall Corp's Heat Mirror products so the SHGC on south and west walls may be lower than the north and east walls.

Energy Conservation and the Value of High-performance Windows

How does the heat gain versus heat loss pan out for various window options? This question has long irked designers. Should you put large, energy-efficient windows in the south wall of a home, or minimize windows and insulate the walls better?

Fairbanks building scientist Ron Smith used the HOT-2000 computer program to do an analysis of these trade-offs to determine where an astute homeowner or builder should put his money: in high-efficiency modern windows or thicker walls? He analyzed a test home with 88 square feet of double-glazed, average windows facing south, 4 square feet north-facing, 40 square feet west-facing, and 28 square feet east-facing: a total amount of window area equal to 20% of the floor area of the home (160 square feet). With these windows, the home's heating energy use was calculated with R-55 ceiling and R-45 wall insulation. The wall heat loss in this calculation was 16.2% of the annual total, while the windows were responsible for 54% of the annual heat loss.

The same size house tested with R-4.3 modern energy-efficient windows and R-42 ceiling and R-30 walls resulted in an annual heat loss distribution where 30% of the total heat was lost by the walls and about 32% lost by the better windows. The latter option (windows that are R-4.3, walls R-30 and ceiling R-value reduced to R-42) saves 18.2 million BTUs of energy. With slightly adjusted ventilation rates (from .40 ACH to .35 ACH in the second case), the second case with the high-efficiency windows saves 25% on annual heating fuel consumption.

So, it is clearly a good investment to put money into high-efficiency windows. With modern window technologies available, the insulation in the walls and ceiling can be reduced in R-values by 20 to 30% with little or no sacrifice in overall performance when windows with a real performance of R-4 or better are used.

Alaskan studies evaluating the cost effectiveness of various window choices also come to similar conclusions (Colt, 1991). In an economic investment analysis, Colt looked at the incremental costs and benefits of R-3.1 windows versus cheaper double-pane, R-1.7 window. Evaluating the windows for gas-heated homes in Anchorage, oil-heated homes in Fairbanks, and oil-heated homes outside Anchorage in southcentral Alaska, Colt showed that under a broad range of assumptions about future fuel prices and the actual cost of R-3.1 windows, these windows are cost-effective relative to baseline double-pane R-1.7 windows. Even if Anchorage's cheap gas prices stay absolutely constant, the efficient windows pay off in Anchorage. In Fairbanks and Southcentral, with vastly higher fuel prices, the investment makes overwhelming economic sense.

A frequently overlooked consideration for high-performance windows is the comfort factor. Uncomfortable cold drafts created by infiltration and cold air convecting off low-quality insulated glass cause some rooms and portions of room not to be used during really cold weather. A quality window can increase the usable area of a house.

Key parameters for a high-performance northern window would include:

- an overall thermal performance of a least R-4 for an operating window and R-5 for a picture window

- openable windows with minimal air infiltration
- minimum twenty-year durability on all major components
- ability to withstand substantial abuse and vandalism
- be repairable in case of broken glass or hardware

Although these parameters may seem to be inclusive, there are many other parameters that should be considered in assessing windows and doors. The following performance criteria provide a suitable framework for future assessments of specific systems:

Physical Performance

Dimensional stability
Warping/racking resistance
UV resistance
Air infiltration
Solar heat gain coefficient
Water/rain resistance
Durability/life span
Maintain performance levels

Function and Performance

General operability
Winter operability
Ventilation effectiveness
Percent rough opening visible

Safety and Security

Fire egress
Resist freezing shut
Combustion product
Resist external breakage
Resist burglary

Construction and Maintenance

Transport & handling
Ease of installing correctly
Level of maintenance required
Ease of maintenance & repair
Glass replacement from the inside of building
Capital cost
Maintenance cost
Life-cycle cost

Other

Consumer acceptance

Durability, Quality, and Hardware Issues

Windows are critical to the real-life performance of energy-efficient housing. They are also the most expensive building element per square foot of area in the house. Selection should command great attention and requires the window specifier to be technically competent and aware of window technologies. This is especially important for Alaskan climates. An excellent review of window developments for northern application (a Canadian perspective) was accomplished by Larsson Consulting of Ottawa, Ontario, in a report entitled Development in Windows, Door and Hardware for Northern Conditions (1990). Considerations from the Larsson report make clear the pitfalls and areas of concern in selecting modern windows for the north:

1. The environment places severe demands on windows, doors, and hardware during installation and operation. Contributing factors include large indoor-outdoor temperature differentials, high winds, and wind-driven snow. Differential settlement is a problem in some areas, and the consequent racking forces are an additional problem.
2. Almost all current window, door, and hardware designs were developed to perform under less severe southern conditions. The lack of designs suited to northern conditions reflects the fact that the northern market is small.
3. Many occupants of northern houses are not responsible for energy costs and this reduces their incentive to operate houses in an energy-efficient way. One consequence is that windows and doors tend to be left open for ventilation to cool down the house, which often makes them impossible to close properly for the rest of the heating season. Because many northern houses are in remote areas, there also tends to be a greater wear and tear on such components than in urban areas.
4. The cost of high-quality components is high and the need to pre-purchase and transport them long distances adds to the cost. This discourages purchase of durable or energy-efficient components and has been a contributing factor to poor overall energy performance in the past. The use of life-cycle costing is making investment more attractive in the eyes of major government agencies. However, individual home builders find it more difficult to take the long view.
5. Many consumers are concerned with cost and style instead of quality, while some builders lack knowledge, motivation, or a concern for quality. These human factors are not unique to the North, but their negative effects on the selection and installation of windows and doors are much more severe.

Recent generations of northern houses have shown a good deal of improvement in the approach to window, door, and hardware design, but northern designers and builders are still limited by costs and by the prevalence of southern thinking in component manufacture. The most hopeful trend is that the recent upgrading of components to meet new energy performance requirements in the south is creating market conditions that will make it possible to produce components that will also meet northern requirements (Larsson, 1990).

Superior hardware is more durable, and because of the small incremental cost ($30 to $45 per window), selecting the best available window hardware only makes sense.

Design and Placement of Windows

The design and placement of windows can have a significant impact on both the comfort level and energy efficiency of a house. The highlights to consider in placement and sizing windows include:

- The majority of windows should face within 30 degrees east or west of due south.
- Avoid large areas of west-facing windows that can lead to overheating late in the day.
- Keep south-facing glass to within 8 to 10% of the floor area for a conventional frame house. Do not use more glazing than this on a south exposure unless shutters are considered.
- Provide for summer shading using overhangs (which are not effective for east, west, or north-facing windows), using deciduous shade trees, where possible or providing for shades or shutters (Figure 6.20).

Although low-E coatings and gas fills can offer significant improvement to center glazing U-values, the full potential is not realized because of the increased losses through the spacer and the frame. They have a more significant effect on large windows where the edge effects are minimized. Use the "warm-edge" technologies when available.

The benefit of the insulating spacer increases as the performance of the center glazing increases.

Most low-E coatings provide a thermal benefit, but at the cost of reduced solar transmission, which for most buildings is not a particularly important factor. Heat Mirror 88 will effectively block the long-wave infrared from leaving the building while allowing 88% of the solar heat gain to enter. Both gas fills and non-conductive spacers improve the overall thermal performance of windows without affecting the solar transmittance.

As the thermal resistance of the glazing units increases, the warmer the inner glazing becomes and a higher indoor relative humidity can be maintained without causing condensation on the glass (see Table 6.1).

The higher inner-glazing temperatures of high-performance windows tend to reduce swings in room air temperatures.

You can save money on space heating by upgrading from standard to high-performance glass. Savings in energy are greater in locations with colder heating seasons, but cost savings depend on climate as well as energy costs. Additional material and performance features to consider include:

- Fixed windows are generally the tightest.
- Turn-tilt, casement, or awning windows are tighter than sliding windows.
- Window framing materials should be made of wood, PVC, or fiberglass. If windows are not openable, we recommend wood frames.


Figure 6.20: Two views of the very well designed architectural shading devices used on the home of the University of Alaska president. The left photo is a view from the front and the right photo is a view looking upward from below the shades. These devices have many advantages: they are in a fixed position, so they don't need to be moved seasonally; they are not solid so they easily allow shedding of snow, and because they are not solid, they allow indirect light to pass through them even when the direct light is shaded.

Window Installation

There are several methods of mounting windows, but in each case a few basic rules must be met. The procedure must provide an absolute airtight seal between the window frame and the building envelope. Breaking the air-vapor retarder at this point will reduce the overall energy efficiency of the building, but more important is the possibility of significant structural damage. Cold air bleeding in around the window and coming in contact with moisture laden interior air will cause condensation in the wall cavity, resulting in mold, mildew, and rotting. All too often the results of a poor window installation will not become apparent until several years after construction, and the responsible builder will be out of the picture. Frequently the installation procedures that are fast and easy are considered good. Fast translates into good, and cheap and fast translates into real good. This is probably the worst place to economize and try to save money.

Nailing Fin Mounting

The wide use of nailing fins is a result of the "fast and easy" line of thinking. Nailing fins may be integrally part of the frame or permanently attached to the window frame to act as a mounting method and a continuation of the air-vapor retarder. Poor installation procedures are not usually apparent at the time the building is built for several reasons. Even if an energy audit is conducted and the blower door test indicates a tightly sealed structure, several things can prevent a true picture of an acceptable window installation:

1. The inspections are usually done during relativity warm weather.
2. The building has not experienced any earthquakes, which are prevalent in Alaska.
3. The structure has not gone through any winter–summer cycles.

Another serious error made in the use of nailing fins is depicted in Figure 6.21. This is a window with a frame approximately 2 ½" thick. The nailing fin is set back from the exterior, one-third the thickness of the frame. The frame of the window has the poorest thermal properties of the entire building envelope. Using the window frame as a brick mold to butt the siding to is a very poor practice, as it gives up one-third of the available insulating value of the frame by setting it outside the insulated wall (Figure 6.22). Mounting with nailing fins is an easy, fast method but is more suited for a warmer and less seismically active location than Alaska.

Installation Materials

The installation materials are as important as the installation procedure. All windows and especially PVC windows must be allowed to move slightly in the rough opening. Expansion and contraction, uneven building settling, and earthquakes dictate that the window must be able to move slightly to eliminate shear loading on the frame. Nailing fins are designed with slotted mounting holes to facilitate this movement. Installation instructions often say not to fasten the top fin at all. Keep in mind the fin is also the air and vapor retarder at this point. Your common sense will tell you the nailing fin can not slide and seal at the same time.

To seal a window to the framing without air leakage, use backer rod, urethane foam, and caulking (see Figure 6.23). The shims used to position the window must be located to leave a ¾-inch space on the outside to allow for backer rod and caulking. The ⅝-inch backer rod is positioned approximately

⅜-inch back in the sealing cavity. Backer rod is a closed-cell polyethylene rope that makes it possible to establish the proper size and shape caulked joint but it is not meant to be a seal or insulation. Caulking and urethane foam will not bond to backer rod.

The walls of an energy efficient house are generally thicker than those of a conventional house. This presents choices of installing the window on the inside or outside face (see Figure 6.24). Mounting on the inside theoretically is more effective from an energy conservation perspective because recessed windows are protected from heat-stealing winds. In addition, the inside pane has fewer condensation problems because the interior air flow over the window surface is improved.

However, inside mounting requires extra care and detailing to construct the deep weatherproof outside sill. In colder areas, thermal bridging may cause interior condensation. It is much easier to have the window recess on the inside and faced with drywall than have a deep exterior sill with the resultant flashing requirements. For this reason, the majority of builders install windows on the outside face. The details required for outside window installation are the same as used in conventional building.

Figure 6.21: Mounting a window using the nailing fin is not a good idea.

Figure 6.22: This window frame sits outside the insulated wall.

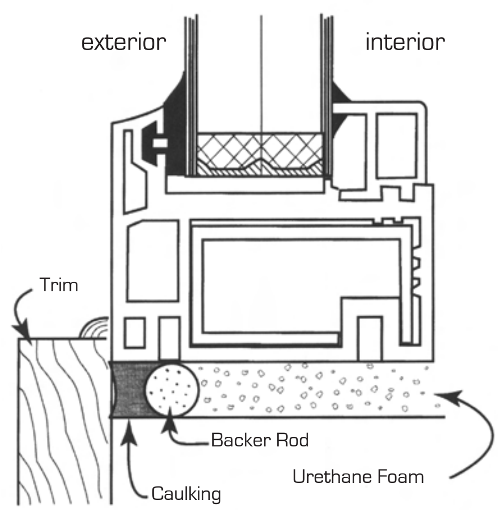


Figure 6.23: Sealing and framing details for PVC window frame

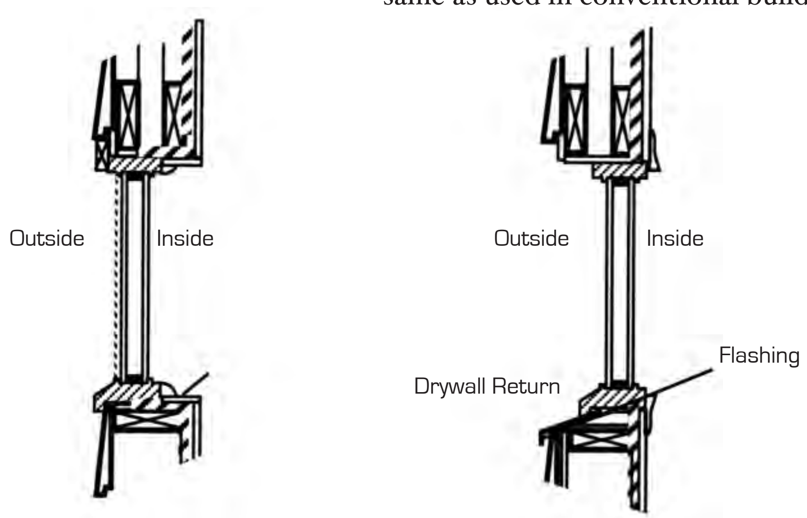


Figure 6.24: Window mounting options: left, window mounted on the outside of the rough opening; right, on the inside.

To make the window as energy-efficient as possible, it must be correctly installed. This requires two separate jobs.

- Insulate the space between the window frame and rough opening.
- Ensure that the air-vapor retarder is continuous and sealed directly to the window frame.

Two methods have been developed for sealing the air-vapor barrier to the window frame:

- Polyethylene wrap: a 6-mil polyethylene flap is attached to the window frame. This method is most commonly applied to wood windows.
- Plywood wrap: the rough opening is lined with exterior plywood and the window frame is sealed to the plywood. Plywood can be an effective air-vapor retarder if the end grain is covered by polyethylene or sealed with caulk.

Polyethylene Wrap

To install polyethylene wrap (Figures 6.25, 6.26, and 6.27), first cut a 24-inch wide strip of 6-mil polyethylene. It should be long enough to go around the window with about 20 inches extra.

Apply a bead of acoustical sealant to one side of the wood window frame. The bead must be located toward the outside of the window frame to ensure that joints between the window frame and jamb extensions are sealed.

Lay the polyethylene strip over the caulking bead and staple it to the frame through the caulking bead.

At the corners place a pleat 1-inch wide in the polyethylene on both sides of the corner. Staple the pleats to the wood frame and inject acoustical sealant to seal the pleats (Figure 6.25). The pleats allow the polyethylene flap to fold back at the corners and seal against the wall air vapor barrier (Figure 6.26). Continue this process around the frame and join the polyethylene strip to itself with a bead of acoustical sealant.

Place a continuous piece of fiber-reinforced tape on the polyethylene above the bead of the acoustical sealant and staple through the tape, polyethylene, and acoustical sealant into the window frame at intervals of less than three inches. This ensures that the polyethylene will stay in place, because staples by themselves do not always have the holding power to keep the polyethylene in place.

Insert the window frame in the rough opening and shim in place if necessary. When installing shims, ensure that they go between the polyethylene flap and the rough opening and not between the polyethylene and the window frame.

Insulate between the window frame and rough opening with nonexpanding polyurethane foam or stuff the space with batt insulation.

Staple the polyethylene flap to the rough opening.

After the wall air vapor retarder is applied, cut out around the window opening. Apply a bead of acoustical sealant between the window flap and wall air-vapor retarder and staple them together.

Plywood Wrap

In the plywood method of sealing, the rough stud opening is framed to accommodate a ½-inch plywood liner covering the width of the opening. This will mean an increase in both height and width of 1 inch.

Seal the air-vapor retarder from the house wall to the plywood liner, with either polyethylene or drywall. In both cases, the seal can be to the edge of the plywood facing the room (Figures 6.28 through 6.32).

Nail the plywood liner into place flush with the interior finish and the

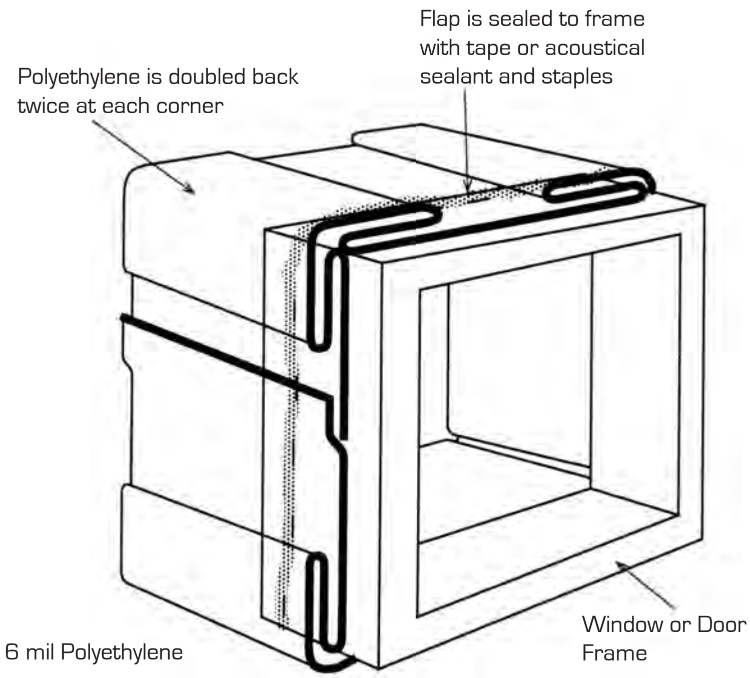


Figure 6.25: Wrapping the window frame

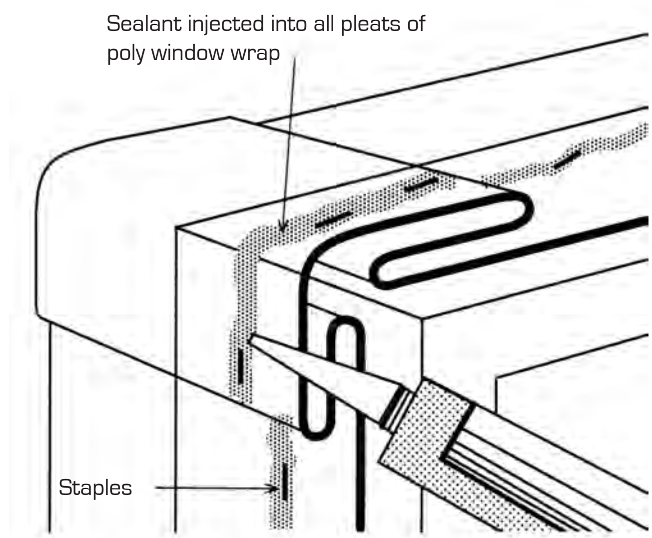


Figure 6.26: Sealing the pleats

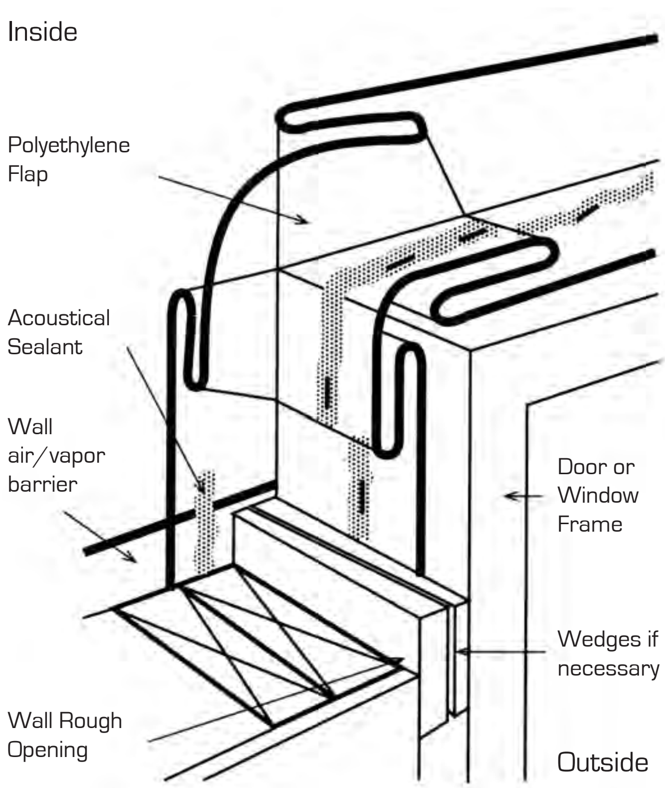


Figure 6.27: Corner pleating

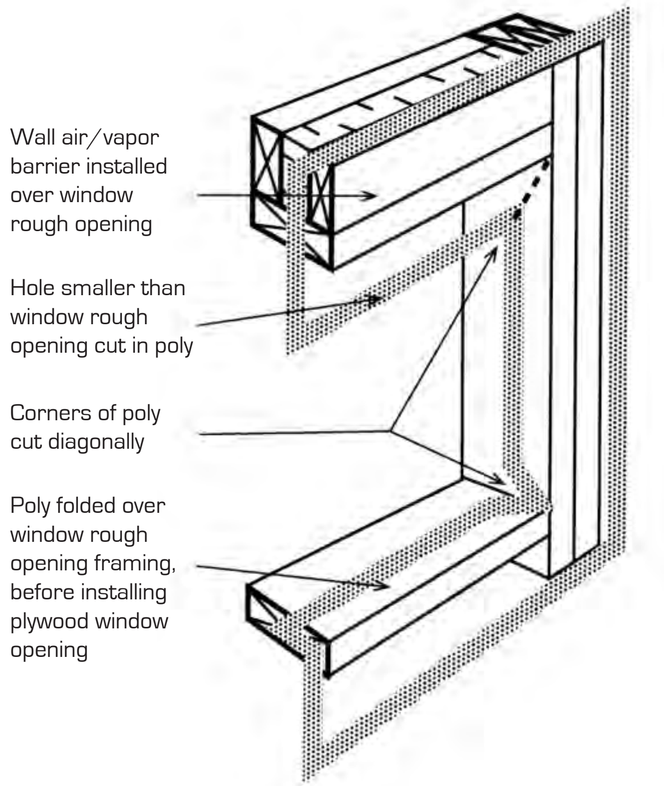


Figure 6.28: Plywood wrap: prior window penetration

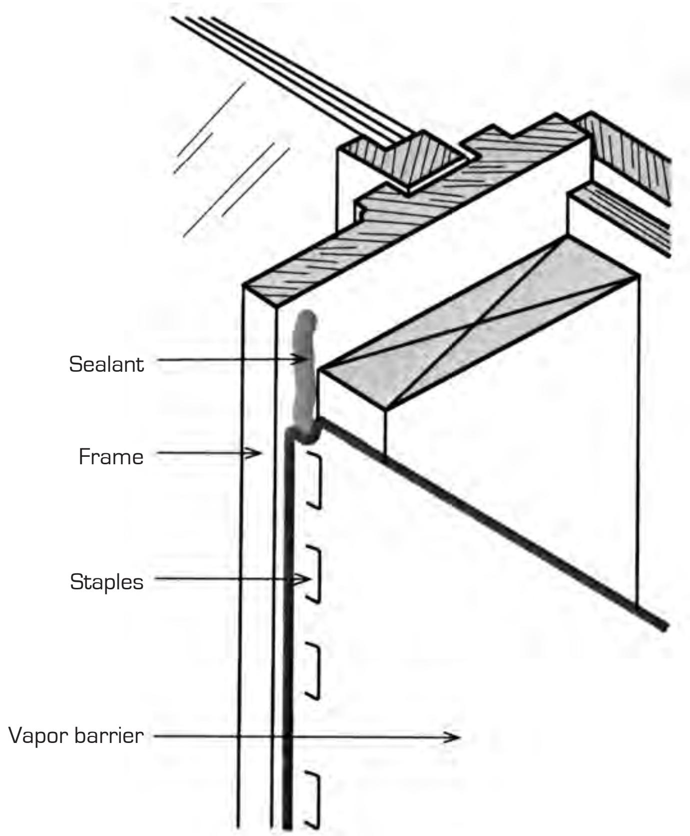


Figure 6.29: Vapor barrier sealed to window frame at edge

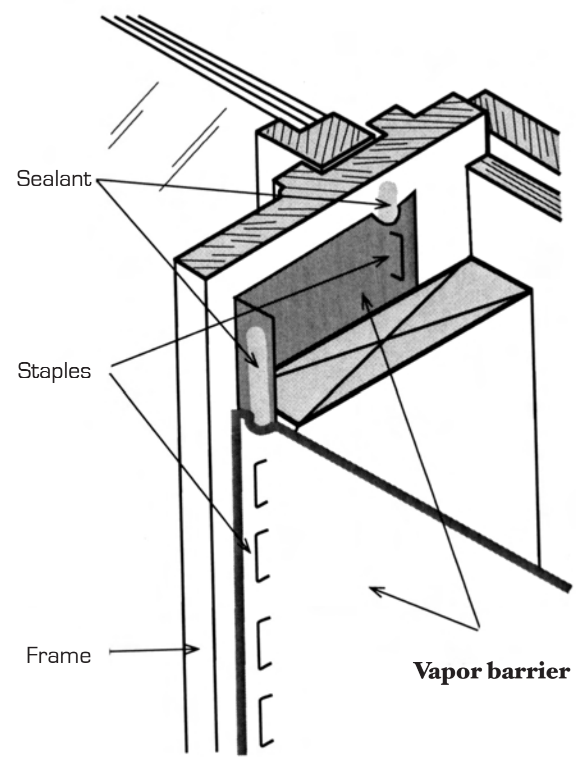


Figure 6.30: Vapor barrier sealed in single frame wall

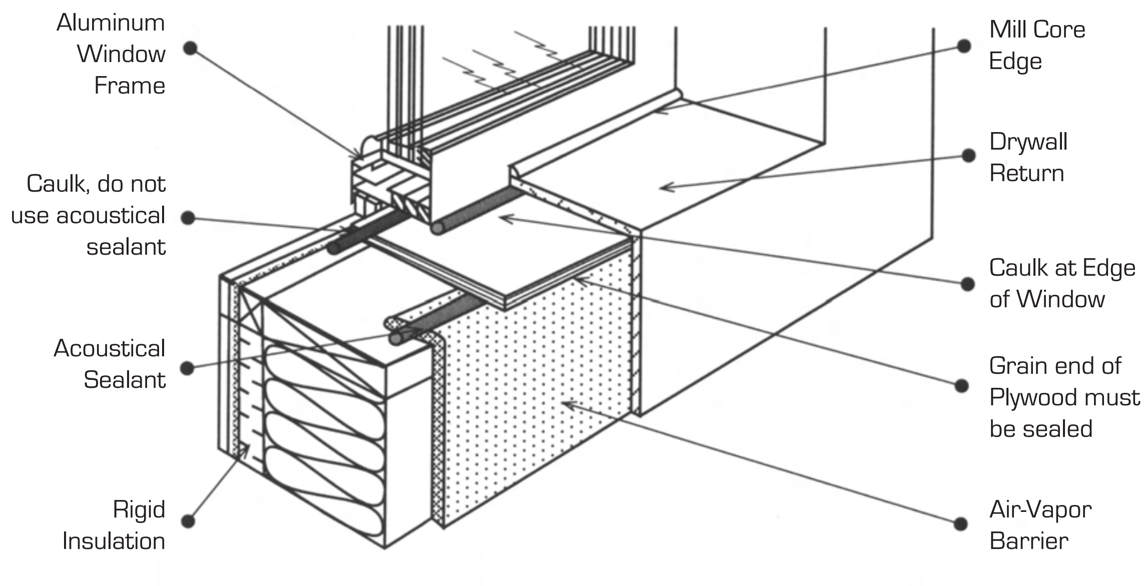


Figure 6.31: Vapor barrier sealed in single frame wall

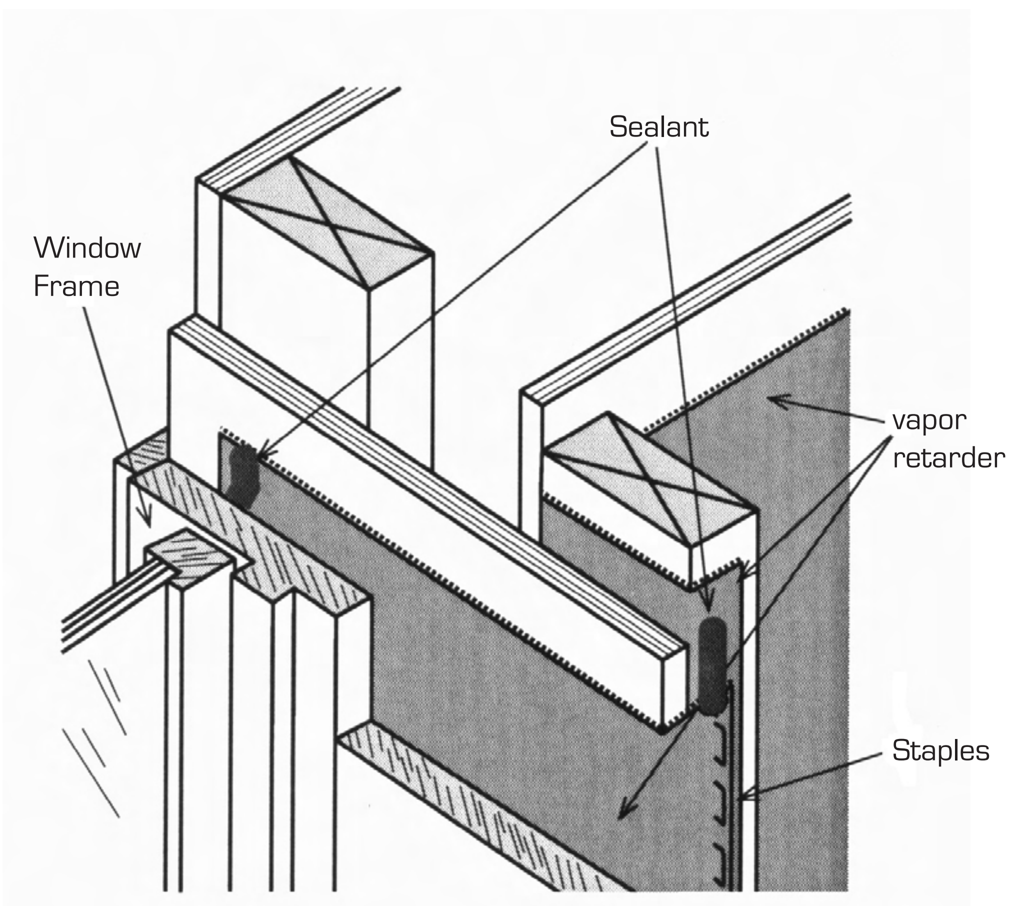


Figure 6.32: Vapor barrier sealed in Saskatchewan type double wall

exterior sheathing. The liner should be caulked to the rough stud on the interior.

Install the window into the liner from the inside or the outside, depending on the intended location. If the window is to be located toward the interior of the assembly, install proper flashing on the sill before installing the window.

Insulate and seal the gap between the window and the plywood frame. This gap should be approximately ½ inch to allow for proper sealing and insulation.

Backer rod is not a seal or an insulation. Its sole purpose is to be a bond breaker between the caulking and the foam, and it gives the caulking an hourglass shape.

The caulking should be single-part polyurethane or neutral-cure silicone. With PVC ("vinyl") windows we recommend Bostik Chemcaulk 900, Tremco 830, (both single-part urethane caulks) or Tremco Spectrum 11 or Tremco 600, both neutral cure silicone caulks. Use these caulks at joints on PVC windows as shown in Figure 6.23. Do not use acid cure silicone caulk for sealing the window to the rough opening, because it will not stick to bare wood.

Allow ½ inch between the window and the plywood wrap in the rough opening for caulking and insulating. Use minimum expanding, single-part, urethane foam insulation of a type that does not become brittle with age.

Installing Drywall

After sealing, install drywall over the liner and install the finished sill (Figure 6.31).

The drywall interior finish is butted and sealed to the window frame to provide a continuous air barrier.

If the window is installed on the outside face of the wall, a drywall return will be required in the rough opening and it should butt onto the face edge of the window frame. Caulk this joint. Using a U-shaped drywall cap called a "mill core edge" to cover the cut edge of the drywall makes caulking this joint a simple matter (Figure 6.31).

When the window is installed on the inside face of the wall, it may be located so that the face edge of the frame is flush with the face of the drywall. This butt joint may be sealed with tape and covered with trim.

Caulking

When the plywood wrap method is used and the seal between the frame and rough opening is sealed by caulking, care must be taken to establish the proper size and shape for the joint (Figure 6.34). If you make this joint ½ inch instead of something less, the membrane established by the caulking can move much more than a small joint. The ½-inch space also makes it easier to insulate the cavity after the caulking is done. As shown in Figure 6.33, the joint should be hourglass shaped, formed by the rounded backer rod on the inside and by tooling the outside. The tooling may be done by wetting a rounded device to keep the caulking material from sticking to it and dragging it over the joint. Sometimes a small amount of liquid dish soap in the water will help; however, soap might change the color slightly when using urethane caulking.

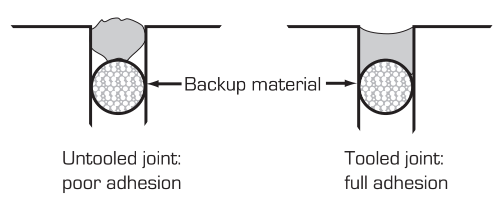


Figure 6.33: The wrong way (left) and the correct way (right) to seal the joint between the window and the rough opening.

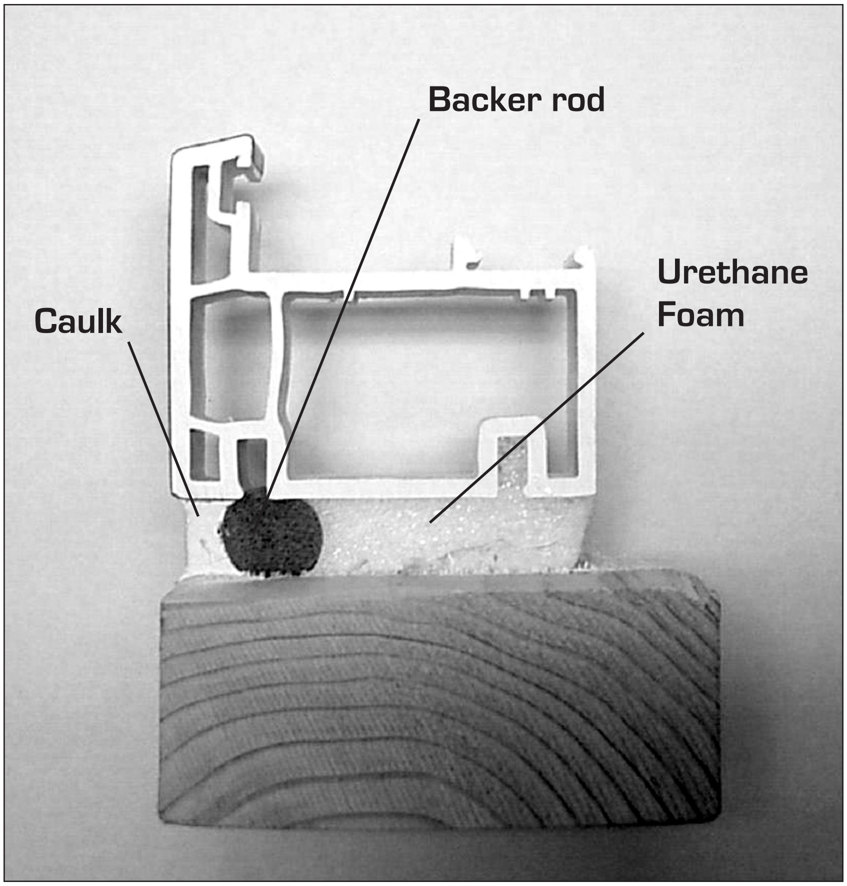


Figure 6.34: The correct way to seal a PVC window frame to the rough opening using caulk, backer rod, and urethane foam.

Figure 6.35: Backer rod applied between the window frame and the rough opening.

This tooling is not for esthetics, but will make the joint thinner in the middle and wider where it is bonded to the substrates. Any relative movement that stretches the caulking will cause the membrane to get thinner in the middle (like stretching a rubber band) and the materials will not separate from the substrates.

Urethane

The most important step in installing a PVC window is selecting the proper caulking material. Single-part urethane bonds very well to PVC, bare wood, and concrete. Not all single-part urethane caulks perform equally, so do some comparing, destructive testing, and reading the manufacturer's specification sheet. Applying it during inclement weather is not usually a problem as long as the temperature is above the manufacturer's recommended limit, which is usually around 35°F. Some of these products are moisture cure and bond faster and better to damp substrates so using a spray bottle to mist the cavity prior to application is a good practice. Again, check the label instructions.

Silicone

Installing windows in Alaska cannot always be done in ideal weather conditions. Although urethane is a great choice when installing windows in rainy weather, it cannot be used when the temperature is below freezing. When the temperature is below 35 degrees F, neutral cure silicone is the caulking of choice. Silicone will not freeze and will cure at subzero temperatures. Don't use acid-cure silicone because it will not bond to bare wood. Any caulking looks good when it is first installed and even may appear okay for a year, but improper materials will eventually fail. If silicone caulking smells like vinegar, it is acid cure and will not adhere to bare wood. If there is a reason that acid cure silicone must be used, the wood must be primed or painted before caulking.

Urethane Foam

Insulating between the window and rough opening is easier with a ½-inch space than with a smaller cavity. Many times specifications call for "stuffing" fiberglass insulation in this cavity. It is very difficult to properly install fiberglass in this small space. Having the fiberglass fluffed to fill the cavity and not stuffed or packed would be a tedious chore. Single-part urethane spray foam (Figure 6.36) is the best choice but here again, choosing the proper material is important. Some simple testing can help in selecting the brand and type of foam to use. First of all, minimum expanding foam is recommended to prevent bowing or bending the window frame as the foam expands and cures. The product should be labeled nonexpanding or minimum expanding. If standard expanding foam is all that is available, making two small applications is the safest practice. Another attribute you need to be aware of is the tendency of some products (usually economy brands) to become very brittle and rigid when they cure. This material will transmit shear loads to the window frame. If any relative movement occurs, the foam breaks like a soda cracker and becomes a very fine dust. Select a product that stays resilient after it cures. Simple testing and comparing of products will help in the selection process.

If a number of windows are to be installed, use larger cans that require an applicator as shown in Figure 6.37. An applicator (trigger operated valve) will give you the ability to use a small amount of foam and shut a valve to save the rest of the material for later use. The applicator also gives the operator compete control over the amount of foam being applied. Small consumer size cans cannot normally be kept once

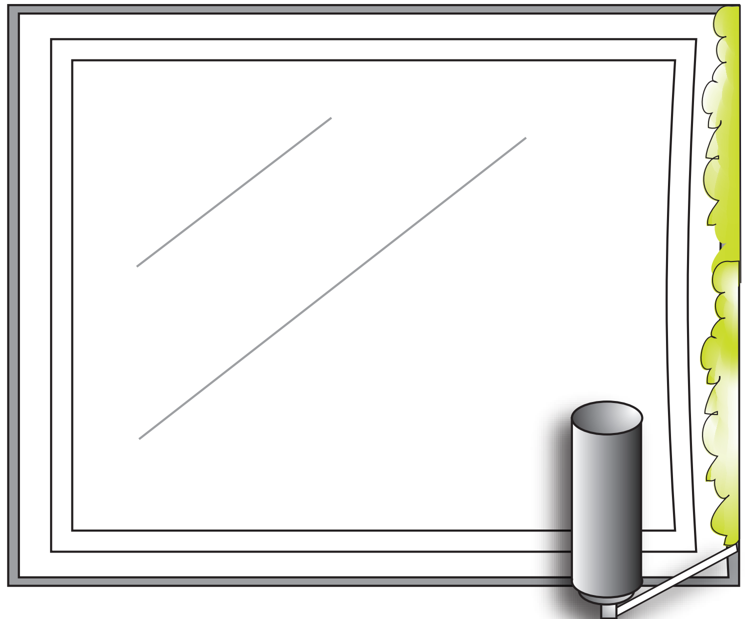


Figure 6.36: Use low-expanding spray urethane foam to insulate between the framing and the window. Note this is insulation, not the air seal.

Figure 6.37: An applicator for spray urethane foam allows you to save the rest of the can for later.

part of the container is used because the foam will cure in the open nozzle. The flow rate of the foam is difficult to control with the push button valve that is usually used.

Be aware that some manufacturers of unreinforced, lightweight, PVC window frames will cancel their warranty if foam insulation is used. It is easy to bow and bend these frames. In no case should urethane foam be considered a seal for the air-vapor retarder. It is impossible to apply foam insulation around a window frame that is shimmed in place and not have air leaks, and no air leakage between the window and the building envelope is acceptable.

Glossary of Window Terms

Argon

A colorless, odorless, inert gaseous element found in air and volcanic gases. Used as a filler in electric bulbs and electronic tubes, or in applications where pressure needs to be balanced. It has a low thermal conductivity.

Cladding

A material, aluminum, vinyl, or other plastic material that is applied as a covering to a wood window frame. The cladding reduces the need for painting and other maintenance usually associated with wood windows.

Emissivity

Unit of measure to measure a surface's emittance. A number between 0.00 and 1.00 that describes a surface's ability to transmit or receive radiation. A perfect black body (black valet) would have an emissivity of 1. The glass liner from a thermos bottle would have an emissivity of .003.

Expansion and Contraction

The physical property of a material's response to temperature changes. Metals have extreme dimensional changes in response to temperature, while porous material such as wood or insulation material change very little. Most rigid plastics have great dimensional changes and are difficult to use as glazing.

Heat Mirror

A low emittance coating applied to a plastic film and suspended between the glazing. The low-E coating is applied by the sputtering technique.

Insulated Glass

Two or more lights of glass (layers) separated by a spacer, with the edges sealed. The spacer is usually aluminum,¼ to 1-inch wide, which provides the separation between the lights. The space between the glass may be filled with plain air, argon or krypton, or the space may be a vacuum.

Low-Emittance (Low-E) Coating

Microscopically thin, virtually invisible, metal or metallic oxide layers deposited on glass or plastic film to reduce the radiative heat flow. A typical type of low-E coating is transparent to the solar spectrum (visible light and short wave infrared radiation) and reflective of long-wave infrared radiation.

Pyrolitic (hard coat)

Typically a metallic oxide usually tin with some additives applied to surface 1, 2, or 3, most commonly applied to the third surface. It is fire-fused to the glass.

Racking

A type of lateral deformation of a building or frame caused by inadequate shear resistance or by larger loads than a structure was designed for. A racking failure occurs when wind stress "accordions" a building, for instance.

Reflective Coating Low-E

Coating applied to glass to change the thermal characteristics. There are two types of coating commercially available.

Sputtered (soft coat)

Multilayered coating deposited on glass or plastic film in a vacuum chamber. Silver is often used. The film must be protected from humidity and contact. Emittance rating as low as .04 may be attained.

Surface Coating

In insulated glass units, the surfaces are numbered from the outside surface to the inside surface, the outside surface being the first surface. In a two-layered unit, there are 4 surfaces. When dealing with films on glass, it is important to which surface the film is applied. Not all films are applied to the same surface.

Thermal Break

In metal door and window frames, a vinyl strip, or other low conductivity material, that separates the inside from the outside. It is intended to break the conduction path from the inside surface to the outside surface. In extruded aluminum door and window frames, the inside surface is separated from the outside surface, and the hollow frame is filled with a foam insulation material.

Thermal Bridge

Conductance of heat through window framing material or glass edge seals.

U-Value

The inverse of R-value. In windows look for low U-value rating. U = 1/R.

Vacuum Deposited

The most expensive coating process. The film is usually silver or silver oxide, and occasionally gold. The metal is usually placed on the third surface in cold climates. Stainless steel and chromium are used in combination as materials also.

Chapter 7
Attics and Roofs

Key Points to Learn

The energy efficiency of roofs and attics can usually be improved by

- installing a wind barrier at the eaves to prevent wind penetration into the roof cavity
- air sealing to eliminate or reduce air movement through the ceiling around plumbing stacks, electrical outlets, at partition-wall top plates, chimneys, flues, and around attic access hatches
- increasing insulation thickness in cathedral ceilings
- eliminating gaps in the insulation, particularly at truss struts
- increasing insulation at the eaves
- reducing thermal bridging through structural members

Hot Roof Versus Cold Roof

Ceilings are usually the best-insulated part of conventional houses. Attic spaces are easy to insulate with low-cost blown or batt insulations. The insulation levels in the attics of energy-efficient houses usually reach R-values of 38 to 60 (12 to 18 inches of blown or batt insulation). However, the insulation quantity alone does not determine its effectiveness.

There are two basic types of roofs used in Alaska. They are commonly called a cold roof and a hot roof.

Cold roofs have a ventilated cavity (attic) above the insulation, and hot roofs do not. This cavity generally consists of lumber rafters or trusses with a 4:12 to 6:12 slope and a flat ceiling. A 6-mil polyethylene air-vapor barrier is installed under the insulation. For the roof to be classified as cold, continuous 2-inch vent slots must be installed at the eaves for natural eave-to-eave ventilation. Also, louvres are installed at the gables. In some situations it may be acceptable to use ridge vents.

A hot roof is simply a roof without ventilation. The important distinction between these two roof types is in their application. A properly designed and constructed cold roof with a well-ventilated roof cavity should have no ice dams or icicles along the eaves (Figure 7.2). The cold roof design is the best option for the Railbelt and in Southcentral, Interior, and Southeast, or any climatic region in the circumpolar north or south that has a long cold winter when snow remains on a building's roof for more than two weeks. Often the period of snow cover can be as much as four to five months.

A hot roof may be a flat, cathedral, or shed roof with no natural ventilation in the roof cavity. In a commercial roof, rigid insulation may be placed on the top of the decking. In a residence, the rafters may be packed with insulation, leaving no air space for natural ventilation of the cavity. Even a gable roof may be a hot roof if adequate ventilation has not been provided.

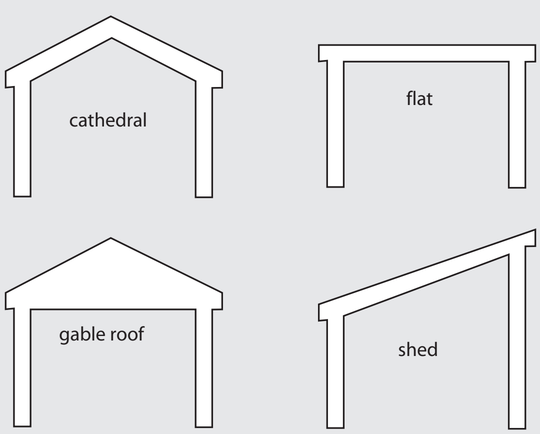


Figure 7.1: Types of hot roof profiles. Photo at top shows structural insulated panels used for a cathedral roof on a timber frame house.

Ice Dams

A hot roof can cause accumulated snow to melt gradually under certain conditions. The water will then flow toward the eaves on a sloping roof. When the water reaches the eaves it will refreeze and build up as an ice dam. As the ice dam increases in height, the surface of the water may become deeper and broader (Figure 7.3).

Water formed behind ice dams may leak under asphalt shingles or over the flashing, accumulate, and freeze in the roof cavity. Also the water may leak through any seam in the roofing.

It is important to note that architectural design that employs multiple levels and roofs can lead to roof sections that are not easily vented. This can be avoided by using vertical vent ducts to other vented roof sections from the top of unvented sections to assure full natural ventilation. All reasonable efforts should be made to avoid hot roof conditions in all new residential construction, and to eliminate unvented roof conditions whenever possible in retrofits (except in western and northern coastal Alaska and the Aleutians). Possible consequences of an unvented roof are:

- Over a period of five to ten years, excess moisture in an improperly ventilated roof cavity may cause delamination of the plywood decking. Over a longer period, it may even cause rotting and structural deterioration of the rafters. During a period of abnormally deep snowfall, the roof could collapse.
- Water leaking into the roof cavity may seep through the insulation and through holes in the vapor retarder and cause water stains on the ceiling.
- Water leaking into the roof cavity may become trapped as a result of inadequate roof ventilation. With higher levels of insulation, the dew point temperature at the deck will

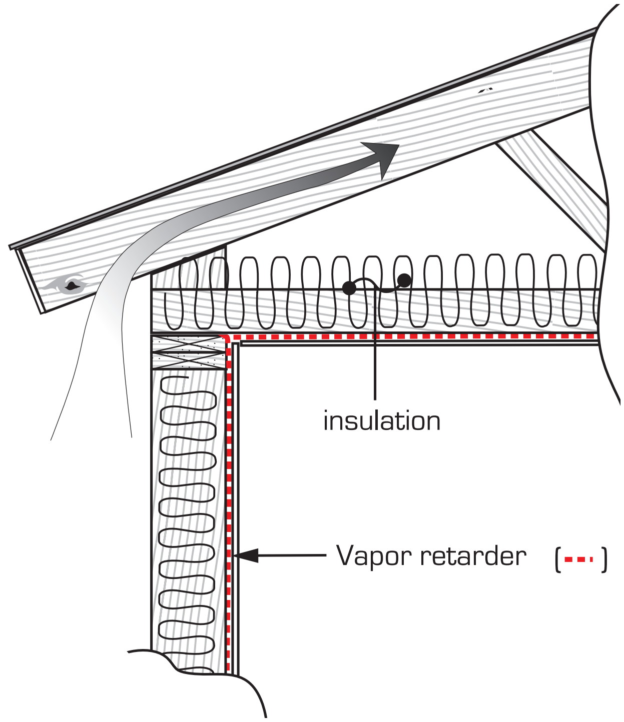


Figure 7.2: Cold roof with vent

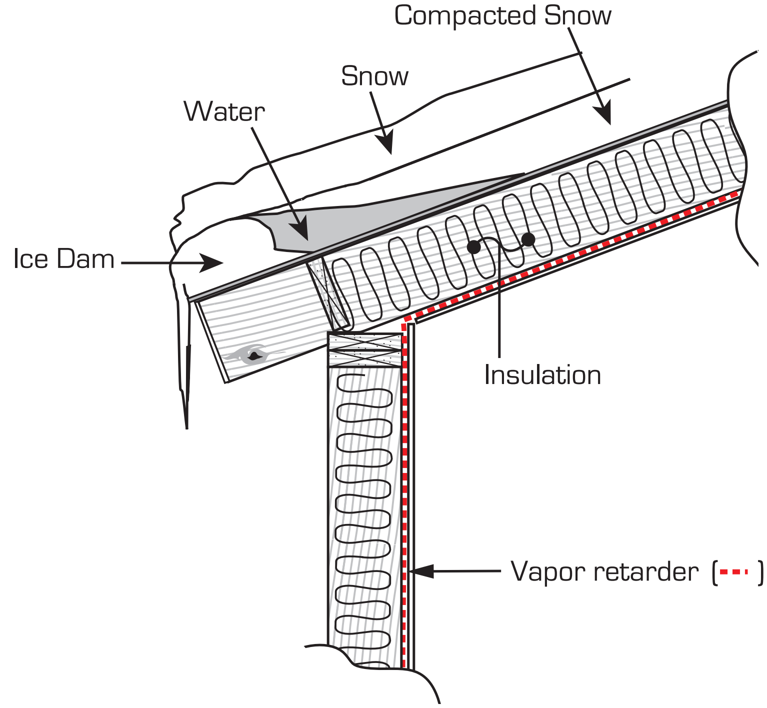


Figure 7.3: Ice dam formation on a hot roof. If the roof cavity is filled with insulation, there is no ventilation. The surface temperature of roof deck may rise above freezing as the depth of snow increases. Water building up behind the ice dam may leak under shingles or over flashing into the roof cavity. Water trapped in the roof cavity eventually causes the plywood deck to delaminate and causes decay of the rafters. Water leaking into the roof cavity may eventually seep through the vapor retarder and stain the ceiling.

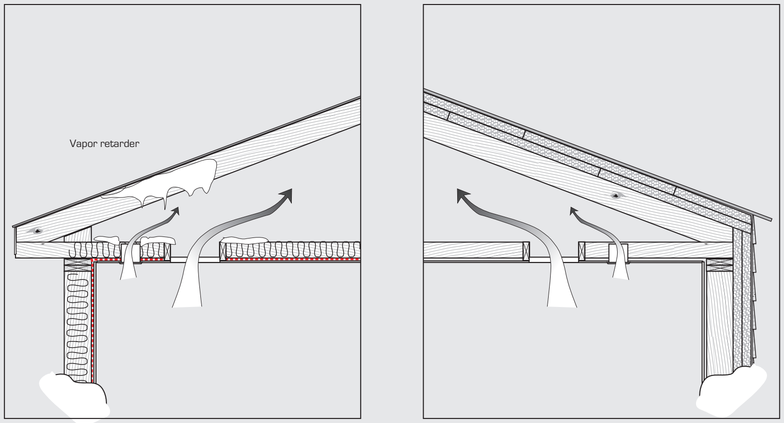


Figure 7.4: An arctic hot roof vs. a conventional roof

In the North, tight envelope construction is one way to prevent building degradation and significantly reduce maintenance and energy costs.

Conventional systems have been installed with a polyethylene vapor barrier above the ceiling, below the roof structure and insulation. Poor installation, degradation of the polyethylene vapor retarder, and openings for ceiling fixtures, electrical outlets, etc. compromise the air-vapor retarder and allow moisture-laden air to pass through. In the North, roof systems that rely on venting to purge moisture, such as open attics and ventilated cathedral ceilings, seldom vent moisture before it condenses and turns into frost.

become lower and moisture in the roof cavity may form heavy masses of ice on the underside of the plywood deck. Sometimes the rafters of a gable roof are completely filled with frost and ice.

- In the spring or during unseasonably warm weather, the large accumulation of ice will suddenly melt. The water will seep through the insulation and accumulate on the air-vapor retarder. This can ultimately cause the ceiling to collapse with a flood of water.

Hot-roof Designs Can Be the Right Choice

In western and northern coastal Alaska and the Aleutians, a hot roof design may be the best alternative. However, it must be a very tight hot roof to be effective and must be used with the following cautions and constraints:

- Blowing snow must not penetrate the hot roof for the same reason it shouldn't get into a cold roof. The roof must be tightly constructed.
- The design strategy relies on wind to clear the roof of accumulated snow to prevent ice dams. This strategy requires a relatively high average annual wind speed (above 10 mph, although the precise average wind speed adequate to regularly sweep accumulated snow off the roof has not been established).
- If a large snow accumulation does occur, the snow should always be removed.

Hot-roof Design Elements

A continuous membrane air and vapor barrier on the warm side of nonorganic insulation, but still on the outside of the structure and decking is essential. This stops moisture-laden interior air travelling through the insulation to the dew point, where condensation occurs. The colder the climate, the more important the quality of installation of the barrier. The arctic hot roof (Figure 7.4) membrane and insulation are on the exterior side of the structural members. This placement achieves the following:

- Potential for damage from condensation is virtually eliminated.
- Interior finishes can be applied directly to the structural framing, with no need for additional strapping or protection for the membrane.
- Penetration of the membrane by mechanical and electrical systems is reduced to elements that must exit

the building, while a secure utility chase is created between structural members.

- With fewer penetrations and the application of the membrane directly above a rigid deck surface, good quality installation is easier.
- Thermal bridging between the structural members and the roof cover is eliminated.

The hot roof system has been used successfully in the North in apartments, houses, and larger buildings for about 15 years.

There are four basic components in a successful hot roof design:

1. Roof deck for continuous, rigid support for the membrane, eliminating the problem of the barrier "drumming" as air moves back and forth through the roof assembly.
2. Continuous membrane as both the air and the vapor retarder, on the warm side of the insulation. Modified bitumen membrane (MBM), a single-ply, torched-on membrane, is a strong sheet material that remains flexible at temperatures as low as −40 degrees F. It has proven to be very suitable in this application. When properly installed and sealed, MBM maintains its integrity and is not susceptible to moisture degradation.
3. Two layers of rigid insulation that are impervious to degradation from moisture. Installing insulation panels at right angles to each other and attaching one layer with "z-girts" and the other with screws minimizes thermal breaks. This also reduces penetration of the membrane.
4. Roof cover that serves as ultraviolet protection and sheds moisture.

Moisture Accumulation

Moisture can occur in ceilings in two ways. First and most important, moisture accumulates when warm moist air rises into the attic space through air leakage paths and condenses on cold surfaces. Second, vapor diffusion will cause water vapor to move into the attic. During the winter in colder regions frost may build up in the insulation, which leads to problems in the spring when the frost melts. Moisture problems can be greater in a well-insulated attic because the air immediately above the insulation is much colder than in poorly insulated attics. The cooler air will not absorb much moisture.

The only effective way to reduce condensation in roof and attic spaces is to prevent it from entering in the first place. This is accomplished by installing a continuous air-vapor retarder. The colder the climate, the more important the quality of the installation of the air-vapor retarder. This detail is perhaps the most crucial in roof/ceiling construction. Building in good vapor retarder and air sealing at the roof/ceiling solves many other heat loss and air leakage problems. A good air/vapor retarder at the top of a building makes everything else work better.

- The warm moist air from inside the building is kept from getting into the attic/roof cavity, so it doesn't need to be removed by attic ventilation.
- No air leakage out the top of the building means no air leaks at the bottom. Air leakage is therefore much easier to control.
- Lower air leakage means healthful moisture levels are easier to maintain in the indoor environment.

Ventilation of the attic and roof space is required in any climate where wind is not a major factor. Ventilation helps exhaust any moisture or water vapor in those spaces and helps cool it in the summer. Attic ventilation is usually accomplished by having a continuous soffit ventilation strip as well as some gable end or other attic ventilation. The common commercially available ridge-cap vent can suffice, but this can be blocked by snow in winter. The most practical roof ventilation solution is the use of gable-end vents in roof systems where this is feasible, rather than ridge-cap vents.

In regions of Alaska where fine, blowing snow is a problem, it is better to seal the attic. This means a hot roof design may be necessary. If moisture from inside the house is prevented from getting into the roof cavity, and there is sufficient insulation to keep snow on the roof surface from melting, there is no need for roof ventilation.

Consider the amount of snowfall and the wind conditions of a particular location when you decide whether or not to build a hot roof. The insulating value of snow is approximately R-.5 per inch. Where the snowfall regularly accumulate on the roof and that snow is likely to remain on the roof for considerable time during the winter, the surface temperature of the roof melt the snow. This leads to ice damming and leaks in the roof.

In western and northern coastal Alaska, wind is a dominant factor and may regularly clear the roofs of snow, so ice damming is not a problem, but snow blowing into the attic through the vents can be (Figure 7.5). Local wind conditions should be considered when deciding if a hot roof is appropriate for a given location.

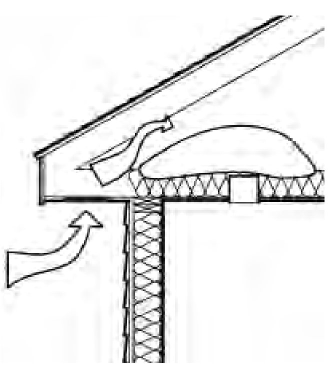


Figure 7.5: Snow gets in through roof vents in windy areas.

Air-vapor Retarder Detailing for Ceiling and Roof

The air-vapor retarder must be continuous. Basic considerations include:

- Carry the air-vapor retarder over the top plates of partition walls.
- Seal around chimney and flue penetrations.
- Provide flexible air- and vapor-tight seals around plumbing penetrations (Figure 7.6).
- Eliminate attic access hatches and use gable-end ventilation of the roof.
- Minimize electrical boxes in the ceiling. When using a polyethylene air-vapor retarder, cross-strapping will provide a cavity for wiring and electrical boxes on the inside of the air-vapor retarder (Figure 7.7). Always be certain that the seams in the polyethylene ceiling air-vapor retarder are supported with solid backing. No seams or joints in the polyethylene air-vapor retarder should ever be made without this backing support.
- Whenever possible, avoid using recessed light fixtures that require a ceiling penetration.

Moisture Damage

Sagging of ceiling finishes can occur in both conventional and energy-efficient houses.

Ceiling sag is caused when the drywall on the ceiling is damp and, as a very viscous fluid would, it sags. The rate of sag is a function of the moisture content of the drywall and the weight the drywall is supporting. Consequently, the amount of sag is time dependent, but it is also related to the spacing of supports and the thickness of the drywall.

Ceiling Sag

In order to keep sag to a minimum, when the drywall is installed it should be completely dry and the following precautions taken to keep it dry:

- Keep the drywall warm: provide heat and insulation.
- Keep the relative humidity low.
- Don't install heavy insulation until the drywall is dry.

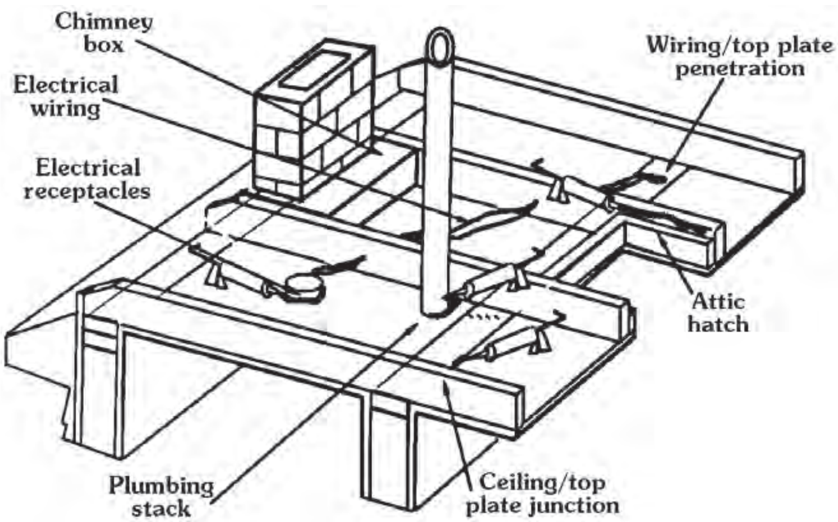


Figure 7.6: Sealing penetrations in the attic

- Keep the spacing of supports close together.
- Use thicker drywall: ⅝ inch minimum; ¾ inch desirable.
- Avoid using water-based texture finishes.
- Provide ventilation during construction. In the winter months, this can be done with a large heat recovery ventilator to minimize heating costs.
- If a polyethylene air-vapor retarder is used, the attic must be insulated before the heat is turned on. Otherwise, the water vapor will condense on the polyethylene.

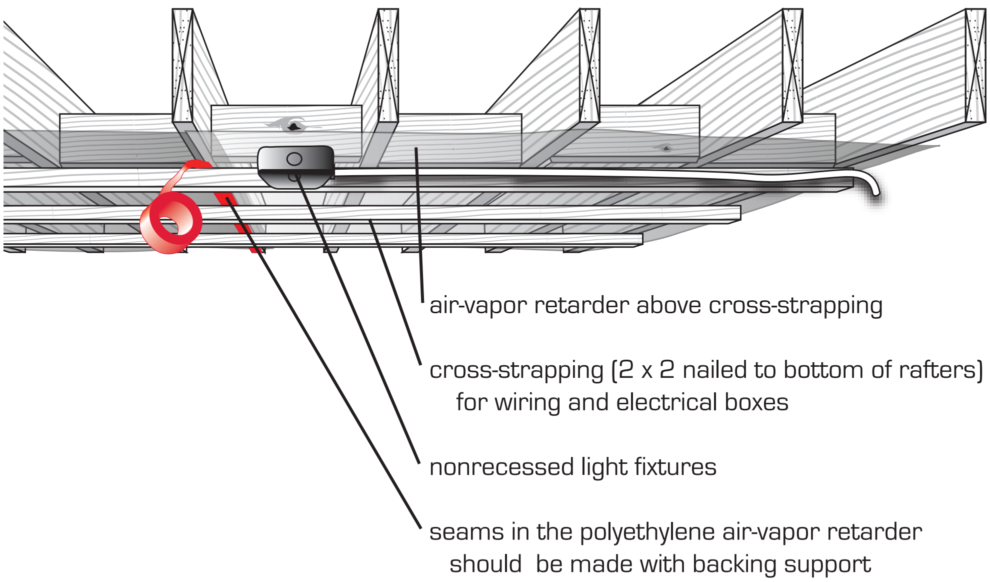


Figure 7.7: Ceiling air-vapor barrier detailing

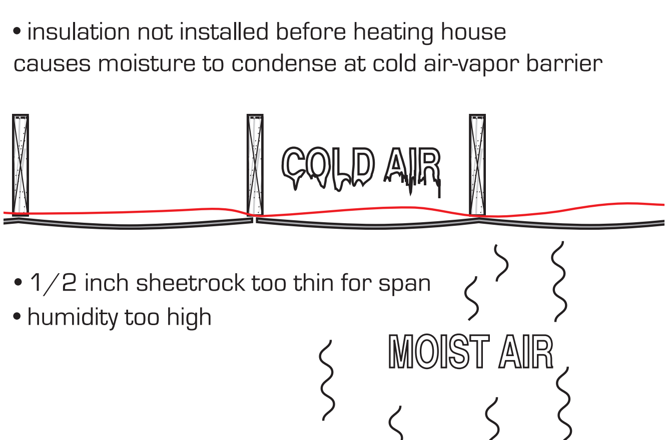


Figure 7.8: Causes of ceiling sag

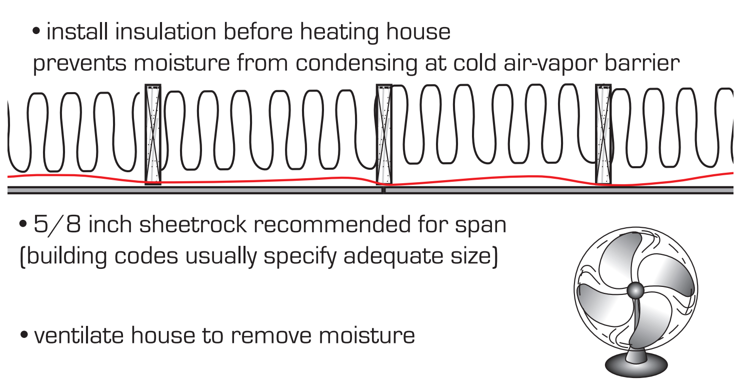


Figure 7.9: Preventing ceiling sag

Ceiling Penetrations

Place as much plumbing as possible in interior partition walls rather than exterior walls. Minimizing plumbing in exterior walls makes it easier to produce an airtight assembly and allows more insulation. To prevent air leakage where plumbing stacks penetrate the ceiling at partition wall top plates, make an airtight and vapor-tight flexible seal. The reason for flexible sealing of plumbing penetrations is that plumbing stacks move because of thermal expansion and contraction and because of shrinkage and settlement of the house frame. Plumbing expansion joints will minimize thermal expansion and contraction.

One of the most effective ways to handle this is to pass the plumbing stack through a rubber gasket such as EPDM, which is sealed to the air-vapor barrier with acoustical sealant or gasketing and clamped down with a plywood collar (Figures 7.10 and 7.11). The hole in the rubber is cut ½ inch smaller in diameter than the plumbing stack diameter and forms a tight friction fit when the plumbing stack is pushed through.

An equally effective option involves a permanent rigid seal of the stack to the air-vapor barrier and a more flexible plumbing system. This may involve an expansion joint in the stack or several bends close to the vent in the attic.

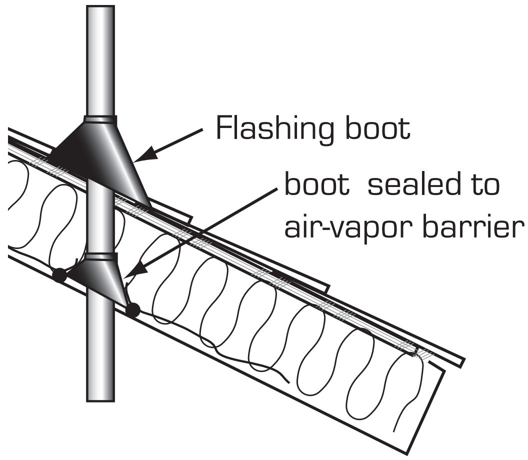


Figure 7.10: Detail of a plumbing stack in a cathedral roof

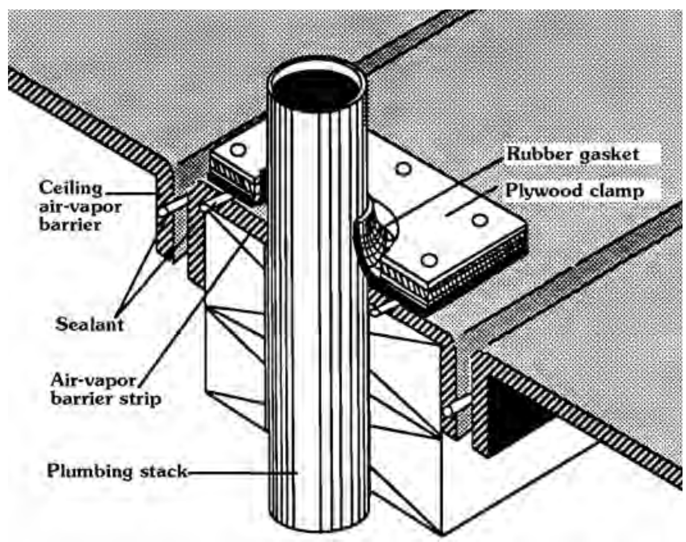


Figure 7.11: Detail of plumbing stack penetration through top plates

Electrical Penetrations

Wiring penetrations of the ceiling often occur through partition-wall top plates and can be sealed directly to the air barrier and top plate with acoustical sealant (Figure 7.7). Some caulking materials may react with the wiring sheathing, and so this method may not be acceptable to electrical inspectors, in which case a rubber gasket, as described for plumbing stacks, could be used.

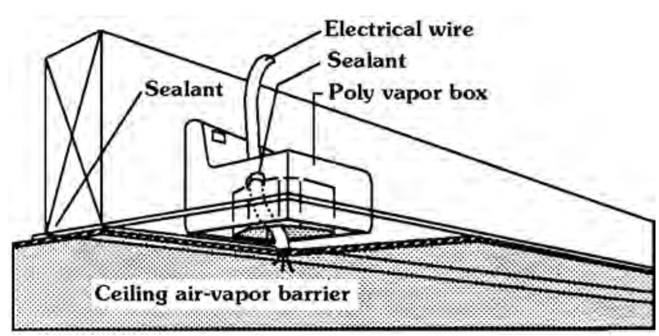


Figure 7.12: Using a polyethelene "hat" to seal an electrical box in the ceiling

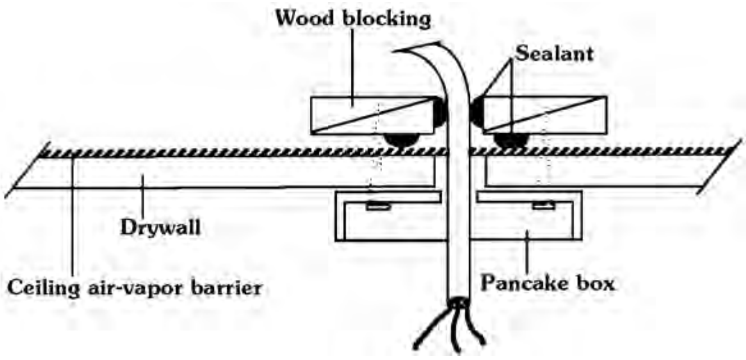


Figure 7.13: Shallow "pancake" electrical box in ceiling

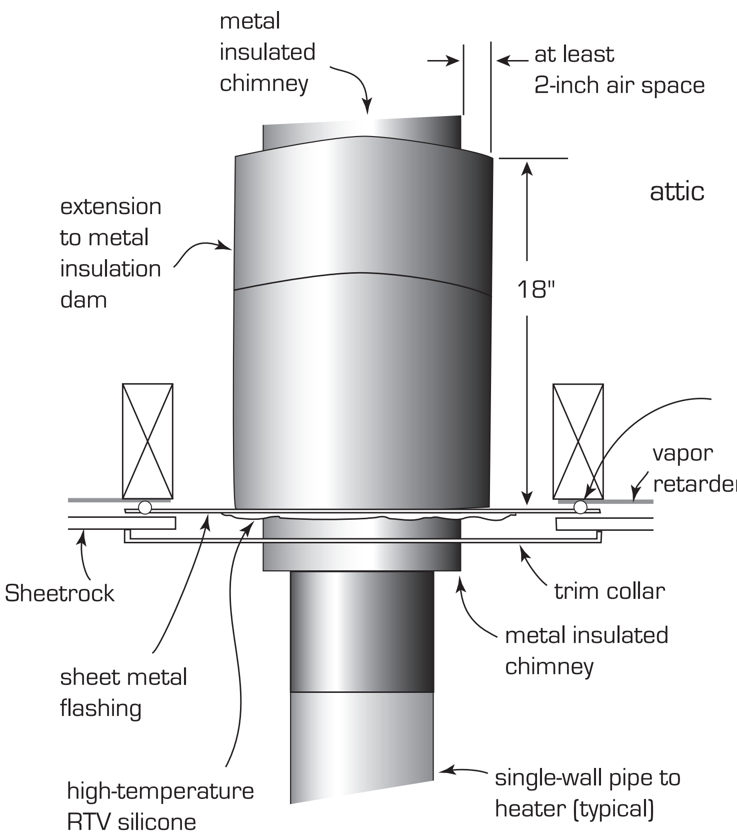


Figure 7.14: Sealing a chimney where it goes through the ceiling

Electrical boxes for lighting fixtures can be sealed in one of the following ways:

- Placing the electrical box in a prefabricated polyethylene envelope (poly hat) (Figure 7.12).
- Placing the electrical box in a site-built wood box wrapped in 6-mil polyethylene.
- Placing the electrical box within a strapped cavity.
- Using a pancake surface-mounted electrical box (Figure 7.13).
- Do not use recessed lights in top-floor ceilings.

Attic Access Hatch

The most effective method for constructing an attic hatch access in an energy-efficient house is to locate the attic access in a gable end. If the access must pass through the ceiling air barrier (as in a hip roof), the hatch frame must be sealed to the ceiling air barrier and the access door weather-stripped, insulated, and latched.

Interior Partitions and Ceilings

Interior partition construction can have a large effect on the energy efficiency of a ceiling. A lot of air movement can occur at the junction of the ceiling and partition wall (Figure 7.15). This problem can be corrected by incorporating a good air barrier. The primary methods of making the air barrier continuous over partitions are:

- Applying polyethylene and drywall across an entire clear span ceiling before erecting interior partitions (Figure 7.16).
- Standard-length studs can be used for interior partition walls if a 1 x 4 shim plate is placed on top of the exterior wall top plate (Figures 7.17 and 7.18). This raises the trusses and allows enough room for ⅝-inch thick drywall and for tilting the partitions into place. Alternatively, studs will need to be cut ⅝ inch shorter. Drywall can be taped before the wall is raised.
- Place a 24-inch wide strip of 6-mil polyethylene between the partition-wall top plates (Figures 7.19 and 7.20), which is later sealed to the ceiling air barrier in each room.

In the case of the drywall air barrier, the interior partition walls can be cut ¾ inch short and temporarily held in place. After the drywall is slipped through the gap, the wall is anchored.

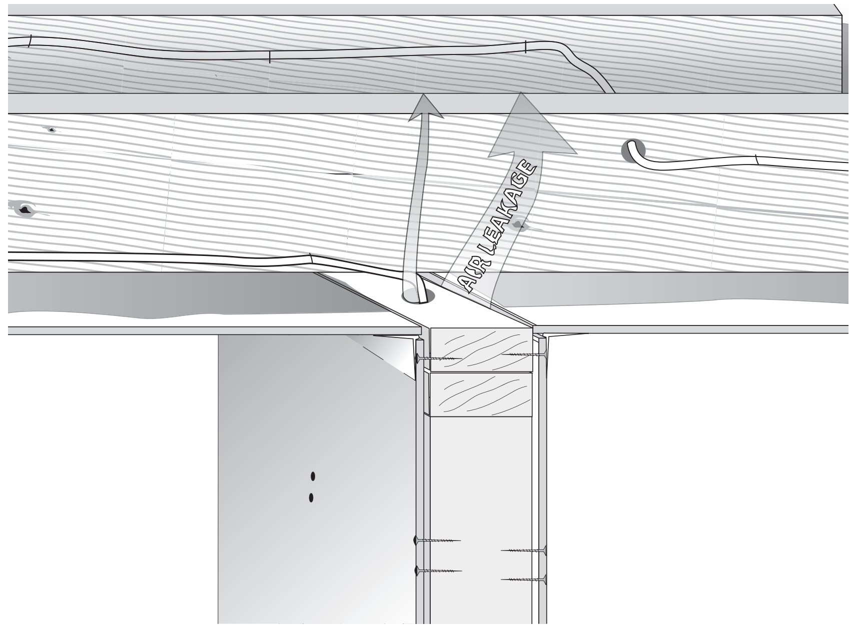


Figure 7.15: Air leaks around the top of partition walls and through holes in top plates that were drilled for wiring.

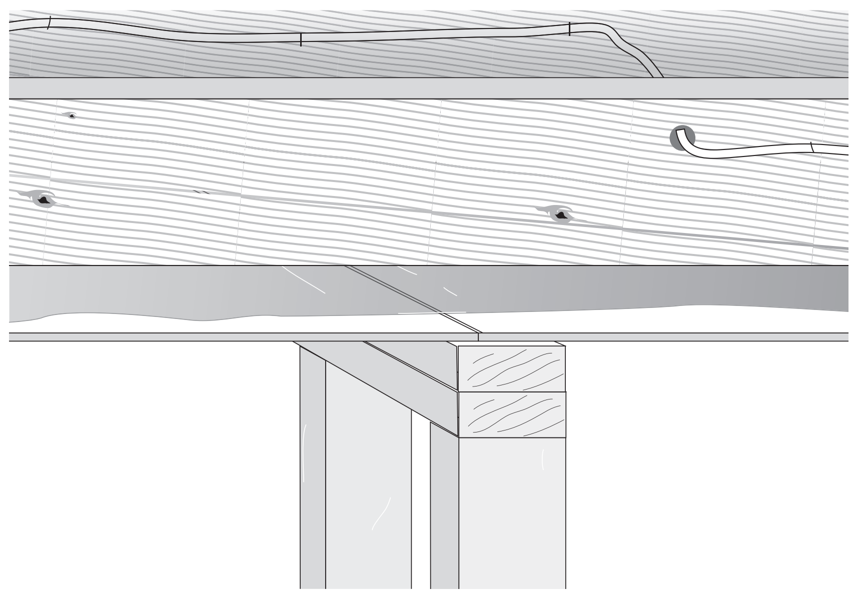


Figure 7.16: Applying polyethelene vapor barrier and drywall on the ceiling before putting up interior walls.

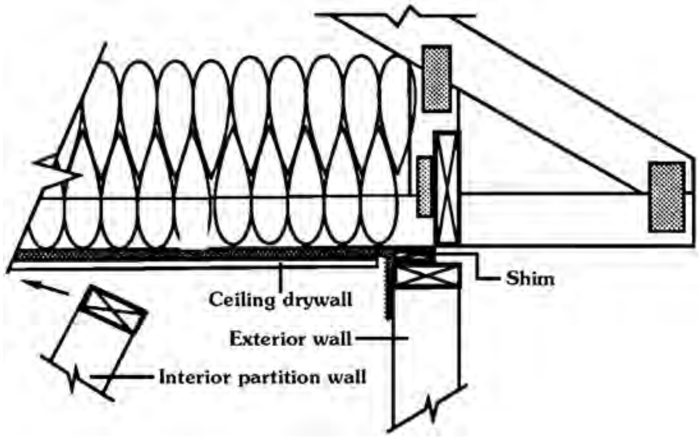


Figure 7.17: Using shorter stud length to fit under ceiling drywall

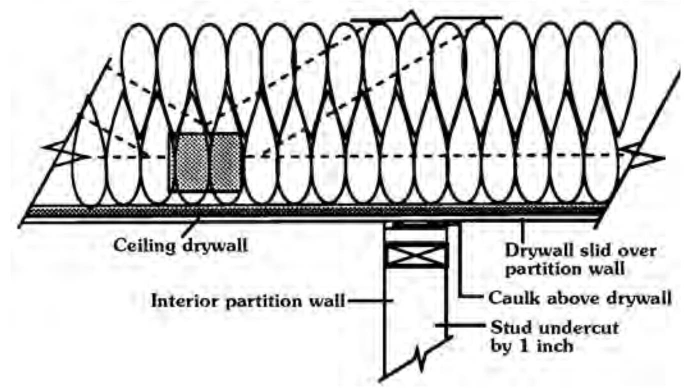


Figure 7.18: Using a shim to make the exterior wall taller to allow for ceiling drywall and standard-length studs for interior walls.

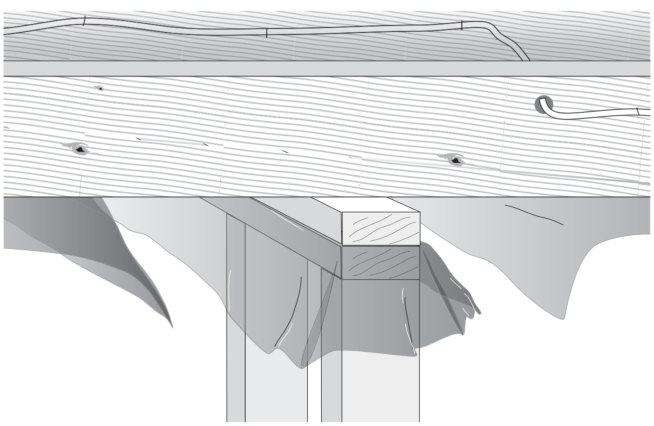


Figure 7.19: Putting a polyethelene tab between the wall top plates to be sealed to the ceiling vapor retarder later

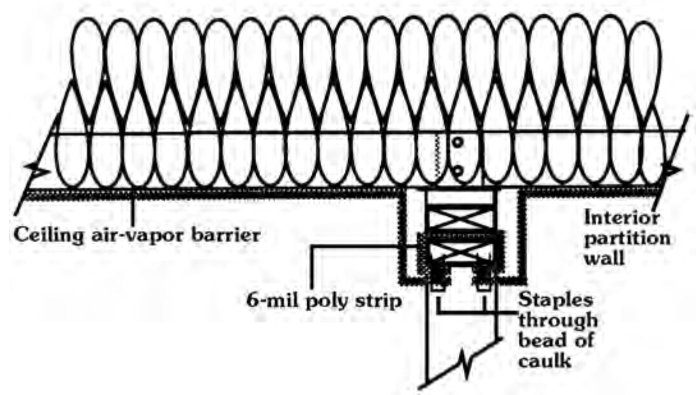


Figure 7.20: Placing a strip of polyethelene between the top plates of an interior wall, to be sealed to the rest of the ceiling air-vapor barrier.

Roof Trusses

Most builders use prefabricated roof trusses. A major weakness of conventional roof trusses is there is less space for insulation at the eaves.

Raised Heel Trusses

The use of raised heel trusses (Figure 7.21) will solve this problem. While costs associated with a raised heel truss (manufacturing cost, extra siding, extra insulation) may total from $100 to $300 per house, energy savings and the prevention of surface condensation justifies the investment by eliminating poorly or inadequately insulated intersections in the building envelope, such as the roof-to-wall connection.

Advantages

- Allows full insulation depth in all areas of the ceiling.
- Provides a clear span and allows for a continuous air-vapor barrier.

Disadvantages

- Slightly higher cost than conventional truss, but often competitive.
- More siding will be required because of larger soffit.

Drop Chord Truss

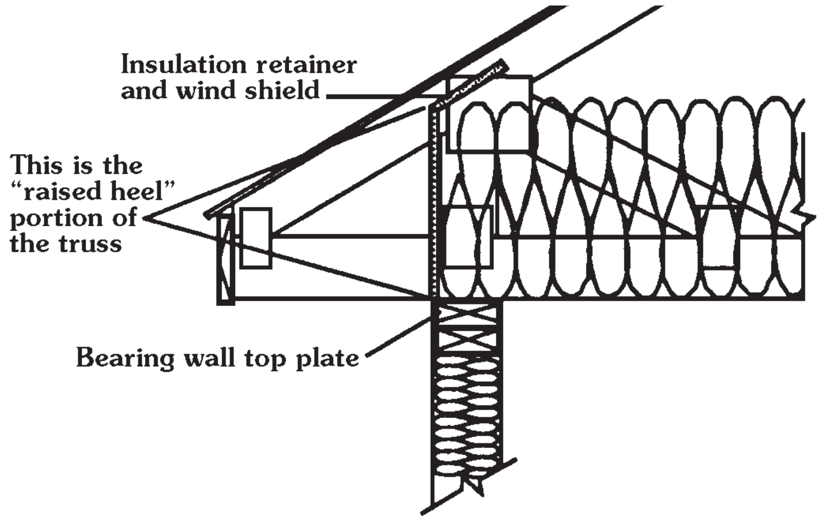
This truss consists of a conventional truss onto which is hung a second lower chord (Figure 7.22).

Advantages

- Can help reduce truss uplift, although it does not eliminate concern about the reaction of the wood.
- Provides full depth insulation up to the perimeter walls.
- Gives a clear span ceiling and a continuous air-vapor retarder.

Disadvantages

- Requires taller studs.
- Requires extra siding.
- Requires blocking at the ceiling and wall junction to attach the air-vapor retarder.



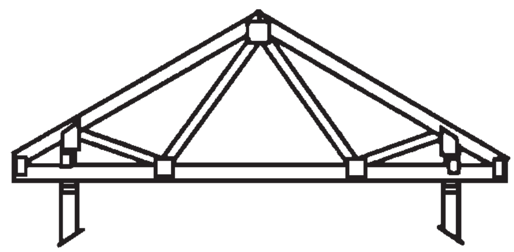
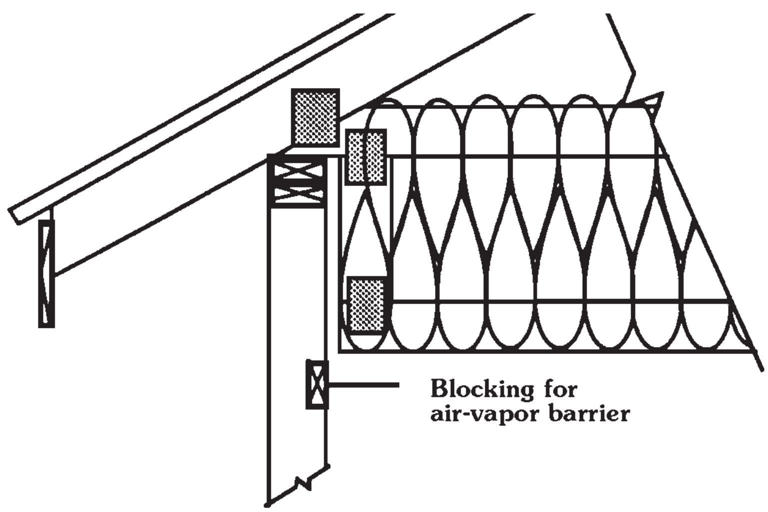


Figure 7.21: Raised-heel roof truss with insulation properly installed



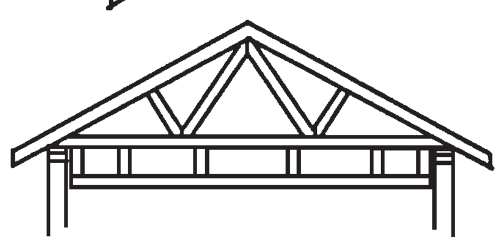


Figure 7.22: Drop Chord Truss

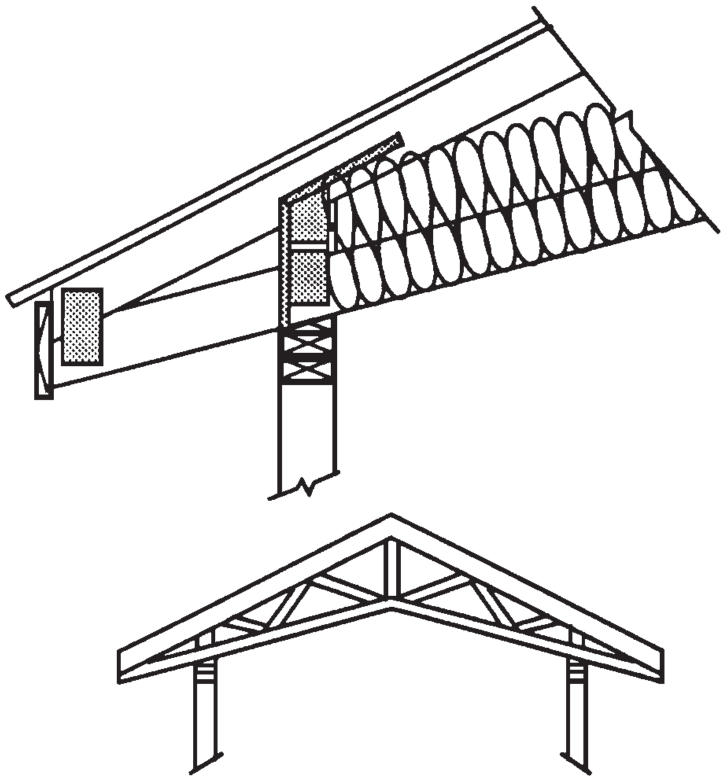


Figure 7.23: Scissor truss

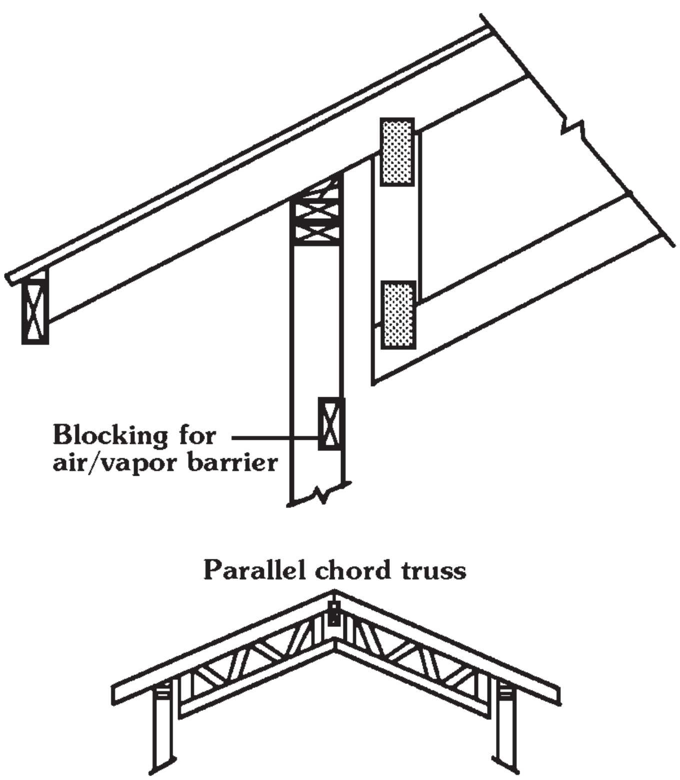


Figure 7.24: Parallel chord truss

Scissor Truss

The lower chords of a scissor truss are sloped rather than horizontal. This allows the builder to construct a house with cathedral ceilings without the need for a central load-bearing beam or wall. Scissor trusses can be modified to accommodate higher insulation levels by constructing them with a raised heel (Figure 7.23).

Advantages

- More easily insulated to high levels than other types of cathedral ceiling.
- In many cases, can be insulated with blown insulation.

Disadvantages

- Costs may be higher than other methods of construction.
- Difficult to insulate between chords, unless using blown insulation.

Parallel Chord Trusses

Parallel chord trusses consist of parallel chords of wood which are joined by an open web of wood, or steel braces, or a solid web of plywood (Figure 7.24). This type of truss permits high levels of insulation in cathedral ceilings.

Advantages

- Allows for large amounts of insulation in cathedral ceilings and also can provide ventilation without purlins.
- Can provide large, clear spans and allow for application of a continuous air-vapor barrier.

Disadvantages

- Higher cost than dimension lumber.
- With a web of steel braces, heat losses due to thermal bridging can be high.
- Difficult to insulate between chords, but blown insulation may help with this problem.

Roof Truss Uplift

In some houses with roof trusses, an upward movement of the ceiling occurs during the winter months, resulting in damage to interior finishes, particularly to interior walls (Figures 7.25 and 7.26). This can result from several things:

- Different moisture contents in the lower and upper chords of the truss.
- Some pieces of lumber expand and shrink much more than the average. If the upper chord of a truss is made of a piece of lumber that has high expansion and contraction characteristics (reaction wood), truss uplift can occur every winter.
- The drying out of the lower chord. In this case, the truss uplift will usually occur only once.

Proper grading of lumber and proper drying of wood can eliminate truss uplift, but the following steps can be taken by the builder to minimize the effects of truss uplift:

- Provide adequate ventilation to the attic area.
- Locate attic vents to ensure good air flow.
- Ensure that the soffit vents are not blocked by insulation.
- When applying drywall, connect the ceiling drywall to the partition-wall top plates with drywall clips. Fasten the drywall to the ceiling at a distance far enough away from the partition so that, in the event the truss rises, the drywall can absorb the deflection without cracking (Figure 7.27).
- Buy trusses that are dry.
- Keep the trusses dry.

In areas with permafrost where the house is built on pilings, opposite effects can occur when parallel-chord floor trusses are used for the floor and the roof: the floor may bow downward while the roof bows upward.

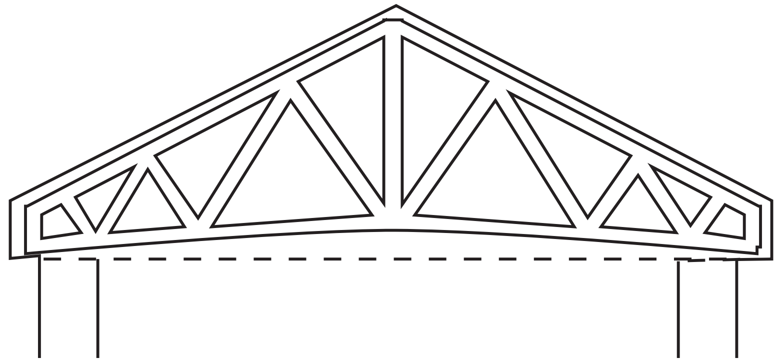


Figure 7.25: Roof truss uplift

Figure 7.26: Damage caused by roof truss uplift

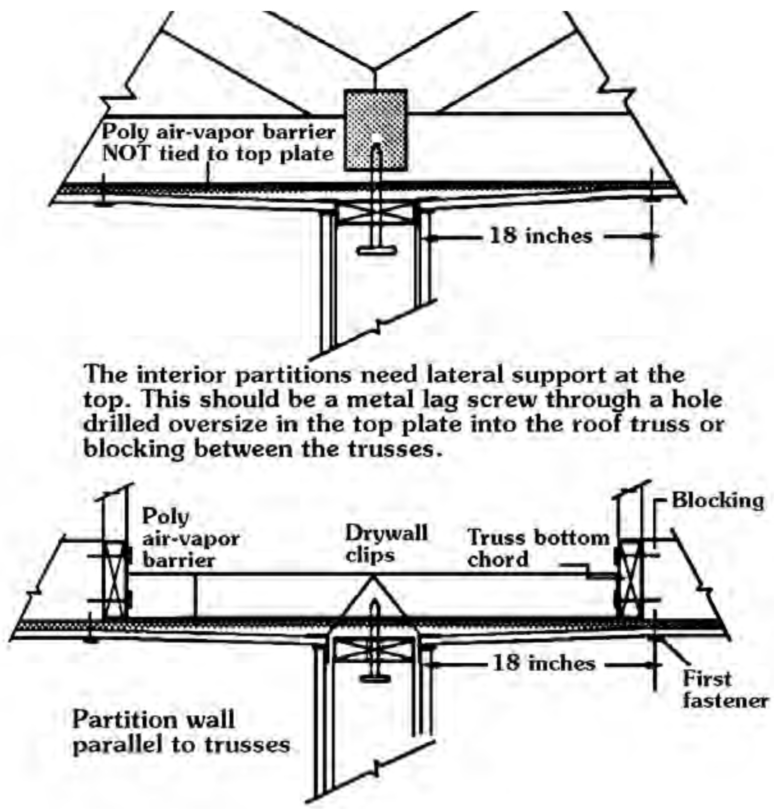


Figure 7.27: Drywall details to avoid damage or ugly cracking from roof truss uplift.

Attic Space Framing

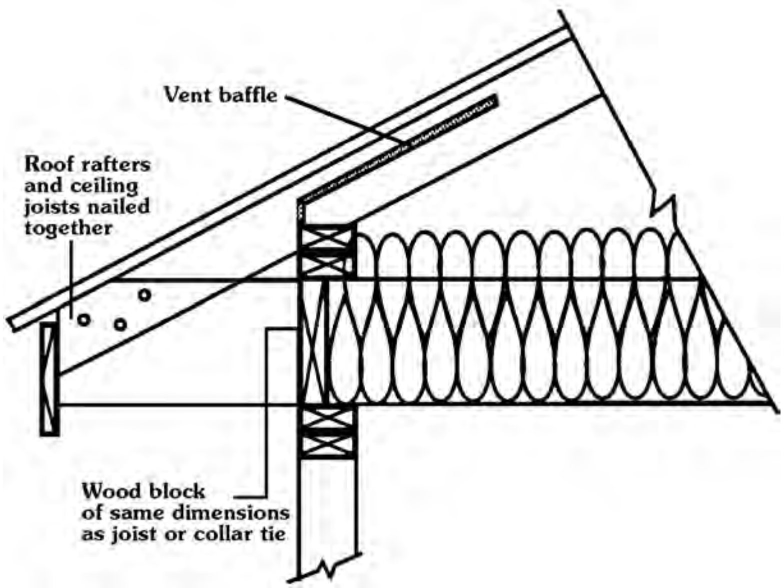


Figure 7.28: Framing an attic using dimensional lumber.

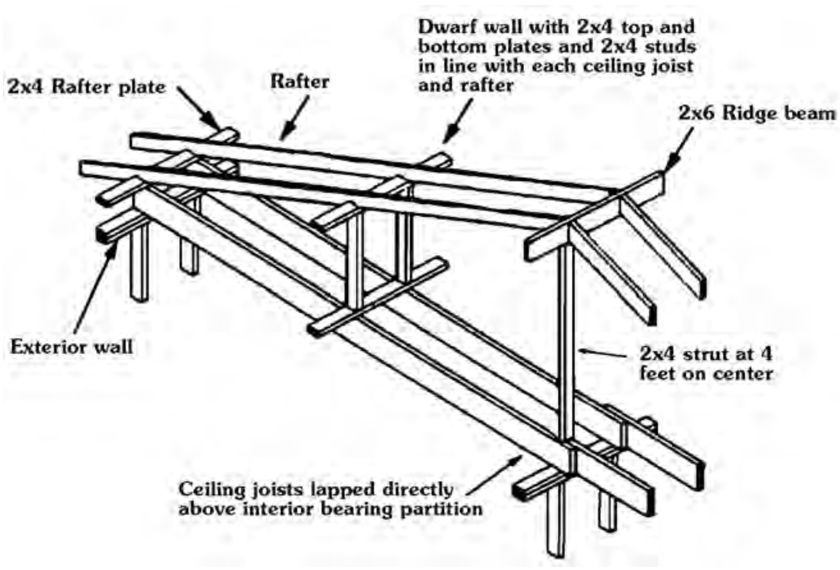


Figure 7.29: Rafter roof design from Harold Orr, Canadian Wood-Framed House Construction (CMHC Pub NHA 5031M, May 1985).

A method of framing an attic space using standard dimension lumber is illustrated in Figure 7.28. Note that the ceiling joists must extend beyond the wall and to the rafter at the eaves to produce a triangulated structure. However, this may not be required in all cases.

The recommended Canadian rafter roof design is described in the following quotation and shown in Figure 7.29. In a rafter-framed attic with a slope less than 4 in 12, the roof loads are carried by beams and not by trusses. The roof rafters and the ceiling joists must be sized to carry the vertical loads imposed by snow and other loads. With this system the loads from the rafters are carried to interior partitions by braces at angles greater than 45°, dwarf walls, and ceiling joists. This reduces the outward thrust of the roof so that continuous ties between the lower ends of opposing rafters are not necessary.

Advantages

- Allows higher insulation levels at the edge of the ceiling.

Disadvantages

- In most cases, more expensive to construct than trusses.

Cathedral Ceilings and Conversion to Cold Roof

Suppose you encounter an older house with an existing cathedral ceiling that is unventilated and has a hot roof problem. If it also is older than 15 years and has asphalt shingle roofing or other roofing material that may be nearing the end of its useful life, you may be able to replace the roof and at the same time convert the old cathedral hot roof into a cold roof.

One method of accomplishing this transition is illustrated in Figure 7.30. Ceiling joists of 2 x 12 (these could also be 2 x 10s or some other dimensional lumber) are commonly used in rafter roofs, and they should be inspected before considering this method of achieving a cold roof. The old roof rafters must be structurally sound. When replacing the roof surface, a new ventilation space can be built above the insulation in the following way: after tearing off the roofing and sheathing, 2 x 3s (2 x 2s are typically of poor quality and are not suggested for this use) are first nailed to the top of each rafter and parallel to them, to give at least 1 ½ inches of air space above the insulation. Then a second layer of 2 x 3s (1 x 4s can also be used) are nailed to the rafters and perpendicular to them to allow for attachment of sheathing and roofing. This alternative assures a cold, ventilated roof with adequate ventilation parallel to each rafter space when tied to appropriate ventilation, and still allows a cathedral ceiling design. The soffit is enclosed under the eave and a 2-inch continuous strip vent is added to the underside of the eave to allow ventilation air to enter the cold cavity above the insulation. This retrofit yields a new cold roof system applied over the old hot roof with minimal additional expense. If you used another deeper truss or rafter over the old roof (first assuring that it is structurally sound) even more insulation could be added before the new roof surface is added.

Advantages

- In some areas, this is lower cost than parallel chord trusses.

Disadvantages

- Limited to a maximum of R-40
- Reduced insulation values at the ceiling joists

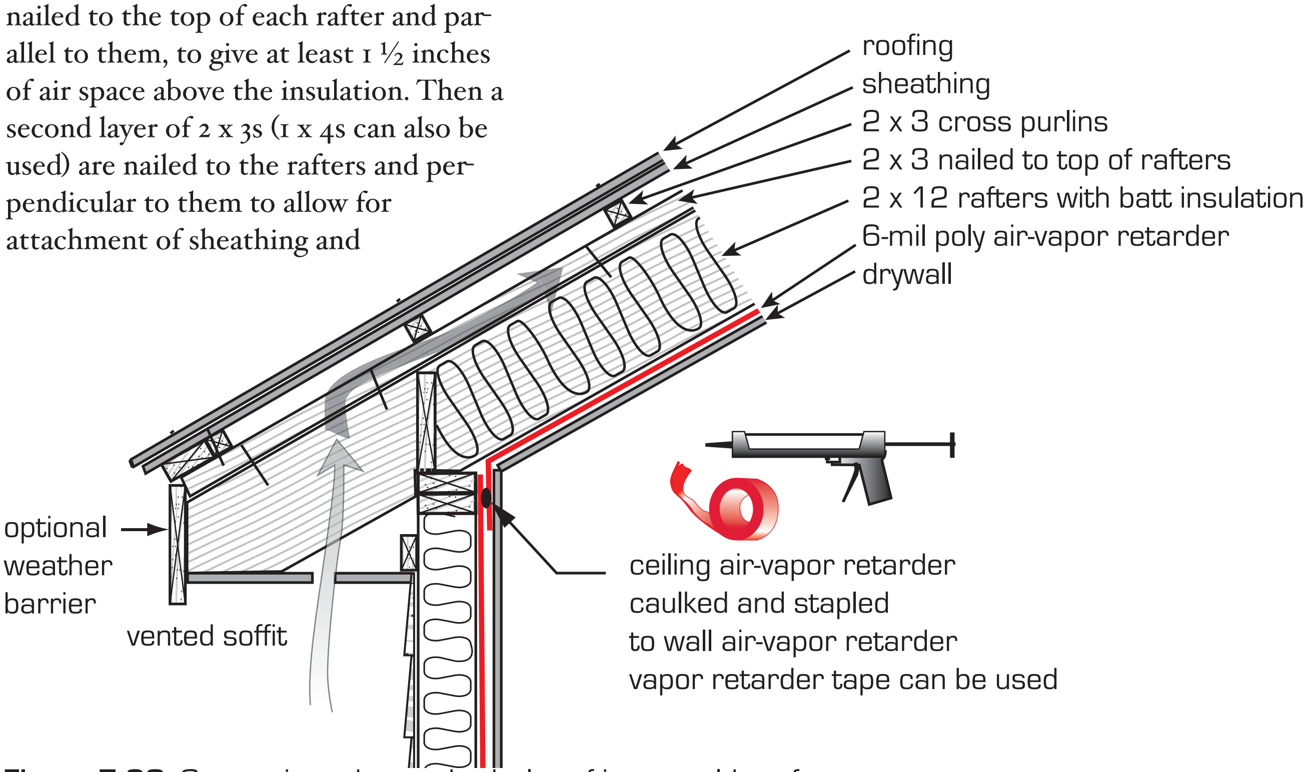


Figure 7.30: Converting a hot cathedral roof into a cold roof.

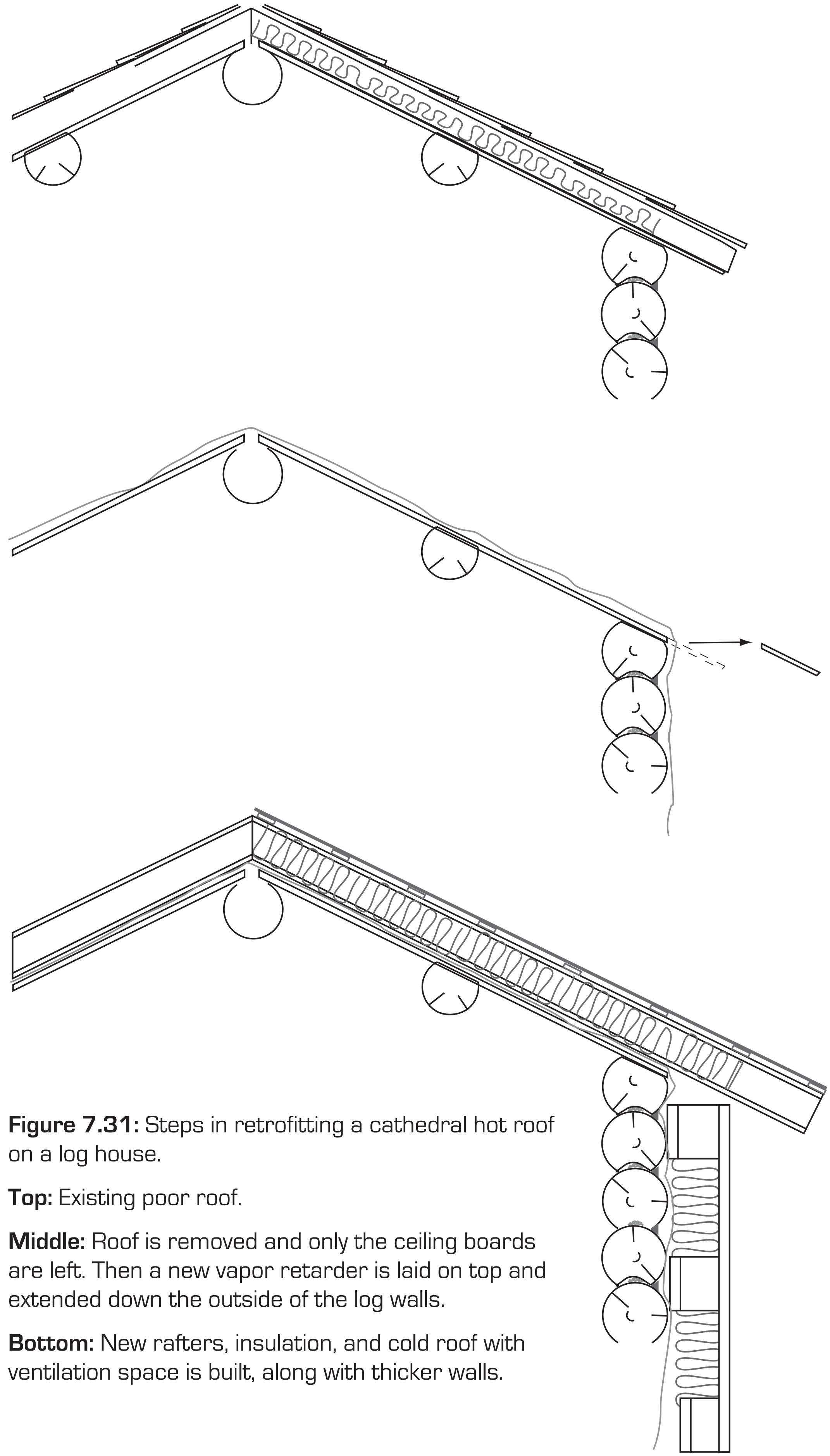


Figure 7.31: Steps in retrofitting a cathedral hot roof on a log house.

Top: Existing poor roof.

Middle: Roof is removed and only the ceiling boards are left. Then a new vapor retarder is laid on top and extended down the outside of the log walls.

Bottom: New rafters, insulation, and cold roof with ventilation space is built, along with thicker walls.

Chapter 8

Heating and Domestic Hot Water

Key Points to Learn

- New systems on the market now integrate domestic water heater with space heating.
- How to avoid oversizing the heating appliance for your home while maintaining a sufficient safety margin.
- Comparison and advantages of different fuel sources and heating systems.
- Keeping heating systems simple and well-maintained are key factors in reliability and performance.
- How to protect the health of your family with informed decision-making on heating.

Heating Systems in Alaska

Selecting a heating system for your home is a big responsibility, and can take some time. The size of the system must be determined by doing a heat loss calculation. Historically, heating systems have been grossly oversized by using *rules of thumb* and comparisons with other buildings. This process has resulted in a substantial waste of energy and unfortunately it continues today. Small gains have recently been made in this area of proper sizing from research that found heating systems in South-central Alaska to be 121% oversized. (Alaska South-central Furnace Sizing Study, Cold-Climate Housing Research Center, cchrc.org) In 1996 AHFC (Alaska Housing Finance Corporation) released AkWarm, a software application for builders, designers, and home owners. AkWarm can analyze energy use and calculate the design heat load that is actually required for the structure.

Heating System Design:

First Step: Determine the "Design Heat Load" of the home. How much heat will you need on that really cold day? What temperature is that really cold day? It is not the coldest day ever recorded, but a slightly warmer temperature called the Outdoor Design Temperature. These design temperatures are published for most communities in Alaska. (Alaska Building Efficiency Standard (1998) Appendix D, 9 pages. also included in the AkWarm computer program.) Why not design for that worst possible day? First of all, there is a lot of safety built into the design heat loss calculation. Internal gains from lighting and appliances are ignored, yet make up 10%–20% of the heat requirements for an energy efficient home. Secondly, short-term periods where the outdoor temperature is below design temperature will have a minimal effect on the indoor temperature because the cool-down effect on a very efficient building will be quite slow. This is another benefit to building an energy efficient building assembly. Proper sizing of the heating system will improve comfort, save energy, and require less maintenance.

There are a number of Design Heat Loss Tools:

- Manual J—This is the mechanical contractors handbook.
- ASHRAE Handbook of Fundamentals—The engineers approach for all building types and sizes.
- AkWarm—This is Alaska's own software, available for free. (www.absn.com)
- Municipality Worksheets: Many building departments provide these for free.
- Industry's "Rule of Thumb" Usually results in grossly over-sizing efficient homes.
- What's in the truck. Or the "one size fits all," contractor assured to be over-sized.

For the builder, the simplest method is to have an energy rater perform an "energy rating from plans" on the proposed design. One of the reports AkWarm generates is a design heat loss calculation. The AkWarm calculation has been tested and monitored in numerous homes and has been found to be very accurate, generally, just slightly over-sizing by 5%–10%, adding a reasonable safety margin.

You may be hard pressed to convince a mechanical contractor who has been living with the "Rule of Thumb" for 30 years to downsize the system by 50% no matter how efficient you built the home. Two options: 1. Have the mechanical contractor do a design heat loss calculation using their industry standard tool, Manual J, or; 2. Keep shopping for a more knowledgeable mechanical contractor.

Second Step: Now that we know how much energy we need to supply to heat the home. Next we need to decide on fuel types.

Fuel Options: This choice is usually an economic one based on the cost of fuel. Refer to the Building In Alaska Publication: Comparative Unit Fuel Costs for Equivalent Dollar Net Heat Output. (Cooperative Extension Publication, appended to this chapter: EEM-01152)

Electricity is generally most expensive per Btu, except for a few hydroelectric communities in Southeast Alaska. This may change as the cost of fuel oil has risen sharply at the time of this printing. New heat pump technology for cold climates may soon prove to be a cost effective alternative to oil or propane.

Propane is more expensive per Btu than heating oil, and in many cases, particularly in rural Alaska, more expensive than electricity. but offers several advantages. One example is a high efficiency 90% + clean burning appliances that is direct vent (sealed combustion). Today there is much discussion what fuel oil prices will do in the future. If you are one who believes fuel oil will become cost prohibitive as a heating fuel, and that natural gas or liquefied natural gas will become the fuel of choice, buying into propane as a fuel for your heating appliance is a choice to consider. Remember, the more efficient you make your home, the less important small differences in fuel costs will make. (Consider investing in the thermal efficiency of your home vs future oil purchases.)

Fuel-oil is the norm when natural gas is unavailable. Other than small space heaters, direct vent boilers and furnaces are not readily available. Tightly constructed boiler or furnace rooms are often necessary for most fuel oil fired appliances. Most locations in Alaska using above-ground tanks must use number 1 ("arctic rated") fuel oil. This ensures that the fuel will flow readily in even the lowest temperatures.

Biodiesel is now available in Fairbanks, Anchorage and Juneau. Biodiesel contains slightly less energy per gallon than fuel oil, but works in some heaters in place of number 2 fuel oil. Biodiesel is typically around 30% cheaper than diesel fuel. Check the manufacturer's instructions for biodiesel/diesel mixes or preheating before trying biodiesel in your appliance.

Natural Gas is still the most cost effective fuel source where it is available in Alaska. Recent price increases in natural gas have not been as extreme as with heating oil price increases.

A few manufacturers offer heating appliances that are easily converted between oil and natural gas, or propane. It may prove to be advantageous to install a system that can be easily modified to utilize one fuel or the other as necessary due to fuel availability and economics.

Coal is rarely used in residential heating systems today, but this may soon change. Many different strategies are available for burning coal. Some appliances also accept wood as an alternative fuel choice. Alaska has huge reserves of coal and wood/biomass and there is interest in preparing these fuels for local markets as other fossil fuels become higher priced.

Wood is usually cheaper than oil, and clean-burning wood appliances have recently become easier to find on the market, making the emissions more in line with oil and gas based systems. Wood is attractive because of its low cost, abundance, and environmental benefits. Wood technologies that are compatible with hydronic distribution systems are available, but most so-called outdoor wood-fired boilers should be avoided due to their low efficiency, high emissions, and high cost. For example, masonry heaters provide a safe, even heat, and emit around 1-5 grams/hour of particulates (smoke). For a map of available fuel types, energy density, and other wood heating information, please go to www.alaskawoodheating.com.

Plans are underway for wood pellet plants in most Alaskan cities. Wood pellet boilers can typically use various sizes of fuel hoppers, and are available in many sizes. Pellet boilers usually incorporate some kind of auto-feed system so manual stoking is not required. Wood pellets are made from low quality wood (typically), and are environmentally friendly, clean, easy, and they are generally cheaper than oil.

Passive solar inputs should be designed into new buildings to contribute to heating the energy efficient home. Even though our northern latitude location causes much of our solar potential to occur during summer months, passive solar design attributes can soften the financial blow from using only fossil fuels. Where any building site offers unobstructed southern exposure the annual heating loads will be reduced by available passive solar inputs. Alaska will never be as solar friendly as Arizona or Montana but ignoring the availability of passive solar is not recommended (see "A Solar Design Manual for Alaska," for further solar discussion. It is viewable by chapter at the Web site: www.alaskasun.org).

Solar thermal hot water also provides good benefit to reducing spring, summer and fall heating inputs. Deciding early to incorporate passive solar heating and solar thermal hot water are intelligent design considerations we encourage you to make before pouring concrete and driving nails! While this manual is an introduction to building science and energy efficient construction, making all available alternatives work for you is simply good planning. Many resources on capturing solar energy are available. See again, "A Solar Design Manual for Alaska" CES publication EEM-01255.

In earlier years, when buildings were constructed using little or no Building Science information, houses required very large inputs of energy to satisfy the winter heating requirement. Today, by designing and assembling houses with high levels of insulation, advanced windows, exceptionally air-tight envelopes and controlled ventilation with heat recovery, we are now able to minimize fuel inputs of all types. Such super energy efficient types of houses are fuel flexible, exceptionally comfortable and inexpensive to operate. And remember, improved health and minimal maintenance are two rewards for following the Building Science approach to home construction.

Third Step: Determine the **Heating System**

The system should always be:

- Safe
- Efficient
- Comfortable
- Clean
- Have reasonable service life
- Easy to maintain.

One of the biggest decisions to be made when selecting your heating system is deciding between air-heating and hydronic, or water-based heating. We will discuss the following types of space heaters and combinations in more detail below.

Space Heater

- Forced-Air
- Combinations
- Hydronic

The following table is a quick guide to the two main ways of distributing heat in your home. The decision you make here will influence your entire building design.

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Table H-1. So what type heating system is best for you?			
Hot Air		***Hot Water***	
Pro	**Con**	**Pro**	**Con**
Lower Cost	Expensive to zone	Easy to zone	Higher cost
Low stand-by heat loss	Noisy	Quiet	High mass boilers have high stand-by heat loss
Can incorporate electronic air cleaner	Circulates dust & dirt	Uses radiant heat	water may need conditioning (mixing, valves, expensive)
Can incorporate air conditioning	Large space for ducts	low cost hot water	
	Expensive to distribute	cheap to distribute	
	Requires separate water heater	Small size	
		May be in out building	

Space heaters: Small console heaters such as the Toyo, Monitor, Rinnai, etc. offer direct venting with reasonable efficiencies. The elimination of a distribution system makes them much less expensive to install and they use less electricity to move the heat around. In a small, very well insulated, open floor plan home, a space heater can be an option with one big caveat; back rooms will generally be cooler. The more efficient your building assembly, the warmer those back rooms will be, but with doors closed, they will be cooler. This is simply unavoidable, and should be anticipated. Many folks like bedrooms to be cooler, so a 5–10 degree cooler room may not be a big deal. For others, it would be. Caution is advised.

Our building science knowledge reminds us that as we cool down the room air, the relative humidity goes up. Higher relative humidity may result in condensation and mold growth. Mold growth is often found on exterior walls, especially in closets, at room partition intersections, and where bedding or furniture makes contact with outside walls. Whole house ventilation to the back rooms can help maintain lower relative humidity but will likely further lower room temperatures with the introduction of cooler air into the room. Back room doors should be left open as much as possible. Many attempts of installing a small thru-the-wall fan have ultimately failed, with noise being a prime complaint. Also, the lack of any real improvement in raising temperatures usually results in closing them off permanently. The amount of heat actually being delivered from a small flow of air that is only a few degrees warmer than the space it is trying to heat just doesn't do much. Adding a little recirculation air to those rooms could be a benefit. As an alternative, a space heater can provide supplemental and backup heat to a central heating system, offering a little more piece of mind during our cold winters.

Forced-Air Furnaces: These are very popular in South-Central Alaska, but fairly rare throughout the rest of the state. A bias has developed against forced-air systems. This is not because they are a bad system, but because they are seldom designed and installed correctly. Furnaces have advantages; combining ventilation air and supplying it to the heating ducts reduces whole house ventilation costs. These systems also provide opportunities to filter the air and condition it for proper humidity. Furnaces also have simpler controls, less pumps, valves, and risk of water damage from leaks.

Common problems with forced-air furnaces:

• **Grossly over-sized**. Over-sizing requires larger ductwork and must distribute much more air than necessary causing drafts (discomfort) and more potential for noise.

• **Leaky duct work**: Traditionally little attention was made to sealing ductwork. Why bother if the ducts are inside the house? Using a little of the building science learned in Chapter 2 lets look at the potential problems of leaky ducts.

• If there is a supply duct running in a closed floor cavity with a few leaky joints, what's happening? The high pressure in the duct forces air out the leaks into the cavity, pressurizing that cavity slightly. At the far ends of that cavity there is likely to be a leaky rim joist. We now have a pressure across the rim joist and a hole to outside. Pressure + hole = flow. We are now potentially increasing the flow of warm moist air thru the building assembly increasing condensation potential and rot of the rim joist.

• If that cavity is used as a return plenum to the furnace, we are now sucking on the rim joist and wall assembly increasing air leakage and energy costs.

Issues in the crawlspace: Many leaky return ducts will depressurize the crawlspace. Not only does this increase air leakage into the crawlspace, but also increases the potential of pulling soil gases like radon out of the ground and then delivers them directly into the house creating indoor air quality problems. Leaky return ductwork in a garage, or worse yet the entire leaky furnace, will cause indoor air quality problems. Oversights like those we've discussed may be responsible for childhood asthma, radon, which is the second leading avoidable cause of lung cancer, and; carbon monoxide. Alaska has an especially high carbon monoxide mortality rate.

• **Inadequate supply and/or returns**: Only a few years ago it was common practice to only supply air to rooms and rely on a common return grill centrally located. These ducts are usually matched to a grossly over-sized furnace which moves a lot of air whenever it operates. What happens to a room if we only push air into it, but don't pull air out of it? Mechanical contractors should always balance the air flows in a forced-air system.

Note-The problem of inadequate supply and return ducting has been partially resolved with contractors now putting return grills in most rooms. Unfortunately many contractors often do not attempt to balance the system. Simple pressure diagnostics show rooms closest to the furnace pull more return air and are thus depressurized. Rooms farthest away still go slightly positive. If a bedroom is put directly above the garage where the furnace is installed (that may be changing soon) that bedroom is mechanically depressurized, sucking more garage air and pollutants into the bedroom every time the furnace comes on.

• **Installing ductwork in unconditioned spaces**: Installing duct work in attics s a cost cutting option that is seen on occasion. Leaky ducts whether supply or returns, are bad. The ducts also replace what should have been insulation in the attic increasing heat loss to the attic. This is clearly bad practice.

• **Poor temperature control**: Many complaints come from small two story condos where the downstairs is cold and the upstairs too warm. Typically the thermostat is located upstairs. Thermostat calls for heat, the furnace fires and delivers a blast of warm air to all registers. What does building science say about warm air rising? The furnace doesn't run long enough to actually warm up the lower level before the thermostat upstairs is satisfied. The open stairway allows warm air from the lower floor registers to rise to the second floor, adding more heat to the upstairs. The downstairs heat load is compounded by the air leakage entering the house primarily on lower level, further adding to the comfort problem. Better furnace sizing and duct layout would go a long way in resolving this comfort issue.

A better forced-air system:

- Furnace sized appropriately to the design heat load of the building. Bigger isn't better.
- Good duct sizing and layout. Slightly oversized ducts are much better than undersized. Less noise and less power (electricity) needed to move the air, and provides a little safety margin to assure adequate flows to those farthest rooms.
- Balanced, little or no pressure differences between rooms or floors.
- Very well-sealed ducts. If in doubt have an energy rater do a duct leakage test during installation. This may be your last chance to fix a problem.
- No ducts in garages or unconditioned space
- Test the system to confirm proper flows to rooms and temperature rise across furnace heat exchanger, check that the safety high limit working properly, and other checks recommended by manufacturer.
- Install a new medium to high efficiency furnace filter installed at start-up which is in a location designed for ease of access.
- Homeowner guide for maintenance

There are a number of guides for proper duct sizing. Manual D is an industry standard. Just as one should do a design heat loss calculation for sizing the heating system, a quick design heat loss for each room to determine appropriate flow requirements will determine proper supply and return duct sizing.

Energy efficient Brushless Permanent Magnet (BPM) blower motors are becoming more popular. (Same as ECM motor which is a trademark of GE.) They are much more efficient than a conventional blower motor and can save considerable electricity. Studies report 40% electrical savings. (PIGG 2003, LBNL59865-2006). These smart blowers have the ability to vary the power to the motor to maintain a constant air flow. For example, as filters get dirty, air flows would normally be reduced, but with the BPM motor the controls would simply increase the power supplied to the BPM motor and maintain the same flow thru the furnace, though electrical consumption will go up. The use of the new constant flow of BPM motors has one downside: poor maintenance. These expensive BPM motors were not designed to operate continuously under full load conditions and premature failures have been common, and very expensive to replace. With increasing energy prices, the future for BPM motors is promising, but current knowledge of their limitations by inexperienced heating system installers should be considered in the selection of furnaces.

Mid efficiency and high efficiency two-stage furnaces have become popular options for furnace selection. They are available with standard PSC (Permanent Split Capacitor) motors and the efficient BPM. The furnaces operate on a low fire during much of the heating season, but when additional heat is required, they go to a high firing rate. The furnace fan also operates at the low and high speed accordingly. Low speed operation is generally much quieter and less drafty. Longer run cycles offer better temperature control for improved comfort. Little or no fuel efficiency gain has been reported with the two-stage firing versus the conventional single stage furnace. The standard PSC furnace blower motor is much less efficient on low speed than the BPM blower, so total energy savings is less with the standard PSC motors over the BPM blower. As mentioned above, the BPM motor failure rate has been problem due to poor maintenance, duct design and/or installation. The costly replacement of the BPM motors (reported to be as high as $500) should be considered in the selection of a furnace.

An important fact to be aware of is this: with an energy efficient home you simply do not need as much heat. Smaller furnaces with less duct work save money. Spend some of it on better design and installation, and use the savings for other energy improvements.

Hydronic Baseboard and Radiant Floor Heat:

Although the forced-air furnace dominates the south-central Alaska market, hydronic heating is the standard for most other regions in Alaska. Hydronic heating, whether utilizing baseboards or a radiant floor system, offers multiple zoning, reduces noise, and is a comfortable heat option. Hot water is usually supplied by a boiler, but a domestic hot water heater has also been successfully used to heat the entire house. With a conventional boiler setup, an indirect water heater is used to provide the domestic hot water. The indirect water heater has heating coils within the tank, or an external double-wall heat exchanger to transfer boiler heat to the domestic hot water without danger of boiler water mixing with the potable water.

Boilers all operate on the same principles: water is moved through a large frame of steel or cast iron and an oil-fed fire burns around the heat exchanger. When a thermostat calls for heat, it signals the zone valves to open and the circulating pump to start operating. When a typical boiler's internal controller senses cold water it causes the burner to fire. Some cast iron boiler systems have built-in safety features to keep water that is too cold from making its way into the boiler, which could crack it. Pressure relief valves set at no more than 30 PSI are absolutely necessary to prevent pressure from building up in the boiler, and air venting valves should be installed at the highest point in the system to relieve extra gases that may build up.

It is now possible to purchase condensing oil and gas boilers with even higher efficiencies than was traditionally possible. Condensing boilers are able to extract more heat out of the combustion gases by allowing the combustion gases to become liquid inside of the boiler. In fuel oil boilers, this usually requires stainless steel tanks which can resist the corrosion of the sulfuric acid in oil-based combustion liquids. Experimental uses of condensing oil boilers by the Cold-Climate Housing Research Center in Fairbanks have shown that the acidic effluent can be safely processed on-site through the use of limestone rocks in an ABS cylinder. A typical efficiency for a condensing boiler is above 90%.

Boilers use a water or glycol mixture as their fluid for heat transport. Many homeowners opt for pure water due to its higher heat transfer capability, lower viscosity (thus lower pumping costs) and lower cost, but glycol is recommended. For domestic water connected systems, food-grade propylene glycol must be used, and is quite expensive. Ethylene glycol is usually not recommended as it is a serious poison, but is the best freeze protection for the money and contains rust inhibitors. If a glycol with rust inhibitors is not used, a chemical such as "Stewart Hall 8-Way" or equivalent, containing chromate and sodium nitrate should be used to protect the ferrous metal in the system.

Efficiency and Controls: Boilers have minimum government-mandated efficiencies called the annual fuel utilization efficiency or AFUE. This is a specific measure of efficiency developed by the government in 1987 but may not fully represent the energy use required to operate a boiler because it neglects standby losses. Using a seasonal efficiency measure has proven to be a better measure of efficiency for boilers. Seasonal efficiency provides a more accurate apple-to-apple comparison of different boilers. Recent research by Dr. Thomas Butcher at the Brookhaven National Laboratory has determined that AFUE actually can skew comparative efficiencies between different boiler designs. Dr. Butcher's report may be found at http://www.bnl.gov/est/files/pdf/ButcherAachenPresentation.pdf Due to efficiency improvements, replacing an inefficient boiler, even a fairly new one with an AFUE around 70, can result in energy savings of up to 25%.

One of the big benefits of hydronic boilers is the ability to easily maintain different temperatures in different parts of a building through the use of zones. Zone valves allow one area to be heated at a time, which reduces overheating and enables heat to be moved efficiently over long distances. Extra large zones or zones very far away from the boiler may need their own circulating pump.

Various controls and operating strategies exist to reduce hot boiler operating standby losses.

Baseboard fin-tubes are quick to install, fairly low-cost, (though rising metals prices may change this), and they are efficient. Traditional wisdom said that baseboards should be installed at exterior walls and under windows to maximize air circulation and reduce moisture buildup on and around windows. However, with today's well-insulated homes and good windows, putting baseboard on interior walls can reduce heat loss through the bottom of the wall and save energy. Since there are different styles of fin tubes available, you should check the heat output, which is usually rated in BTUs per foot length of baseboard. This is especially important if you are planning to use a lower-temperature heat source such as a water heater or solar heated water. The distribution system should always be slightly oversized above the house heating design load, though it is important to size the distribution system on a room-by-room basis, and to not just divide the total heating load by BTUs per foot of baseboard. Use the resources at the beginning of this chapter for help in determining the design heat loads of various rooms.

Radiant Floors have become the system of choice for most modern home-builders due to their comfort, even heating, and low water temperatures. Radiant heating in general relies on heating the objects in a room rather than the air itself, which is more comfortable but also more efficient. Most radiant hydronic systems employ plastic pipe in a poured slab or over subflooring in lightweight concrete or gypcrete. Check the manufacturer's specifications for spacing needed for a given heat load and concrete thickness.

Plywood subflooring with radiant tubing has been gaining popularity of late, and must be used with aluminum diffuser plates to spread and direct the heat. In both installations it is necessary to insulate under the heated floor. For wet (concrete) applications, heat may easily be lost to the ground or groundwater, wasting money. In plywood-based systems, achieving the desired level of heat transfer of the building may necessitate a high level of insulation below the plywood, and heating of the crawlspace will occur if the floor is not insulated adequately. A radiant layer beneath the heating pipes should be installed, or a grooved-plywood product with built-in radiant shielding should be used.

Radiant floors use lower-temperature water, typically between 100-120° F. This reduces standby losses at the boiler and keeps the floor from overheating. Floor temperatures above 85 degrees result in discomfort and steps should be taken to keep the floor temperature below 85°F. Radiant floors are typically some of the more expensive heating systems, but should give life-long service if installed correctly.

Radiant forced-air systems have been used in floors in the past, but these suffer from some of the same problems of control and inefficient blower fans as poorly ducted forced-air systems discussed earlier in this chapter. If designed correctly, however, a forced-air radiant floor could be comfortable and make use of displacement ventilation to efficiently ventilate and heat a room.

For more information see http://eere.energy.gov/buildings/info/homes/coolinghome.html

For a free program to assist you with modeling radiant systems, see: http://windows.lbl.gov/software/therm/therm.html

Proper sizing of oil boilers can be a real challenge because there aren't many choices-the smallest are typically in the 75,000 BTU range. For this reason, as well as physical size and cost considerations, some people have started using domestic water heaters for space heating and domestic dual-uses. Proper sizing is important because cycling and standby (jacket) loss of boilers, especially high-mass cast iron boilers, increases with oversized capacity.

Stand-by heat loss

Stand-by heat loss is the heat transmitted to the surrounding area of the boiler room and convected up the chimney during the off cycle. Domestic cast iron boilers have ½ inch of fiberglass insulation on the sides and top and none on the bottom. This minimal amount of insulation is not sufficient for a boiler that is operating regularly from 140° F to 200° F. There is not room between the metal cabinet and the cast iron sections to increase the amount of insulation. It is not unusual to enter a mechanical room and find 80°+ F air temperatures. Most typical oil fired heating systems prefer a negative .02" of water column draft over the fire, which is maintained by the use of a barometric damper. The warm air in the mechanical room bleeds through the damper and up the chimney continuously under these operating conditions. In many small homes in rural Alaska, the stand-by heat loss from the boiler will often over heat the living space, causing the unit to be controlled by the service switch.

Advantages of a Low Mass Boiler

Typical cast iron boilers have from 6 gallons (50 lbs) to 15 gallons (125 lbs) of water in them. That is in addition to 400 lbs to 600 lbs of cast iron. This large mass may be sitting in the mechanical room at a high operating temperature, waiting for a call for heat or a need for DHW. All the while it is radiating and conducting heat to surrounding area while convection carries heat up the chimney. If the boiler uses a control that does not maintain temperature for a DHW tank-less coil, the boiler may be cooled down to ambient (room) temperature. In that case on a call for DHW, 4 to 7 hundred pounds of water would need to be heated to bring the storage tank up to temperature.

A low mass boiler works more like a hot air furnace. The boiler weighs 250 lbs and holds 2½ gal (21 lbs) of water. Before a call for heat it is at ambient temperature just like a hot air furnace. On a call for heat the burner and the circ pump start. Water is circulated from the supply to the return header of the boiler. In approximately 90 seconds, the return header is 170° F and the energy manager opens the appropriate zone valve/s to satisfy the demand. Near the end of the cycle the burner is stopped and the circulating pump continues to run (just like the fan of a hot air furnace) to purge the last of the heat out of the boiler until it is back to ambient temperature. There is very little loss to the surrounding area. Consequently low mass boilers are not as disadvantaged when over-sized as are typical high mass boilers. Barometric dampers are not used so very little warm air goes up the chimney. This process can make a 20%+ difference in fuel consumption compared to typical high mass boilers.

Boiler Controls

Typical boilers have a control that manages a boiler temperature suitable for the coldest mean temperature expected in winter. If the boiler has a tankless coil, it may also maintain a minimum temperature to insure adequate DHW when there is not a call for heat. The control also doubles as a switching relay to control the circulating pump on a call for heat. These controls are responsible for much of the stand-by heat loss. After-market controls are available that maintain the boiler temperature as necessary depending on outside air temperature. The outdoor reset control will lower the mechanical room ambient temperature which can make the home more comfortable in warm weather, as well as reduce stand-by heat loss. A savings of 6% to 10% can be expected by adding an outside temperature reset control. A manual reset, over temperature trip is another very good option on all heating units. Adding such a control is like buying insurance and bolting it to the heating unit. Should the regular temperature control fail, the over temperature trip will shut down the unit before an unsafe temperature is reached. The building occupant can restore heat by pressing the red button (reset) on the over temperature trip. Repair or replacement of the boiler temperature control is necessary to return the system to automatic. In the case of a hot air furnace, overheating will probably be caused by a broken blower drive belt, bad blower motor, or an obstruction in the return air to the furnace. This problem would have to be corrected before heat could be restored.

Domestic Hot Water (DHW)

Supplying DHW is a significant heat load in the modern building. In a super-insulated 5-star home, depending on occupancy, the DHW may energy use may equal or exceed the heating load. Buildings with hot air heating systems frequently are equipped with electric water heaters. <u>This is not the best choice</u>! The initial cost of an electric water heater is lower, but as a rule, electricity is a more expensive option than fuel oil or gas. At the time of writing, heating with electricity will cost a family 69% more than heating the same amount of water with a relatively new boiler. An office building with no bathing, cooking, or clothes washing facilities could be a candidate for electric water heating. As a rule, any use of high resistance electric appliances is discouraged, particularly in rural Alaska. There are many different types of domestic water heaters available; only a few are described here, and not all

Table H-2

LIFE-CYCLE COSTS FOR DIFFERENT TYPES OF WATER HEATERS

Water heater type	Efficiency	Cost[1]	Annual energy cost[2]	Life (years)	Cost over 13 years[3]
Conventional gas storage	57%	$380	$337	13	$4,767
High-eff. gas storage	65%	$525	$296	13	$4,373
Conventional oil storage	55%	$950	$636	8	$10,165
High-eff. oil storage	66%	$1,400	$520	8	$9,562
Conventional electric storage	90%	$350	$792	13	$10,650
High-eff. electric storage	95%	$440	$734	13	$9,986
Demand gas	70%	$650	$302	20	$4,571
High-eff., pilotless demand gas	84%	$1,200	$170	20	$3,406
Demand electric (2 units)	100%	$600	$800	20	$11,000
Electric heat pump	220%	$1,200	$271	13	$4,717
Indirect water heater with efficient gas or oil boiler	79%	$600	$289	30	$4,357
Solar with electric back-up	n/a	$2,500	$242	20	$5,640

• Approximate cost. Includes installation.

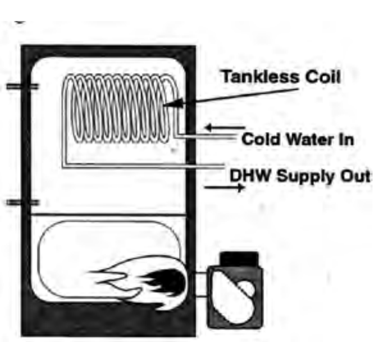
• Energy costs based on hot water needs for typical family of four and energy costs of 16¢/kWh for electricity, $1.297/therm for gas, $3.15/gallon for oil.

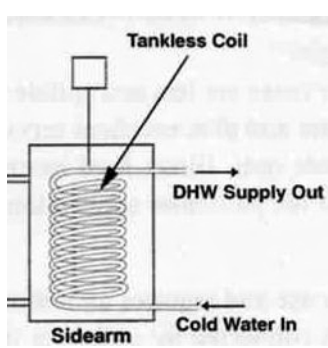
• Future operation costs are neither discounted nor adjusted for inflation.

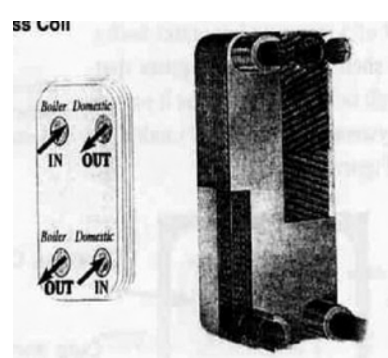
Source: American Council for an Energy-Efficient Economy. Energy costs interpolated to Fairbanks, Alaska in February, 2008

may be available locally. Here is a cost-breakdown of many different types of water heaters, along with their expected longevity.

High mass cast iron boilers have been marketed in Alaska for years, partly by promoting the "tank-less coil" as an endless supply of DHW and eliminating the water heater. Thirty years ago, this was standard practice and is responsible for many boiler sales. This process incorporates a ½" copper coil with heat transfer fins that is submerged in the heating fluid of the boiler, and domestic water circulates through the coil on its way to the hot water faucet.







Figures H-1-3.

Flat plate heat exchanger.

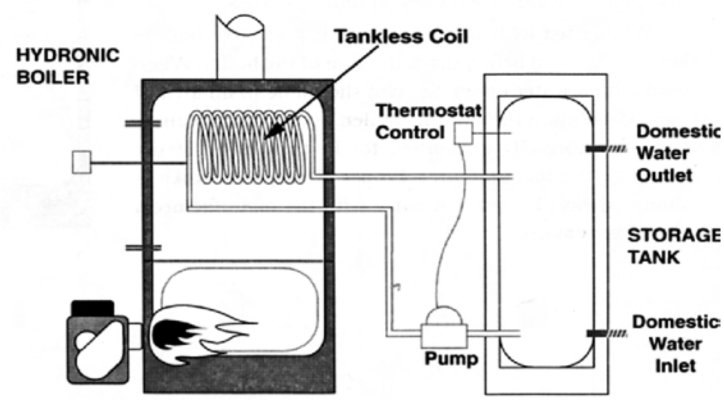


Figure H-4.

It is advertised as an endless supply of DHW from 2 to 4 GPM (depending on boiler size) of water at the shower or sink. Boiler controls establish two different temperatures as needed to supply DHW or heat the building as called for. These temperatures would typically be around 160° F for heating DHW and 180° F to 200° F for space heating. Reading the fine print of the O & M manual that comes with the boiler will stipulate that in order to produce the DHW flow rate as advertised, the boiler must be at 200° F and the inlet water must be 40° F. This is seldom the case in much of Alaska. This system as designed causes a tremendous stand-by heat loss as the boiler is standing-by at a high temperature continuously in order to provide the hot water on demand!

Several alternatives to utilizing the tank-less coil are available. One method is to simply use a DHW storage tank. One storage tank method that is gaining popularity is the "coil within a tank", some times called a "Boiler Mate". These tanks are insulated well and have minimal heat loss to the surrounding area. This is an old method of heating and storing DHW that was originally used in hotels, apartment buildings, and other commercial buildings. This method of supplying hot water allows the DHW tank to be just another heating zone by using a zone valve or a circulating pump to respond to the call for hot water. During the off cycle the boiler temperatures can cool down to ambient, which helps to reduce stand-by heat loss. Storage tanks with heating coils are relatively expensive, $700 to $1000 depending on size and manufacture. Not all tanks have removable coils for cleaning. In the event the storage tank is depleted of hot water (cooled to 80° F) the recovery time is approximately 35 minutes to get 120° F water to the faucet.

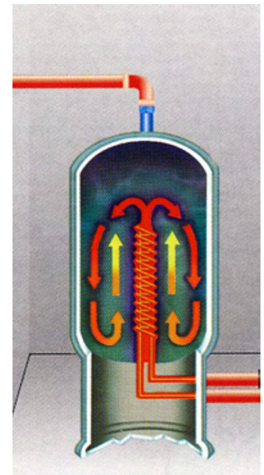


Figure H-5.

Another method of heating and storing DHW is to use an electric water heater for a storage tank. These tanks are well insulated, and must be approved by the ASME (American Society of Mechanical Engineers) as pressure vessels, and are relatively inexpensive, ($250 to $300). The heat source can be a tank-less coil side arm, or a flat plate heat exchanger. Flat plate heat exchangers are usually the most efficient heat exchanger available, and are recommended. Hot and cold connections are made to the normal connections on top of the tank. The same pressure and flow rate can be expected in the hot and cold service lines. A plastic tube inside the tank will carry the incoming cold water to the bottom of the tank. Cold water will be pumped from the bottom of the storage tank though a heat exchanger, and returned to the top. The water will stratify as the heated water rises to the top. This method of heating and storing DHW allows nearly the whole tank of water to be used before the next heating cycle begins. When the tank is down to about five gallons of hot water, the circulating pump starts and makes up water at about three GPM. A minimum number of heating cycles are required but hot water is always available at the faucet.

Installing a Domestic Hot Water Storage Tank

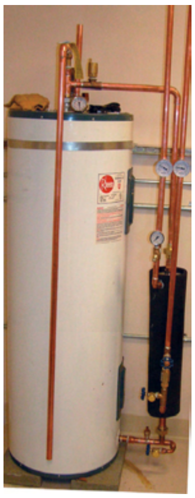


Figure H-6. Here is an example of a low-cost electric water heater that has been converted to a boiler-mate using the side-mounted heat exchanger.

1. Select a super-insulated, electric hot water heater to be used as a storage tank. A tall skinny tank instead of a short fat one, is preferred, because this will enhance stratification between the hot and cold water. A 30 to 50 gallon capacity is usually adequate.

2. The tank should be set on a stand 3 to 4 inches off the floor to allow for air circulation, preventing condensation and corrosion.

3. Domestic supply and return lines are connected to the normal connections on top of the tank.

4. Remove and dispose of the water heater drain valve connection from the tank. Using brass or copper fitting only, provide a hose bib for a tank drain and a supply line for a small (3 to 5 gpm) bronze or stainless steel circulating pump, like a Taco 003 or equivalent. The circulating pump will pump cold water from the bottom of the storage tank to the tank-less coil, shell and tube, or flat plate heat exchanger.

5. Remove the pressure/temperature (T/P) relief valve from the top of the tank. Since there will be no heating taking place in the storage tank, the temperature sensor is disabled by cutting it off at the bottom of the valve.

6. Tanks that have the T/P relief on the side of the tank will have a tee installed near the port to receive the effluent from the domestic water heater as well as the relief valve.

7. Tanks with the T/P relief port on the top, should have a short plastic tube approximately 12 inches long installed in the tapping to carry the hot water from the heater a short distance from the hot water supply to the home. This will prevent short cycling of hot water and possible scalding.

8. Install a circulating pump with around three GPM capacity. A March model 809 or Taco 003 is adequate. The pump should be isolatable (valved on both sides).

9. The pump should be controlled by a switching relay that has auxiliary contacts such as a Taco SR 501, RIB 2401D or Honeywell R889A or equivalent. The thermostats originally intended for the heating elements of the electric water heater can be used to operate the 2401D, SR 501 or R889A switching relay. (The Taco SR501 and the Rib 2401D will require a separate 24V power supply.) The top thermostat will trip the relay to start the circulating pump and heat the top part of the storage tank. When the top thermostat is satisfied and opens, the bottom thermostat will hold the relay closed through the auxiliary contacts until the entire storage tank is hot. (Note: The bottom thermostat and the auxiliary contacts cannot trip the relay.) Only the 24V control power will be connected to the storage tank.

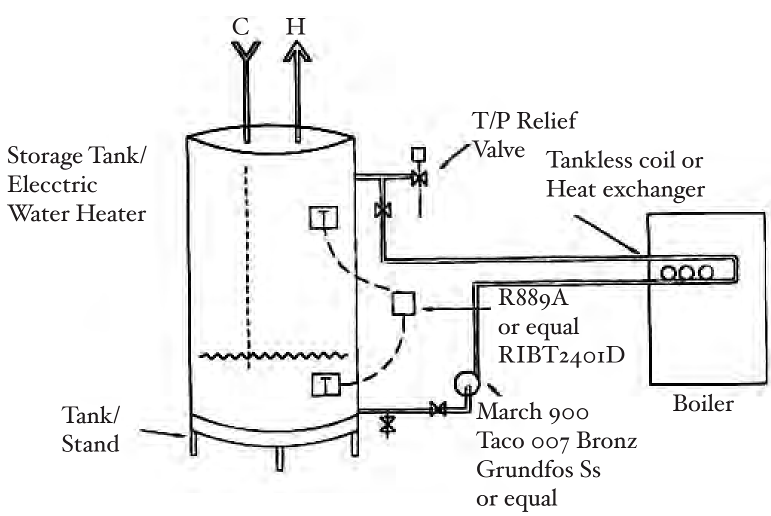


Figure H-7.

Solar DHW

Despite our cold climate, we here in Alaska do get quite a bit of sunshine. According to data from NREL (the

National Renewable Energy Lab) many places in Alaska are comparable to locations in the lower 48 for annual solar energy. Alaskans have used solar DHW successfully for many years. Proper installation requires the use of an antifreeze solution to circulate in the solar collector loop, so that it is always protected from freezing. This is only a brief mention of solar DHW; for more information, get the Cooperative Extension's *A Solar Design Manual for Alaska*.

The other options have exclusively, except perhaps for wood, required an outlay of money for fuel. Solar hot water systems are more expensive to install than other options we've described, but their fuel is free. Thousands of gallons of equivalent diesel in the form of solar energy fall on the roof of the average Alaska residence every year in the form of sunlight. The proper installation could save thousands of dollars worth of fuel costs over its lifetime. The only drawback is that most of this solar energy comes in the summer, with very little sunlight arriving during the winter, and therefore DHW needs must be fulfilled by another source during the coldest three months of winter.

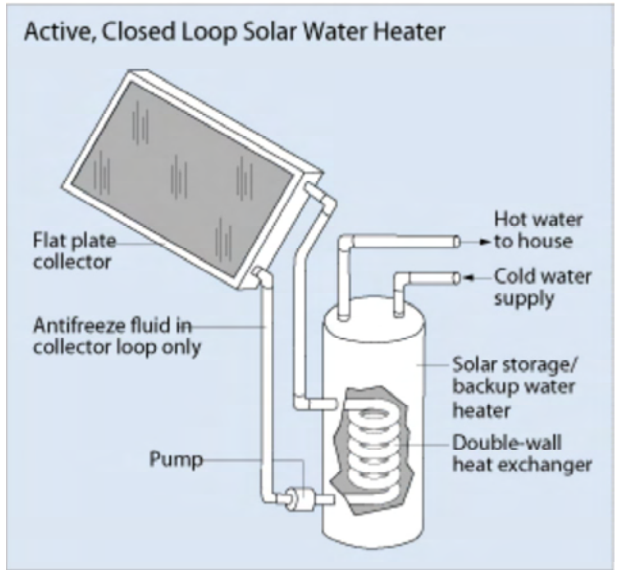


Figure H-8.

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[1]Rutkowski, Hank. Manual J: Residential Load Calculation. Air-Conditioning Contractors of America, 2001.

[2]Rutkowski, Hank. Residential Duct Systems, Manual D. Air-Conditioning Contractors of America, 1995.

[3]Lekov, Alex et. Al. "Residential Two-Stage Gas Furnaces-Do They Save Energy?" Lawrence Berkely Labs. 2006. Available online at http://www-library.lbl.gov/docs/LBNL/598/65/PDF/LBNL-59865.pdf.

BUILDING IN ALASKA

EEM-04953

YOUR OIL FURNACE:
Keep It Running Efficiently

by Richard Seifert
Extension Energy Specialist

In the past, the owner of an oil heating system had no direct way of monitoring the performance of the burner. Consequently, the owner didn't know when maintenance or a tune-up was required. A recent State report* recommends that oil heating systems be owner-monitored by purchasing a bi-metallic thermometer with a temperature range of 150°F - 750°F (see note). The thermometer is used to measure the temperature of the exhaust in the stack. Almost any change in the performance of a heating unit will result in a change in stack temperature. The efficiency decreases no matter if the stack temperature rises or falls from the tune-up value, although a higher temperature is much more common than a lower one.

A homeowner simply inserts a thermometer into the stack and checks the temperature at regular intervals. Checking every two months is recommended. A small hole is usually present in the stack of most burners which have been tuned, and is a handy place for inserting the thermometer. The hole is made by a furnace repair person during an initial burner tune-up to enable measurements to be taken and exhaust gas samples to be extracted.

Compare the measured stack temperature to the temperature of the stack recorded at the time of a tune-up. This enables the homeowner to see if the system's efficiency is dropping. A rule of thumb is that a change of 40°F represents a drop in efficiency of 1%. Using this information, the homeowner can decide when a burner needs to be tuned. Generally, a change of 80°F to 100°F from the last tune-up is an indication of need for another tune-up.

In the past, a record of the stack temperature was usually not given to the homeowner. This made it impossible to evaluate the rate of degradation of burner performance. The furnace maintenance

*This paper is based on research reported by the Alaska Department of Transportation and Public Facilities Research Section. The research was published in a report entitled *Furnace Efficiency Testing*, by Joe Durrenburger. 1983.

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and Rich Seifert's Homepage at: www.uaf.edu/ces/faculty/seifert

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person and the homeowner were left without any knowledge of past performance, and without evidence to help them decide whether or not a burner needed to be tuned.

Now, the Cooperative Extension Service has a sticker available (attached) that can be placed directly on your oil furnace as a permanent record of tune-up information. On the sticker, the furnace maintenance person should record the following:

— date of the tune-up
— stack temperature
— CO_2 number
— smoke number
— combustion efficiency
— nozzle size

This information should be a part of a normal tune-up. Recording the tune-up then becomes a reference and historical record of the burner's performance. Additional burner maintenance stickers can be obtained by calling the Cooperative Extension Service at 474-7201. Please ask for publication number EEM-04953A.

Below is a recording chart to help in keeping track of furnace stack temperature changes. Compare your measurements with the stack temperature entered on the sticker at the time of the most recent tune-up. When the change is more than 80°F, call for a tune-up.

Note. To make a temperature measurement, you will need a thermometer with a range of 150°F to 750°F. A bimetallic thermometer is constructed of two metals and is recommended for its durability. It typically costs $65 (2006/07 price). Presently the best supplier is Brooklyn Thermometer Company, Inc., 90 Verdi Street, Farmingdale, NY 11735, phone (800) 241-6316, fax (631) 694-6329. The 2006 thermometer catalog number is 5236. Call the company for the latest information.

Tune-up Stack Temp.	Date	Stack Temp.	Change	Date	Stack Temp.	Change

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BUILDING IN ALASKA

EEM-01152

Comparative Unit Fuel Costs for Equivalent Dollar Net Heat Output

Energy costs continue to rise. This has resulted in a need for comparing fuel costs between different sources such as natural gas, fuel oil, electricity, propane, and wood. The following table provides a method for comparing the unit fuel costs. Each fuel cost on the table is indexed to the cost of fuel oil per gallon. These are incrementally raised by one penny and all the other costs are compared to the cost of fuel oil, as a base of comparison.

The heating output for different heating source efficiencies are shown at the end of the table. The heating appliance efficiencies depend on many things, such as the method in which the fuel is burned, the air supply for combustion, the cleanliness of the combustion chamber, and how efficient the device is in using the fuel.

Over the past two decades, particularly fuel oil and propane heaters, as well as natural gas burners and boilers have all increased their efficiencies. These efficiencies have been adjusted upwards making fuel a little more productive than in the past, meaning you actually get more heat from the fuel with these newer, more efficient, heaters.

For this particular cost comparison (done in 2005) we use the following efficiencies of burning for various fuels. For fuel oil—we assume a minimum of 80% heating efficiency, which means you get 80% of the gross fuel content per gallon. For electricity—you are assumed to get 100% of everything that comes into your home, so even though it's not produced at a 100% efficiency from the coal, which is burned, you get 100% of what you pay for with electricity.

Natural gas— the heating plant efficiency is assumed to be at least 80%. You certainly can do better but we have assumed the minimum. For propane—we have kept it at 70%. It's hard to know how efficient propane fueled appliances are. For bituminous coal—we've also kept that at 55% since that is about the efficiency of a coal-fired hydronic boiler. And for soft wood—we've raised the efficiency slightly from 50 to 65% owing to the better efficiency of new fuel burning stoves. There are masonry stoves that can do better than the standard airtight stoves with regard to complete combustion of wood.

To use the table, simply start with the comparison you want to make for a fuel. Suppose you want to know how good a buy soft wood per cord is if you have to pay $110 per cord. To compete with wood at that price, fuel oil would have to cost $1.34 a gallon and propane would have to cost 78¢ a gallon. In 2005 both of these fuels are much more expensive than this. Fuel oil is about $1.85 a gallon and propane is about the same. So comparing those three fuels, soft wood is by far the least expensive per BTU heat output.

One of the cost comparisons you might want to make is how expensive does fuel oil have to be before it's equal to the cost of electricity for heat? Most of the electricity in Alaska costs between 9¢ and 11¢ per kwh. If electricity costs 11¢ a kwh, fuel oil would have to cost $3.56 a gallon to be equivalent. For comparison, natural gas would have to cost $25.80 per thousand cubic feet to compete with electricity at 11¢ a kwh. Those are just a few of the comparisons it's possible to make with a table like this.

The calculation formulas used to make this table are shown at the end of the table.

TABLE 1a
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

	COMPARATIVE UNIT FUEL COST (DOLLARS)					
Net Heat Production BTU/Dollar	**Fuel Oil Cost per Gallon**	**Electric Cost per KWH**	**Natural Gas Cost per CCF**	**Propane Cost per Gallon**	**Coal Cost per Ton**	**Soft Wood Cost per Cord**
48850	2.26	0.0699	$1.64	$1.32	$191.40	$186.29
48634	2.27	0.0702	$1.64	$1.32	$192.25	$187.11
48421	2.28	0.0705	$1.65	$1.33	$193.10	$187.93
48210	2.29	0.0708	$1.66	$1.33	$193.94	$188.76
48000	2.30	0.0711	$1.67	$1.34	$194.79	$189.58
47792	2.31	0.0714	$1.67	$1.34	$195.64	$190.41
47586	2.32	0.0717	$1.68	$1.35	$196.49	$191.23
47382	2.33	0.0720	$1.69	$1.36	$197.33	$192.06
47179	2.34	0.0723	$1.70	$1.36	$198.18	$192.88
46979	2.35	0.0726	$1.70	$1.37	$199.03	$193.70
46780	2.36	0.0730	$1.71	$1.37	$199.87	$194.53
46582	2.37	0.0733	$1.72	$1.38	$200.72	$195.35
46387	2.38	0.0736	$1.72	$1.39	$201.57	$196.18
46192	2.39	0.0739	$1.73	$1.39	$202.41	$197.00
46000	2.40	0.0742	$1.74	$1.40	$203.26	$197.83
45809	2.41	0.0745	$1.75	$1.40	$204.11	$198.65
45620	2.42	0.0748	$1.75	$1.41	$204.95	$199.47
45432	2.43	0.0751	$1.76	$1.41	$205.80	$200.30
45246	2.44	0.0754	$1.77	$1.42	$206.65	$201.12
45061	2.45	0.0757	$1.78	$1.43	$207.50	$201.95
44878	2.46	0.0761	$1.78	$1.43	$208.34	$202.77
44696	2.47	0.0764	$1.79	$1.44	$209.19	$203.60
44516	2.48	0.0767	$1.80	$1.44	$210.04	$204.42
44337	2.49	0.0770	$1.80	$1.45	$210.88	$205.24
44160	2.50	0.0773	$1.81	$1.46	$211.73	$206.07
43984	2.51	0.0776	$1.82	$1.46	$212.58	$206.89
43810	2.52	0.0779	$1.83	$1.47	$213.42	$207.72
43636	2.53	0.0782	$1.83	$1.47	$214.27	$208.54
43465	2.54	0.0785	$1.84	$1.48	$215.12	$209.37
43294	2.55	0.0788	$1.85	$1.48	$215.96	$210.19
43125	2.56	0.0791	$1.86	$1.49	$216.81	$211.01
42957	2.57	0.0795	$1.86	$1.50	$217.66	$211.84
42791	2.58	0.0798	$1.87	$1.50	$218.51	$212.66
42625	2.59	0.0801	$1.88	$1.51	$219.35	$213.49
42462	2.60	0.0804	$1.88	$1.51	$220.20	$214.31
42299	2.61	0.0807	$1.89	$1.52	$221.05	$215.14
42137	2.62	0.0810	$1.90	$1.53	$221.89	$215.96
41977	2.63	0.0813	$1.91	$1.53	$222.74	$216.78
41818	2.64	0.0816	$1.91	$1.54	$223.59	$217.61
41660	2.65	0.0819	$1.92	$1.54	$224.43	$218.43
41504	2.66	0.0822	$1.93	$1.55	$225.28	$219.26
41348	2.67	0.0825	$1.93	$1.55	$226.13	$220.08
41194	2.68	0.0829	$1.94	$1.56	$226.97	$220.91
41041	2.69	0.0832	$1.95	$1.57	$227.82	$221.73
40889	2.70	0.0835	$1.96	$1.57	$228.67	$222.55
40738	2.71	0.0838	$1.96	$1.58	$229.52	$223.38
40588	2.72	0.0841	$1.97	$1.58	$230.36	$224.20
40440	2.73	0.0844	$1.98	$1.59	$231.21	$225.03

TABLE 1b
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

	COMPARATIVE UNIT FUEL COST (DOLLARS)					
Net Heat Production BTU/Dollar	Fuel Oil Cost per Gallon	Electric Cost per KWH	Natural Gas Cost per CCF	Propane Cost per Gallon	Coal Cost per Ton	Soft Wood Cost per Cord
40292	2.74	0.0847	$1.99	$1.59	$232.06	$225.85
40145	2.75	0.0850	$1.99	$1.60	$232.90	$226.68
40000	2.76	0.0853	$2.00	$1.61	$233.75	$227.50
39856	2.77	0.0856	$2.01	$1.61	$234.60	$228.32
39712	2.78	0.0859	$2.01	$1.62	$235.44	$229.15
39570	2.79	0.0863	$2.02	$1.62	$236.29	$229.97
39429	2.80	0.0866	$2.03	$1.63	$237.14	$230.80
39288	2.81	0.0869	$2.04	$1.64	$237.98	$231.62
39149	2.82	0.0872	$2.04	$1.64	$238.83	$232.45
39011	2.83	0.0875	$2.05	$1.65	$239.68	$233.27
38873	2.84	0.0878	$2.06	$1.65	$240.53	$234.09
38737	2.85	0.0881	$2.07	$1.66	$241.37	$234.92
38601	2.86	0.0884	$2.07	$1.66	$242.22	$235.74
38467	2.87	0.0887	$2.08	$1.67	$243.07	$236.57
38333	2.88	0.0890	$2.09	$1.68	$243.91	$237.39
38201	2.89	0.0893	$2.09	$1.68	$244.76	$238.22
38069	2.90	0.0897	$2.10	$1.69	$245.61	$239.04
37938	2.91	0.0900	$2.11	$1.69	$246.45	$239.86
37808	2.92	0.0903	$2.12	$1.70	$247.30	$240.69
37679	2.93	0.0906	$2.12	$1.71	$248.15	$241.51
37551	2.94	0.0909	$2.13	$1.71	$248.99	$242.34
37424	2.95	0.0912	$2.14	$1.72	$249.84	$243.16
37297	2.96	0.0915	$2.14	$1.72	$250.69	$243.99
37172	2.97	0.0918	$2.15	$1.73	$251.54	$244.81
37047	2.98	0.0921	$2.16	$1.73	$252.38	$245.63
36923	2.99	0.0924	$2.17	$1.74	$253.23	$246.46
36800	3.00	0.0927	$2.17	$1.75	$254.08	$247.28
36678	3.01	0.0931	$2.18	$1.75	$254.92	$248.11
36556	3.02	0.0934	$2.19	$1.76	$255.77	$248.93
36436	3.03	0.0937	$2.20	$1.76	$256.62	$249.76
36316	3.04	0.0940	$2.20	$1.77	$257.46	$250.58
36197	3.05	0.0943	$2.21	$1.78	$258.31	$251.40
36078	3.06	0.0946	$2.22	$1.78	$259.16	$252.23
35961	3.07	0.0949	$2.22	$1.79	$260.00	$253.05
35844	3.08	0.0952	$2.23	$1.79	$260.85	$253.88
35728	3.09	0.0955	$2.24	$1.80	$261.70	$254.70
35613	3.10	0.0958	$2.25	$1.80	$262.55	$255.53
35498	3.11	0.0961	$2.25	$1.81	$263.39	$256.35
35385	3.12	0.0965	$2.26	$1.82	$264.24	$257.17
35272	3.13	0.0968	$2.27	$1.82	$265.09	$258.00
35159	3.14	0.0971	$2.28	$1.83	$265.93	$258.82
35048	3.15	0.0974	$2.28	$1.83	$266.78	$259.65
34937	3.16	0.0977	$2.29	$1.84	$267.63	$260.47
34826	3.17	0.0980	$2.30	$1.85	$268.47	$261.30
34717	3.18	0.0983	$2.30	$1.85	$269.32	$262.12
34608	3.19	0.0986	$2.31	$1.86	$270.17	$262.94
34500	3.20	0.0989	$2.32	$1.86	$271.01	$263.77
34393	3.21	0.0992	$2.33	$1.87	$271.86	$264.59

TABLE 1c
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

	COMPARATIVE UNIT FUEL COST (DOLLARS)					
Net Heat Production BTU/Dollar	Fuel Oil Cost per Gallon	Electric Cost per KWH	Natural Gas Cost per CCF	Propane Cost per Gallon	Coal Cost per Ton	Soft Wood Cost per Cord
34286	3.22	0.0995	$2.33	$1.87	$272.71	$265.42
34180	3.23	0.0999	$2.34	$1.88	$273.56	$266.24
34074	3.24	0.1002	$2.35	$1.89	$274.40	$267.07
33969	3.25	0.1005	$2.36	$1.89	$275.25	$267.89
33865	3.26	0.1008	$2.36	$1.90	$276.10	$268.71
33761	3.27	0.1011	$2.37	$1.90	$276.94	$269.54
33659	3.28	0.1014	$2.38	$1.91	$277.79	$270.36
33556	3.29	0.1017	$2.38	$1.91	$278.64	$271.19
33455	3.30	0.1020	$2.39	$1.92	$279.48	$272.01
33353	3.31	0.1023	$2.40	$1.93	$280.33	$272.84
33253	3.32	0.1026	$2.41	$1.93	$281.18	$273.66
33153	3.33	0.1029	$2.41	$1.94	$282.02	$274.48
33054	3.34	0.1033	$2.42	$1.94	$282.87	$275.31
32955	3.35	0.1036	$2.43	$1.95	$283.72	$276.13
32857	3.36	0.1039	$2.43	$1.96	$284.57	$276.96
32760	3.37	0.1042	$2.44	$1.96	$285.41	$277.78
32663	3.38	0.1045	$2.45	$1.97	$286.26	$278.61
32566	3.39	0.1048	$2.46	$1.97	$287.11	$279.43
32471	3.40	0.1051	$2.46	$1.98	$287.95	$280.25
32375	3.41	0.1054	$2.47	$1.98	$288.80	$281.08
32281	3.42	0.1057	$2.48	$1.99	$289.65	$281.90
32187	3.43	0.1060	$2.49	$2.00	$290.49	$282.73
32093	3.44	0.1063	$2.49	$2.00	$291.34	$283.55
32000	3.45	0.1067	$2.50	$2.01	$292.19	$284.37
31908	3.46	0.1070	$2.51	$2.01	$293.03	$285.20
31816	3.47	0.1073	$2.51	$2.02	$293.88	$286.02
31724	3.48	0.1076	$2.52	$2.03	$294.73	$286.85
31633	3.49	0.1079	$2.53	$2.03	$295.58	$287.67
31543	3.50	0.1082	$2.54	$2.04	$296.42	$288.50
31453	3.51	0.1085	$2.54	$2.04	$297.27	$289.32
31364	3.52	0.1088	$2.55	$2.05	$298.12	$290.14
31275	3.53	0.1091	$2.56	$2.05	$298.96	$290.97
31186	3.54	0.1094	$2.57	$2.06	$299.81	$291.79
31099	3.55	0.1097	$2.57	$2.07	$300.66	$292.62
31011	3.56	0.1101	$2.58	$2.07	$301.50	$293.44
30924	3.57	0.1104	$2.59	$2.08	$302.35	$294.27
30838	3.58	0.1107	$2.59	$2.08	$303.20	$295.09
30752	3.59	0.1110	$2.60	$2.09	$304.04	$295.91
30667	3.60	0.1113	$2.61	$2.10	$304.89	$296.74
30582	3.61	0.1116	$2.62	$2.10	$305.74	$297.56
30497	3.62	0.1119	$2.62	$2.11	$306.59	$298.39
30413	3.63	0.1122	$2.63	$2.11	$307.43	$299.21
30330	3.64	0.1125	$2.64	$2.12	$308.28	$300.04
30247	3.65	0.1128	$2.64	$2.12	$309.13	$300.86
30164	3.66	0.1131	$2.65	$2.13	$309.97	$301.68
30082	3.67	0.1135	$2.66	$2.14	$310.82	$302.51
30000	3.68	0.1138	$2.67	$2.14	$311.67	$303.33
29919	3.69	0.1141	$2.67	$2.15	$312.51	$304.16

TABLE 1d
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

	COMPARATIVE UNIT FUEL COST (DOLLARS)					
Net Heat Production BTU/Dollar	Fuel Oil Cost per Gallon	Electric Cost per KWH	Natural Gas Cost per CCF	Propane Cost per Gallon	Coal Cost per Ton	Soft Wood Cost per Cord
29838	3.70	0.1144	$2.68	$2.15	$313.36	$304.98
29757	3.71	0.1147	$2.69	$2.16	$314.21	$305.81
29677	3.72	0.1150	$2.70	$2.17	$315.05	$306.63
29598	3.73	0.1153	$2.70	$2.17	$315.90	$307.45
29519	3.74	0.1156	$2.71	$2.18	$316.75	$308.28
29440	3.75	0.1159	$2.72	$2.18	$317.60	$309.10
29362	3.76	0.1162	$2.72	$2.19	$318.44	$309.93
29284	3.77	0.1165	$2.73	$2.19	$319.29	$310.75
29206	3.78	0.1169	$2.74	$2.20	$320.14	$311.58
29129	3.79	0.1172	$2.75	$2.21	$320.98	$312.40
29053	3.80	0.1175	$2.75	$2.21	$321.83	$313.22
28976	3.81	0.1178	$2.76	$2.22	$322.68	$314.05
28901	3.82	0.1181	$2.77	$2.22	$323.52	$314.87
28825	3.83	0.1184	$2.78	$2.23	$324.37	$315.70
28750	3.84	0.1187	$2.78	$2.24	$325.22	$316.52
28675	3.85	0.1190	$2.79	$2.24	$326.06	$317.35
28601	3.86	0.1193	$2.80	$2.25	$326.91	$318.17
28527	3.87	0.1196	$2.80	$2.25	$327.76	$318.99
28454	3.88	0.1199	$2.81	$2.26	$328.61	$319.82
28380	3.89	0.1203	$2.82	$2.26	$329.45	$320.64
28308	3.90	0.1206	$2.83	$2.27	$330.30	$321.47
28235	3.91	0.1209	$2.83	$2.28	$331.15	$322.29
28163	3.92	0.1212	$2.84	$2.28	$331.99	$323.12
28092	3.93	0.1215	$2.85	$2.29	$332.84	$323.94
28020	3.94	0.1218	$2.86	$2.29	$333.69	$324.76
27949	3.95	0.1221	$2.86	$2.30	$334.53	$325.59
27879	3.96	0.1224	$2.87	$2.30	$335.38	$326.41
27809	3.97	0.1227	$2.88	$2.31	$336.23	$327.24
27739	3.98	0.1230	$2.88	$2.32	$337.07	$328.06
27669	3.99	0.1234	$2.89	$2.32	$337.92	$328.89
27600	4.00	0.1237	$2.90	$2.33	$338.77	$329.71
27531	4.01	0.1240	$2.91	$2.33	$339.62	$330.53
27463	4.02	0.1243	$2.91	$2.34	$340.46	$331.36
27395	4.03	0.1246	$2.92	$2.35	$341.31	$332.18
27327	4.04	0.1249	$2.93	$2.35	$342.16	$333.01
27259	4.05	0.1252	$2.93	$2.36	$343.00	$333.83
27192	4.06	0.1255	$2.94	$2.36	$343.85	$334.66
27125	4.07	0.1258	$2.95	$2.37	$344.70	$335.48
27059	4.08	0.1261	$2.96	$2.37	$345.54	$336.30
26993	4.09	0.1264	$2.96	$2.38	$346.39	$337.13
26927	4.10	0.1268	$2.97	$2.39	$347.24	$337.95
26861	4.11	0.1271	$2.98	$2.39	$348.08	$338.78
26796	4.12	0.1274	$2.99	$2.40	$348.93	$339.60
26731	4.13	0.1277	$2.99	$2.40	$349.78	$340.43
26667	4.14	0.1280	$3.00	$2.41	$350.62	$341.25
26602	4.15	0.1283	$3.01	$2.42	$351.47	$342.07
26538	4.16	0.1286	$3.01	$2.42	$352.32	$342.90
26475	4.17	0.1289	$3.02	$2.43	$353.17	$343.72

TABLE 1e
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

	COMPARATIVE UNIT FUEL COST (DOLLARS)					
Net Heat Production BTU/Dollar	Fuel Oil Cost per Gallon	Electric Cost per KWH	Natural Gas Cost per CCF	Propane Cost per Gallon	Coal Cost per Ton	Soft Wood Cost per Cord
26411	4.18	0.1292	$3.03	$2.43	$354.01	$344.55
26348	4.19	0.1295	$3.04	$2.44	$354.86	$345.37
26286	4.20	0.1298	$3.04	$2.44	$355.71	$346.20
26223	4.21	0.1302	$3.05	$2.45	$356.55	$347.02
26161	4.22	0.1305	$3.06	$2.46	$357.40	$347.84
26099	4.23	0.1308	$3.07	$2.46	$358.25	$348.67
26038	4.24	0.1311	$3.07	$2.47	$359.09	$349.49
25976	4.25	0.1314	$3.08	$2.47	$359.94	$350.32
25915	4.26	0.1317	$3.09	$2.48	$360.79	$351.14
25855	4.27	0.1320	$3.09	$2.49	$361.63	$351.97
25794	4.28	0.1323	$3.10	$2.49	$362.48	$352.79
25734	4.29	0.1326	$3.11	$2.50	$363.33	$353.61
25674	4.30	0.1329	$3.12	$2.50	$364.18	$354.44
25615	4.31	0.1332	$3.12	$2.51	$365.02	$355.26
25556	4.32	0.1336	$3.13	$2.51	$365.87	$356.09
25497	4.33	0.1339	$3.14	$2.52	$366.72	$356.91
25438	4.34	0.1342	$3.14	$2.53	$367.56	$357.74
25379	4.35	0.1345	$3.15	$2.53	$368.41	$358.56
25321	4.36	0.1348	$3.16	$2.54	$369.26	$359.38
25263	4.37	0.1351	$3.17	$2.54	$370.10	$360.21
25205	4.38	0.1354	$3.17	$2.55	$370.95	$361.03
25148	4.39	0.1357	$3.18	$2.56	$371.80	$361.86
25091	4.40	0.1360	$3.19	$2.56	$372.64	$362.68
25034	4.41	0.1363	$3.20	$2.57	$373.49	$363.51
24977	4.42	0.1366	$3.20	$2.57	$374.34	$364.33
24921	4.43	0.1370	$3.21	$2.58	$375.19	$365.15
24865	4.44	0.1373	$3.22	$2.58	$376.03	$365.98
24809	4.45	0.1376	$3.22	$2.59	$376.88	$366.80
24753	4.46	0.1379	$3.23	$2.60	$377.73	$367.63
24698	4.47	0.1382	$3.24	$2.60	$378.57	$368.45
24643	4.48	0.1385	$3.25	$2.61	$379.42	$369.28
24588	4.49	0.1388	$3.25	$2.61	$380.27	$370.10
24533	4.50	0.1391	$3.26	$2.62	$381.11	$370.92
24479	4.51	0.1394	$3.27	$2.63	$381.96	$371.75
24425	4.52	0.1397	$3.28	$2.63	$382.81	$372.57
24371	4.53	0.1400	$3.28	$2.64	$383.65	$373.40
24317	4.54	0.1404	$3.29	$2.64	$384.50	$374.22
24264	4.55	0.1407	$3.30	$2.65	$385.35	$375.05
24211	4.56	0.1410	$3.30	$2.65	$386.20	$375.87
24158	4.57	0.1413	$3.31	$2.66	$387.04	$376.69
24105	4.58	0.1416	$3.32	$2.67	$387.89	$377.52
24052	4.59	0.1419	$3.33	$2.67	$388.74	$378.34
24052	4.59	0.1419	$3.33	$2.67	$388.74	$378.34
24000	4.60	0.1422	$3.33	$2.68	$389.58	$379.17
23948	4.61	0.1425	$3.34	$2.68	$390.43	$379.99
23896	4.62	0.1428	$3.35	$2.69	$391.28	$380.82
23844	4.63	0.1431	$3.36	$2.69	$392.12	$381.64
23793	4.64	0.1434	$3.36	$2.70	$392.97	$382.46

TABLE 1f
COMPARATIVE UNIT FUEL COSTS FOR EQUIVALENT DOLLAR NET HEAT OUTPUT

COMPARATIVE UNIT FUEL COST (DOLLARS)

Net Heat Production BTU/Dollar	Fuel Oil Cost per Gallon	Electric Cost per KWH	Natural Gas Cost per CCF	Propane Cost per Gallon	Coal Cost per Ton	Soft Wood Cost per Cord
23742	4.65	0.1438	$3.37	$2.71	$393.82	$383.29
23691	4.66	0.1441	$3.38	$2.71	$394.66	$384.11
23640	4.67	0.1444	$3.38	$2.72	$395.51	$384.94
23590	4.68	0.1447	$3.39	$2.72	$396.36	$385.76
23539	4.69	0.1450	$3.40	$2.73	$397.21	$386.59
23489	4.70	0.1453	$3.41	$2.74	$398.05	$387.41
23439	4.71	0.1456	$3.41	$2.74	$398.90	$388.23
23390	4.72	0.1459	$3.42	$2.75	$399.75	$389.06
23340	4.73	0.1462	$3.43	$2.75	$400.59	$389.88
23291	4.74	0.1465	$3.43	$2.76	$401.44	$390.71
23242	4.75	0.1468	$3.44	$2.76	$402.29	$391.53
23193	4.76	0.1472	$3.45	$2.77	$403.13	$392.36
23145	4.77	0.1475	$3.46	$2.78	$403.98	$393.18
23096	4.78	0.1478	$3.46	$2.78	$404.83	$394.00
23048	4.79	0.1481	$3.47	$2.79	$405.67	$394.83
23000	4.80	0.1484	$3.48	$2.79	$406.52	$395.65
22952	4.81	0.1487	$3.49	$2.80	$407.37	$396.48
22905	4.82	0.1490	$3.49	$2.81	$408.22	$397.30
22857	4.83	0.1493	$3.50	$2.81	$409.06	$398.12
22810	4.84	0.1496	$3.51	$2.82	$409.91	$398.95
22763	4.85	0.1499	$3.51	$2.82	$410.76	$399.77
22716	4.86	0.1502	$3.52	$2.83	$411.60	$400.60
22669	4.87	0.1506	$3.53	$2.83	$412.45	$401.42
22623	4.88	0.1509	$3.54	$2.84	$413.30	$402.25
22577	4.89	0.1512	$3.54	$2.85	$414.14	$403.07
22531	4.90	0.1515	$3.55	$2.85	$414.99	$403.89
22485	4.91	0.1518	$3.56	$2.86	$415.84	$404.72
22439	4.92	0.1521	$3.57	$2.86	$416.68	$405.54
22394	4.93	0.1524	$3.57	$2.87	$417.53	$406.37
22348	4.94	0.1527	$3.58	$2.88	$418.38	$407.19
22303	4.95	0.1530	$3.59	$2.88	$419.23	$408.02
22258	4.96	0.1533	$3.59	$2.89	$420.07	$408.84
22213	4.97	0.1536	$3.60	$2.89	$420.92	$409.66
22169	4.98	0.1540	$3.61	$2.90	$421.77	$410.49
22124	4.99	0.1543	$3.62	$2.90	$422.61	$411.31
22080	5.00	0.1546	$3.62	$2.91	$423.46	$412.14
22036	5.01	0.1549	$3.63	$2.92	$424.31	$412.96
21992	5.02	0.1552	$3.64	$2.92	$425.15	$413.79

FOOT NOTES:

01. Fuel Oil	Gal	138000.	BTU at Heating Plant efficiency of 0.80.
02. Electric	KWH	3413.	BTU at Heating Plant effciency of 1.00
03. Natural Gas	CCF	100000.	BTU at Heating Plant efficiency of 0.80.
04. Propane	GAL	91800.	BTU at Heating Plant effciency of 0.70.
05. Bit Coal	TON	17000000.	BTU at Heating Plant Effciency of 0.55.
06. Soft Wood	CRD	14000000.	BTU at Heating Plant Efficiency of 0.65.

THESE COSTS ARE STRICTLY FUEL COSTS AND DO NOT INCLUDE EQUIPMENT AND OPERATING COSTS.

Formula: THERM = Fuel BTUs *efficiency/fuel cost

Fuel Cost = Fuel BTUs *efficiency/THERM

Chapter 9
Ventilation

Key Points to Learn

- Every Alaska home should be built tight and have proper controlled ventilation.
- Ventilation is important to control both moisture and indoor pollutants.
- Good installation practices
- Commissioning (making sure it works)
- Operation and maintenance

Principles of Good Ventilation

The two main reasons to ventilate are to control moisture and to dilute pollutants. Good ventilation makes a home healthier and more comfortable, while poor ventilation can cause serious health risks to the occupants and structural damage to the house. Current research in Alaska homes reinforces the need for appropriate ventilation to reduce exposure to such harmful pollutants as carbon monoxide, benzene, and radon.

In the past, buildings were ventilated by the wind and other uncontrolled forms of air leakage. However, leaky buildings do not guarantee good indoor air quality. Particularly in a cold climate, comfort and health problems may result if the building is too leaky. A building leaking air during the coldest part of the winter will cause continuous drying of the indoor air and can lead to increased upper respiratory disease and discomfort. Leaky buildings enhance the transport of outdoor pollutants into the building through garages and damp crawlspaces. And as we learned in earlier chapters, leaking air carries moisture into the walls and attic of a house, leading to mold and rot.

Build It Tight

Most people no longer accept the cold, drafty houses of the past. Now, houses are expected to be cozy, draft free, and energy efficient. Even when builders don't intend to build a tight house, modern building materials tend to make newly constructed homes much tighter than old ones. Plywood, housewrap, better windows, caulk, and expanding foam are a few examples of common products that tighten a house.

In other chapters we discuss the many reasons to control the air flow in a home:

- comfort
- drafts
- health
- odors, particles, gases
- energy savings
- moisture control
- sound control
- required by codes

We also discuss many air-sealing techniques and systems. Every Alaska home should begin with a well–sealed and insulated envelope.

Ventilate It Right

Next, every Alaska home requires proper, controlled ventilation. When we control the amount and location of air moving into and out of the house, that air can then be:

- heated
- cooled
- humidified
- dehumidified
- cleaned, filtered
- distributed, mixed

As always when bringing in fresh air, energy is spent in the process, but it is under our control!

The Alaska Building Energy Efficiency Standard (BEES) requires all homes built to the BEES must comply with the ventilation requirements of ASHRAE 62.2-2004 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, and the Alaska –Specific Amendments. Refer to the ASHRAE 62.2 Standards and the AHFC amendments for detailed information. See standards on the next page.

ASHRAE 62.2-2004 including AHFC amendments

- Whole Building Ventilation rate is 10 cfm per person plus 1 cfm for every 100 sqft of floor area. Or see Table 9.1.
- Bathroom Exhaust Fan—50 cfm intermittent or 20 cfm continuous.
- Kitchen range hood—100 cfm intermittent required if continuous kitchen exhaust is less than 5 air changes per hour.
- Measures must be taken to assure ventilation air comes directly from outdoors and not from adjacent dwelling units, garages, and unconditioned crawlspaces.
- Quiet exhaust and whole house fans, including range hoods:
  Intermittent exhaust fans must have a maximum sound rating of 3 sones. (Exception for large range hoods which exceed 400 cfm.)
  Continuous ventilation fans must be rated at a maximum of 1 sone
- Clothes dryers shall be exhausted directly to the outdoors
- Maximum exhaust capacity where atmospherically vented combustion appliances or wood stoves is limited to 15 cfm/100ft^2 for the two largest exhaust fans. (Typically range hood and clothes dryer)
- Garages—must prevent migration of contaminants to adjoining occupiable spaces. A duct leakage test must be performed if a furnace or ductwork is located in the garage.
- Supply-only systems not allowed during the heating season. Balanced, heat recovery systems are strongly recommended.

Other Concerns

Recent research on indoor air quality in Alaska homes provides some sobering statistics.

Attached Garages

Most garages in Alaska are attached or "tuck-under." Many garages are heated and house the home's heating system as well. Recent research data suggests:

- Attached garages provide about 30% of the natural ventilation for homes.
- Attached garages significantly increase in-home exposure to benzene and carbon monoxide from in-garage car starts.
- Pollutant transfer is particularly high with furnaces in the garage. It is difficult to adequately seal duct and furnace leaks.
- Garages are the most common source for indoor carbon monoxide, which disperses rapidly once inside the home.
- Exhaust-only house ventilation appears to increase the flow of garage pollutants to the house, but it likely provides some reduction in total exposure.
- In tight garages, it might be necessary to provide garage exhaust ventilation to remove pollutants and prevent them from entering the house.

Crawlspaces

- Crawlspaces provide about 30% of natural ventilation air for homes.
- Increased testing indicates that radon may be more of a concern in Alaska than previously believed. Radon that enters crawlspaces can easily become part of the house air. Exhaust-only ventilation systems, because they depressurize the house, may increase the amount of radon that enters the living space.

Ventilation Codes

Most building ventilation codes are based on ASHRAE Standard 62. ANSI/ ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. It is the only nationally recognized indoor air quality standard developed solely for residential buildings. It requires mechanical spot ventilation for specific sources of indoor pollutants. It also requires general ventilation that operates whenever the house is occupied to maintain indoor air quality. The number of occupants determines the amount of general ventilation required. Even this standard acknowledges how difficult it may be to provide acceptable indoor air:

> While acceptable indoor air quality is the goal of this standard, it will not necessarily be achieved even if all requirements are met: (a) because of the diversity of sources and contaminants in indoor air and the range of susceptibility in the population; (b) because of the many other factors that may affect occupant perception and acceptance of indoor air quality, such as air temperature, humidity, noise, lighting, and psychological stress; (c) if the ambient air is unacceptable and this air is brought into the building without first being cleaned (cleaning of ambient outdoor air is not required by this standard); (d) if the system(s) are not operated and maintained as designed; or (e) when high-polluting events occur.

Sizing Your System: How Much Ventilation Air Do You Need?

It costs money to bring cold outdoor air into a home and then heat and distribute it, so we don't want to bring in any more than is needed to get the job done.

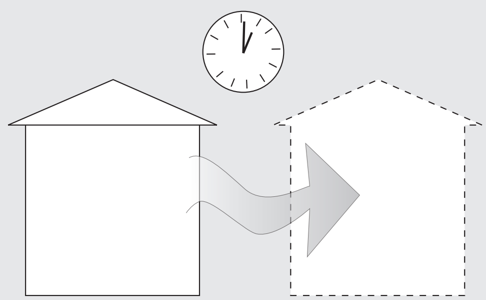
According to ASHRAE Standard 62.2-2004, single, detached residential buildings are required to meet a whole house ventilation rate based on the number of bedrooms in the house, or the number of occupants, plus an infiltration credit (1 CFM per 100 sq. ft plus 7.5 CFM per additional occupant, which includes a 2 CFM per 100 sq. ft. allowance for infiltration). There are a variety of ways to meet this standard.

Table 9.1: ASHRAE 62.2-2004 Ventilation Air Requirements, CFM

Local codes may require different continuous ventilation rates: always check with your building officials to determine your specific requirements.

Floor Area (ft^2)	Bedrooms				
	0–1	2–3	4–5	6–7	>7
<1500	35	55	75	95	115
1501–3000	50	70	90	110	125
3001–4500	65	85	105	125	145
4501–6000	80	100	120	140	160
6001–7500	95	115	135	155	175
>7500	110	130	150	170	190

Air changes per hour is how many times all the air in a given volume of space (a house) is completely replaced in one hour's time.



Ventilation System Design Elements

A ventilation system that will be effective at maintaining reasonable indoor air quality and building durability must be designed that way. There is no "right" ventilation system that is appropriate for all homes. There are many factors that will influence particular design decisions. These may include:

- Code requirements
- Size and type of building
- Combustion appliance type
- Availability of equipment, parts, and service
- Knowledge and skill of the provider
- Owner and builder preferences
- Budget

At the same time, there are some qualities that should be part of any ventilation design:

- Effective indoor air quality control
  - Removes contaminants
  - Adequate air distribution to all rooms, especially bedrooms
- Comfort
  - Quiet
  - Tempered supply air
- Simplicity of operation
- Affordability
  - Energy efficient
  - Low maintenance
  - Equipment properly sized and installed
- Safety and durability
  - Balanced flows
  - System controls
  - No backdrafting concerns

Spending a little extra time on the ventilation system when designing a home can make installation easier and more affordable. It can also make operation more successful and more affordable.

Basic Decisions

- How will the house air pressures be controlled?
  - This is most often based on the type of combustion appliances: spillage susceptible or not?
  - If make-up air is required, how is it provided?
  - If make-up tempering is required, how is it provided?
- How will ventilation be distributed? This is often decided based on the type of heating system: forced air or not?
- How will comfort be maintained?
- How are contaminants removed?
- Will the outdoor air be acceptable year-round?

Effective Ventilation Systems

The best way to control indoor air quality is to keep pollutants from entering the house in the first place. However, not all indoor pollutants can be eliminated. Moisture and odors and other chemical pollutants are produced by many different activities, so ventilation is important.

There are two components of an effective mechanical ventilation system: local exhaust ventilation and central or whole-house ventilation for general indoor air quality.

Local Exhaust Ventilation

Local or spot ventilation captures pollutants at their source and exhausts them to the outside. This is not continuous ventilation, but is used on an as needed basis.

Kitchen Range Hoods

Cooking in the kitchen generates a lot of moisture and odors. While there are various ventilation strategies for a kitchen, the range hood is by far the most common.

Kitchen range hoods installed directly over the range capture heated air, moisture, smoke, and odors, while the fan exhausts them to the outside through ductwork. A filter trap makes it easy to remove and clean grease.

A kitchen range hood should be at least the same width as the cooking surface and mounted directly over it, 18 to 30 inches above the cooking surface. For normal cooking conditions, two-speed or variable speed controls provide a choice of a lower speed and quieter operation. Sone ratings vary. Choose a quiet or remote mounted fan so noise doesn't keep occupants from using the range hood when they cook.

Range hoods should be sized correctly. For a typical range, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the Home Ventilation Institute (HVI) recommend 100 cubic feet per minute (CFM). Larger fans may need to have make-up air provided, to prevent excessively depressurizing the home and potentially causing combustion equipment to backdraft.

Downdraft kitchen exhausters require a higher volume and velocity of air to capture contaminants. They are an alternative when canopy-style hoods are not desired due to location of the cooking surface and kitchen esthetics; however, their performance cannot equal that of hoods that capture the rising column of air above the cooking surface.

Nonducted, recirculating kitchen range hoods do not provide ventilation. For optimum kitchen air quality, always vent kitchen range hoods, kitchen fans, or downdraft kitchen exhausters directly outside the home.

Bathroom Fans: Moisture Control Where It is Needed Most

During a bath or shower, the humidity level in a bathroom provides a perfect breeding ground for mold, mildew, and microorganisms that can impact health and building durability. Exhaust fans ducted to the outside remove moisture and prevent these types of problems.

- For most effective bathroom ventilation, ASHRAE recommends 50 CFM of intermittent or 20 CFM of continuous ventilation.
- Fans should be installed as near to the shower as possible and, if marked as suitable for this location, directly over it to capture the moisture as directly as possible.

- Fans should have a control that will allow them to run at least 20 to 30 minutes after each shower. This could be a timer or dehumidistat controller.

Other Areas For Spot Ventilation

Many other rooms in the house can benefit from spot ventilation. Examples might include laundry and utility rooms; workshops and hobby areas; family rooms; and recreation rooms. Ventilation units for use in these areas are similar to those used for baths and kitchens.

Outdoor Vents for Clothes Dryers

You must vent dryers directly to the outside of the house. In many newer homes the laundry room is located away from the exterior walls, resulting in long ducts, which can restrict airflow. In these cases booster fans can be used to ensure proper airflow.

Local Exhaust Ventilation Considerations

- **Exhaust air close to the source.**
- **Provide quiet fans.** Noisy fans won't get used. Fan noise is measured in sones. The higher the sone level, the noisier the fan. Spot fans are typically rated at 3 to 4 sones, though some can be quite a bit louder. Fans rated at 1.5 sones are very quiet, and low-capacity fans rated as low as 0.5 to 1 sones are nearly inaudible.
- **Provide short, direct duct runs.** A low-sone fan attached to a duct that twists and turns, or is kinked or too small, will be just as noisy as the noisiest model. It will not provide as much ventilation as a short-ducted fan either.
- **Make sure fans provide the desired ventilation flow.** Measure fan flow after installation to verify that the system is operating properly.

Continuous, Whole-House Ventilation Strategies

While spot ventilation will certainly help control moisture problems, it may not provide adequate ventilation for the entire home. A whole house ventilation system is designed to operate continuously to provide fresh air whenever the occupants are home. One or more fans can be combined to supply fresh air and exhaust stale air to provide continuous general ventilation throughout the home. These units typically have two-speed motors. The low speed setting gives continuous ventilation, usually 10 CFM per person or 0.35 ACH. The high speed setting can quickly vent moisture or odors. Ductwork extends to rooms requiring ventilation.

It is important to choose a climate-appropriate system. Supply-only systems are best suited to hot and humid climates. In the heating season in cold climates, continuously operating supply ventilation may pressurize the home, driving warm humid indoor air into the wall cavities and attics, where condensation may occur.

Exhaust-Only Systems

A continuous whole-house exhaust system provides ventilation by using a single-point or multipoint central fan to remove air from the building. This system places the building under a slight negative pressure, drawing supply air into the building envelope through gaps or provided vents.

Unfortunately, fireplaces, wood stoves and gas-burning appliances were not designed to operate in a negative pressure environment. Under some conditions, even a slight negative pressure could cause flue gases, including carbon monoxide, to spill into the living space. **Exhaust-only ventilation systems should only be used in conjunction**

with sealed combustion appliances that draw air from outside, or when combustion appliances are located in a sealed room.

Exhaust-Only Ventilation Concerns

- If the building envelope is tight, negative pressure inside the building may lead to backdrafts from combustion appliances. Often these systems incorporate a pressure relief damper to alleviate pressure imbalances.
- Supply air enters the building in an uncontrolled manner and may be pulled in from undesirable areas such as garages, musty basements or crawlspaces, or dusty attics.
- Whole-house exhaust systems may not be appropriate in areas where levels of outside environmental contaminants are high. For example, researchers have found that exhaust systems may actually increase the indoor levels of radon.
- In severe climates, very cold supply air may create drafts. The largest cost of operating this system is for heating supply air rather than from operating the fan.
- Filtration cannot be added to an exhaust-only ventilation system.

Balanced Ventilation Systems

A balanced ventilation system uses two fans with separate ducting systems, one to supply fresh air and one to remove stale air from the building (Figure 9.4). The system should not affect the pressure balance of the interior space unless the return path between the supply and exhaust is blocked.

This ventilation strategy can be used effectively in any climate. It is possible to include a heat exchanger to recover heat from the exhaust air and use it to precondition the supply air. Extensive ducting is used to supply fresh air to living and sleeping rooms, while a separate exhaust system removes stale, often moist air from the kitchen and bathrooms.

Advantages include prefiltration of the supply air and energy savings from the heat recovery of the exhaust air.

Figure 9.1: Surface-mounted exhaust fan. The simplest controlled ventilation system uses a quiet, high-quality surface-mounted fan. Fresh air enters through passive vents located in window sashes or outside walls. Surface-mounted fans provide good ventilation for smaller areas. Large houses may need more than one.

- Noise Rating: 2.0 sones or less
- Locations: central bathroom
- Air Flow Capacity: 50–400 CFM
- Heat Recovery: none
- House Pressure: negative
- Makeup Air: passive inlets
- Multispeed Operation: no

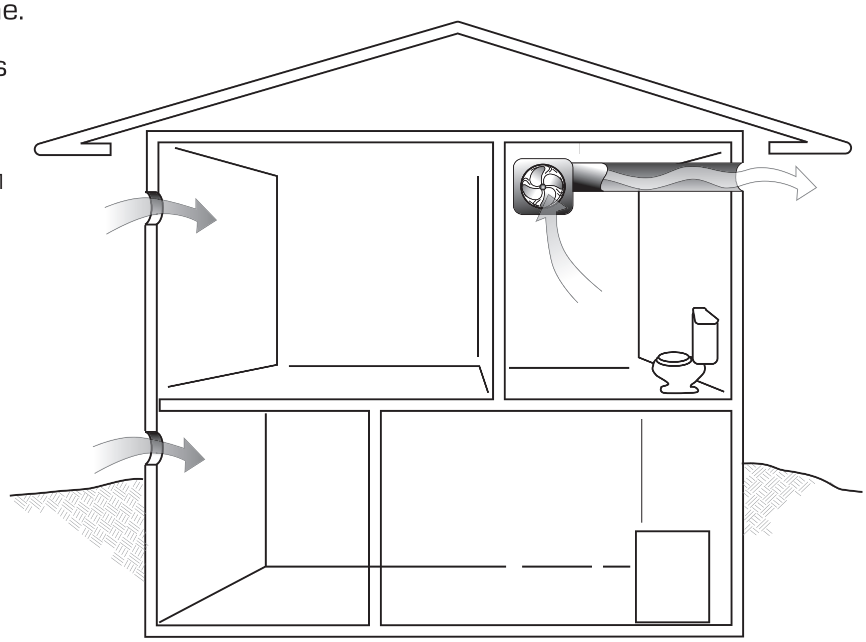


Figure 9.2: Remote-mounted in-line fans can pick up stale air from a single point or they can be attached to a branched duct system with pickups in two or three locations. This makes them a good choice for large houses. If properly rated, the fan could be attached to a range hood.

- Noise Rating: not applicable
- Locations: basement, attic, or crawlspace
- Air Flow Capacity: 80–400 CFM
- Heat Recovery: none
- House Pressure: negative
- Makeup Air: passive inlets
- Multispeed Operation: optional
- Equipment Cost: $150 to 250

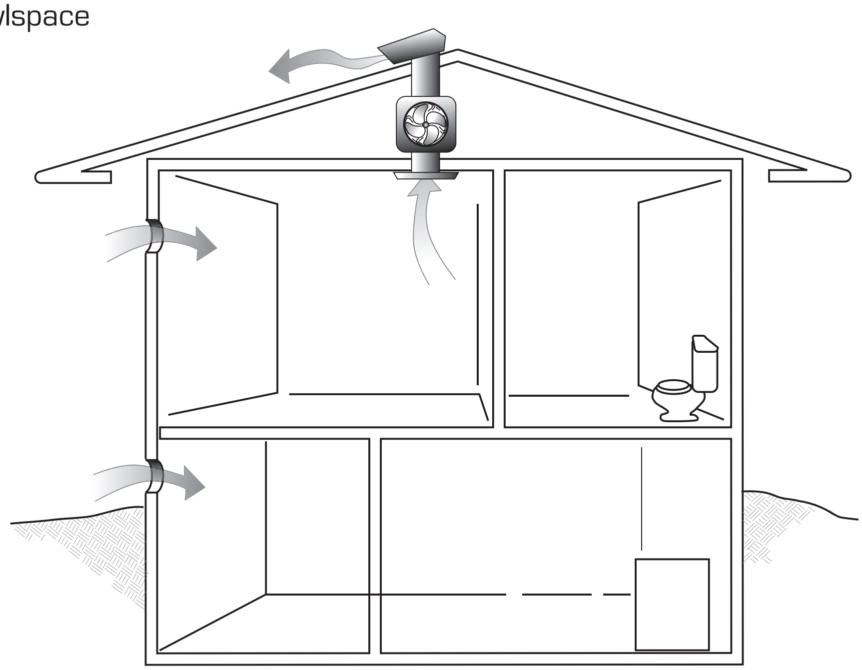
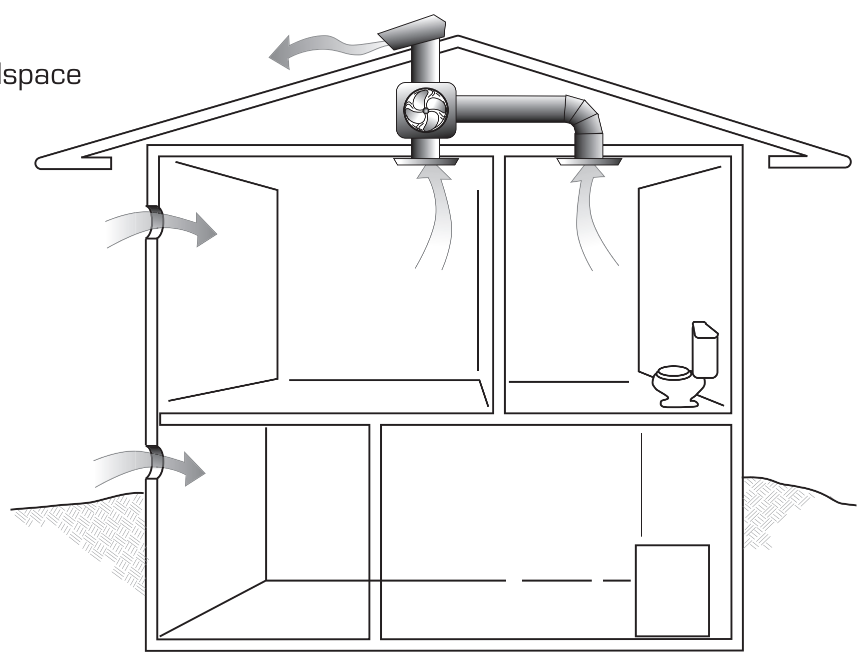


Figure 9.3: Remote-mounted multiport. Large houses and several multifamily units can be ventilated by a single multiport fan. Some units can accept a duct from the range hood. Most operate at two or more speeds. Several manufacturers sell complete kits with all the ducts and accessories. These may cost a bit more, but the kits simplify installation.

- Noise Rating: not as important
- Locations: basement, attic or crawlspace
- Air Flow Capacity: 100–400 CFM
- Heat Recovery: none
- House Pressure: negative
- Makeup Air: passive inlets
- Multispeed Operation: optional
- Equipment Cost: $200 to 700



Some disadvantages include installation costs, maintenance costs (because there are multiple fans), and fan noise when systems are not installed properly. Various strategies for soundproofing include insulating ducts and preventing fan vibrations. Reducing noise from ventilation systems has a positive impact on indoor air quality by reducing the likelihood that occupants will block vents or turn off the system.

Experience has also shown that balanced air flow can be difficult to achieve in a home with a balanced ventilation system connected to a forced-air heating system. Detailed duct design and careful installation and flow-balancing techniques are needed. Even then, air flow can be thrown off by someone closing a door between a supply and a pickup.

Heat and Energy Recovery Ventilation

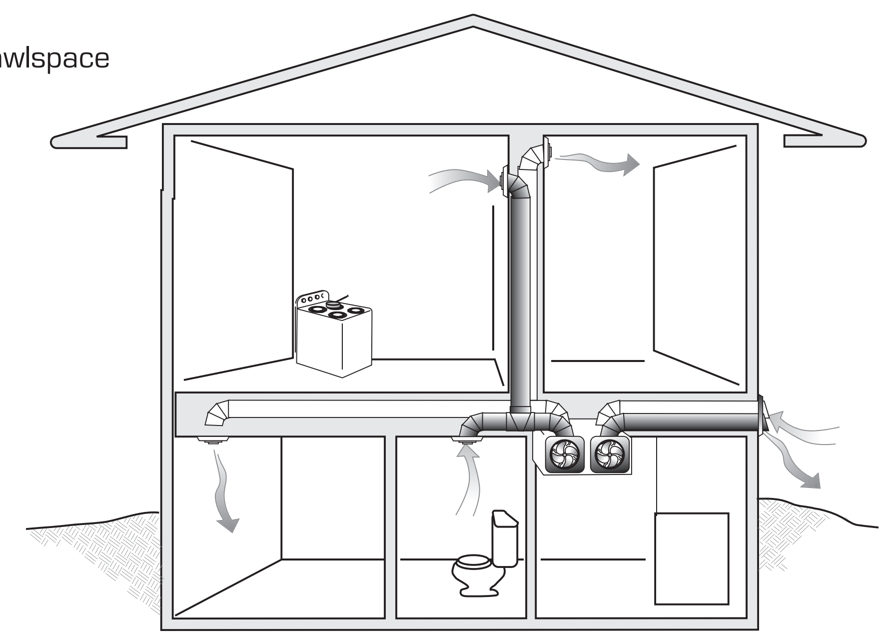
Controlled ventilation systems collect the outgoing air into a single duct, so it is possible to capture heat from that air with a heat-recovery ventilator (HRV). The most common type of HRV is an air-to-air heat exchanger. It transfers heat from the outgoing air stream to the incoming one. In these systems, air flow is balanced (Figure 9.5). An energy recovery ventilator (ERV) also modifies the humidity content of the fresh air through the transfer of water vapor from one air stream to the other. This may cause problems where moisture control is an issue. Since HRVs and ERVs combine both exhaust and fresh air intake, they are considered balanced pressure systems. One of the primary functions of an HRV is to temper the incoming supply air to minimize draft complaints and reduce the cost of heating the fresh air.

How They Work

Mechanically, the HRV or ERV is a combination of fans, controls, and heat recovery elements that exhaust stale air from the home, bring fresh air in from outdoors, and transfer heat en-

Figure 9.4: Balanced non-heat-recovery ventilation. (Only a few manufacturers provide balanced ventilators without heat recovery.)

- Noise Rating: not applicable
- Locations: basement, attic, or crawlspace
- Air Flow Capacity: 100–400 CFM
- Heat Recovery: none
- House Pressure: balanced
- Makeup Air: ducted
- Multispeed Operation: optional
- Equipment Cost: $400 to 800



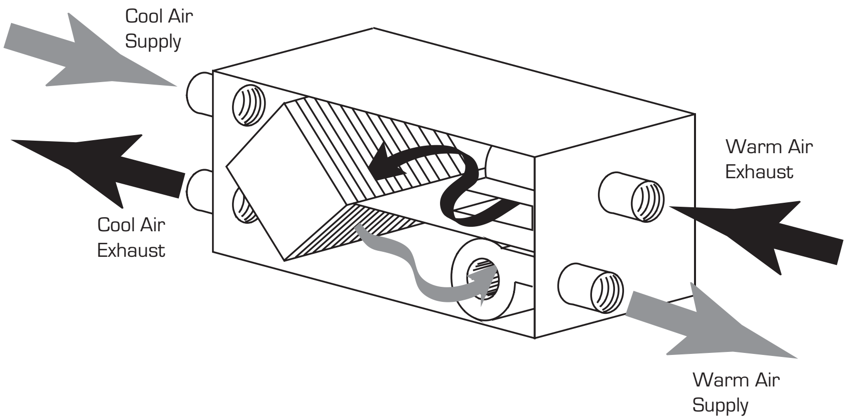


Figure 9.5: A typical heat-recovery ventilator schematic for air flow through the plate-type heat exchanger.

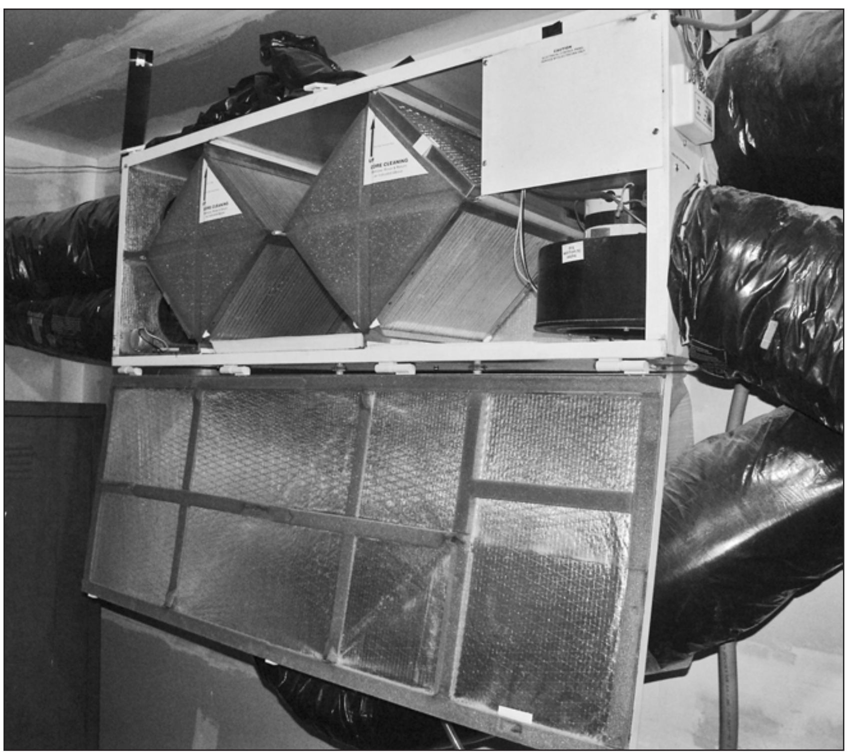


Figure 9.6: A heat-recovery ventilator opened for cleaning and maintenance. Two plate-type heat exchangers are used in this large-capacity model.

ergy from one airstream to the other. A continuously running HRV or ERV provides a steady supply of fresh air to the home, while recovering a portion (60% to 70%) of the energy normally lost through non-heat-recovery ventilation.

ERV's as opposed to HRV's are most useful when the average outdoor dewpoint temperature is well below the indoor dewpoint during winter and above the interior dewpoint temperature in summer. The closer the outdoor dewpoint is to the indoor dewpoint, the lower the ERV benefit. Where the outdoor dewpoint is well below the interior dewpoint, the ERV benefit is in recovering back some of the interior generated moisture to keep the house from being too dry. Where the outdoor dewpoint is above the interior dewpoint, the ERV benefit is to reduce the incoming moisture load in the outside air to reduce cooling/dehumidification energy consumption and to potentially keep the house dryer.

HRV's and ERV's have filters that minimize the entry of pollen, dust, and insects into the home with the fresh air. They are intended to operate year-round. Models suitable for use in extremely cold climates are equipped with automatic defrost mechanisms, allowing continuous operation throughout winter. HRV's and ERV's are available as stand-alone units with independent ductwork or they may be connected to existing forced air heating systems.

Balanced air flow can be difficult to achieve in a home with a balanced ventilation system connected to a forced-air heating system. Detailed duct design and careful installation and flow-balancing techniques are needed. Even then, air flow can be thrown off by someone closing a door between a supply and a pickup.

Furnace Integration

It is tempting to combine a controlled ventilation system with existing forced-air heating system ductwork. This can be accomplished by either supplying and exhausting ventilation air through the heating system's supply and exhaust ductwork, or by simply supplying fresh air.

However, before using heating ducts for fresh air distribution, several issues need to be recognized.

- Duct systems in new and existing homes have significant air leakage.
- Homes with forced air systems frequently have air pressure differences around the house that increase building air leakage.
- Typical furnace blowers are turned by large, inefficient motors. Running the typical single-speed blower an additional eight hours per day could easily burn more than 2,000 kilowatt hours per year. Some new air handlers reduce energy use with multispeed controls or more efficient motors. Consider an ECM blower with interlocking controller.

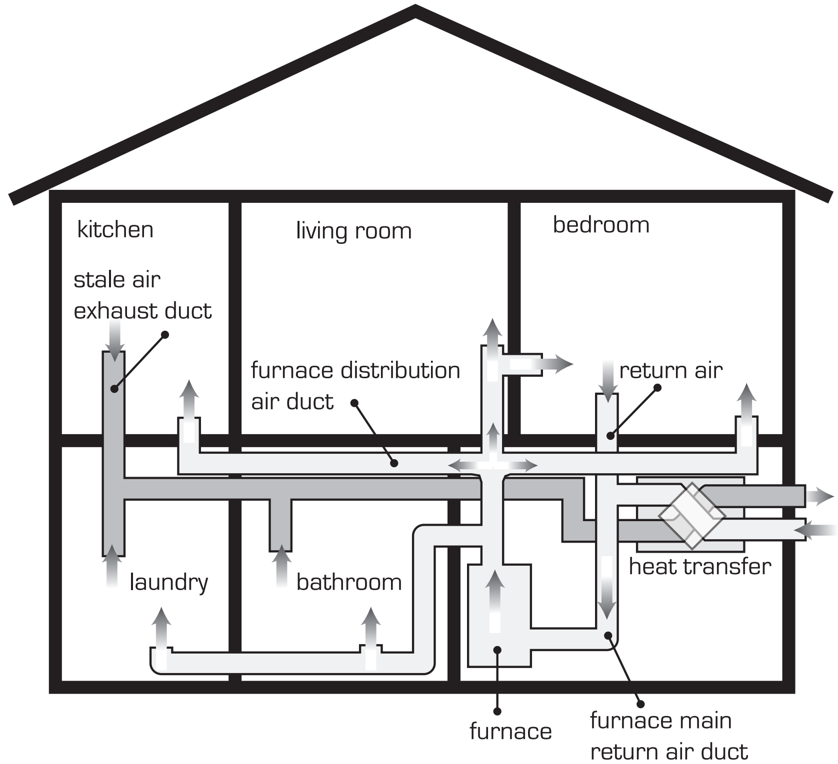
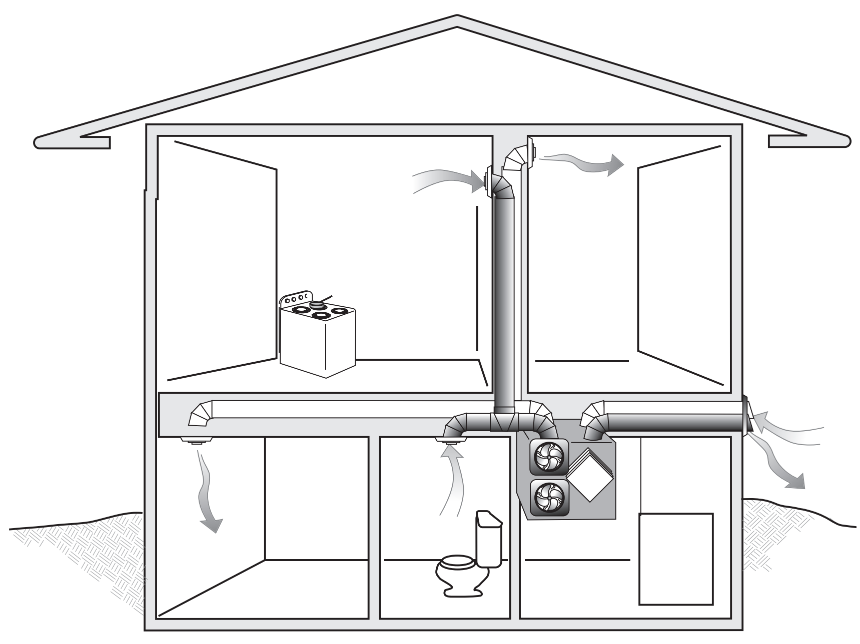


Figure 9.7: An HRV installed in conjunction with a forced-air furnace system

Figure 9.8: Heat recovery ventilation. This type of ventilation provides balanced air flow and recovers up to 85% of the heat from outgoing air. By warming the incoming air, HRVs provide greater comfort in cold climates than other types of ventilation systems. Units can be sized for any home and small commercial buildings.

- Noise Rating: not applicable
- Locations: basement, inside utility room, or any tempered space
- Air Flow Capacity: 150–1,200 CFM
- Heat Recovery: 60 to 85% recovery efficiency
- House Pressure: balanced
- Makeup Air: ducted
- Multispeed Operation: standard on most units
- Cost: $1.35 to $1.50 per square foot



- Balancing the HRV requires adjusting flows when the furnace is on low, high, and off.
- Proper furnace sizing and modulating the burn will maximize furnace runtime and maintain balance.
- Make sure that both furnace and HRV manufacturers approve of the connection.
- An alternative option is to provide an indirect connection of HRV supply. This will allow the HRV to operate in a more balanced mode whether the furnace is on or off.
- What happens to air quality, distribution when the furnace is off?
- Duty cycle issue: 60 CFM = 120 CFM at 50% run-time

An HRV can also be installed to work in conjunction with a forced-air furnace system, as illustrated in Figure 9.7. In this case, the HRV's fresh-air duct is connected to the furnace's main return air duct. The fresh air enters the furnace and is distributed throughout the house using the regular system of ductwork. In such a configuration, the furnace blower should run continuously at low speed when the HRV is operating to ensure a regular flow of fresh air throughout the house. (The furnace blower can also be wired to operate at the normal higher speed for heating and cooling. However, this higher speed can be noisy and may make the rooms feel cool if used to distribute ventilation air continuously.) Separate, additional ductwork may be needed to transfer stale air from wet rooms such as the bathroom and kitchen to the HRV.

How Much Does Ventilation Cost?

A house that is leaky enough to provide effective natural ventilation costs more to heat, it is likely to be drafty, and the air quality may still be poor. Controlled ventilation brings a specific amount of outside air and distributes it through the house. Nevertheless, pulling outside air into a space and then heating it up does consume energy and still costs money. While the home builder and buyer may be concerned about the up-front costs of fans, ductwork, grilles, and installation, in Alaska it is cost of heating fresh air that is most important.

An energy use modeling program, such as the State of Alaska's AKWarm software program, can be most helpful in comparing costs. You can see from Table 9.2 that both the type of ventilation system and the airtightness are important. For every area of the state, at 2005 energy costs, heat recovery ventilation in combination with a tight building shell is the most cost effective option. Note also that in a leaky house (7 air changes per hour at 50 Pascals), there is so much natural ventilation provided by the house leaks that the mechanical ventilation systems are useless.

Table 9.2: AKWarm-predicted annual energy costs for a home comparing ventilation system and airtightness levels

Location	Airtightness 1.5 ACH @50 Pa			Airtightness 4 ACH @50 Pa			Airtightness 7 ACH @50 Pa		
	HRV	Continuous Non-HRV Vent	No Controlled Vent*	HRV	Continuous Non-HRV Vent	No Controlled Vent*	HRV	Continuous Non-HRV Vent	No Controlled Vent*
Fairbanks	$2560	$2761	$2807	$2705	$2741	$2807	$2976	$2976	$2976
Juneau	$1798	$1932	$1961	$1885	$1917	$1961	$2055	$2055	$2055
Anchorage	$1552	$1600	$1593	$1569	$1580	$1593	$1632	$1632	$1632
Nome	$3741	$4065	$4152	$4055	$4068	$4152	$4702	$4702	$4702
Barrow	$1323	$1365	$1369	$1368	$1368	$1372	$1494	$1494	$1494

* No controlled ventilation assumes open windows to provide adequate ventilation.

Table 9.3: Equipment & installation costs for new mechanical ventilation systems (Rudd 2005) (Note: equipment costs do not include ducting or labor costs, which will vary depending on the installation design.)

Ventilation System Description	Central fan use*	Equipment Costs	Installation Costs	Total Costs
Single-point Exhaust	Off	$70	$0	$70
	10 min/hr	$125	$20	$145
Multipoint Exhaust, 2 bath fans	Off	$140	$0	$140
	10 min/hr	$195	$20	$215
Multipoint Exhaust, remote fan	Off	$450	3 points, $400	$850
			4 points, $500	$950
Single-Point HRV	Off	$800	$550	$1350
	10 min/hr	$800	$570	$1370
Multipoint HRV	Off	$800	3 points, $750	$1550
			4 points, $770	$1570
Central-fan integrated supply with continuous single-point exhaust	Off	$125	$100	$225
	15 min/hr	$125	$100	$225
	15 min/hr w/damper	$180	$120	$300
Central-fan integrated supply with intermittent exhaust	Off	$160	$100	$260
	15 min/hr	$160	$100	$260

*Central fan is used to mix and distribute air

Components of a Ventilation System

Figure 9.9: This sequence shows a defrost mechanism on an HRV. It operates as a flap valve automatically triggered by temperature to change the source of fresh air for a few minutes. This valve opens ductwork from an indoor source and warm air is run through the heat exchange core to melt accumulated frost from condensation.

A ventilation system generally consists of the following equipment:

- Insulated ducts for incoming (fresh) and outgoing (stale) air, along with exterior hoods
- Ductwork to distribute fresh air throughout the home and to collect stale air
- Fans to circulate air throughout the home and to exhaust stale air to the outdoors
- Operating controls to regulate the system according to ventilation needs
- If it is an HRV it will have:
  - a heat-exchange core, where heat is transferred from one air stream to the other;
  - filters to keep dirt out of the heat-exchange core;
  - a defrost mechanism to prevent freezing and blocking of the heat-exchange core when the temperature of the incoming air is cold;
  - a drain to remove any condensation from inside the HRV (may not be required with all models); and

Fans

Controlled ventilation systems operate many hours every day. Some never turn off. You want a durable, high-quality fan intended for continuous operation. Most high-quality fans use permanent split capacitor motors.

Three of the most important characteristics to look for in a fan are size, noise level, and energy efficiency. If a fan is the wrong size, too noisy or too costly to operate it will not be used as often as it should be, making it ineffective. Fans selected for whole-house ventilation systems should be manufactured for continuous operation and long life (greater than 10 years), and installed in a location that is easily accessible for regular maintenance.

Fans should be sized and selected to provide necessary airflows based on the type, length, and design of the duct system. Because fans have differing capacities for moving air, it is important to make sure the fan has enough capacity for the application. Fan exhaust capacity is rated in cubic feet per minute (CFM). The fan's certified CFM rating appears on the product or on the Home Ventilating Institute (HVI) label displayed on each unit, in the manufacturer's literature describing the fan, and in the HVI Certified Products Directory at www.hvi.org.

The CFM rating typically assumes the fan is working against an air pressure resistance of 0.1 inch of water—the resistance provided by about 15 feet of straight, smooth metal duct. In practice, most fans are vented with flexible duct that provides much more resistance. Many ventilation experts suggest choosing a fan based on a resistance of 0.30 inches of water.

Bathrooms, Kitchens, and Other Rooms

For adequate ventilation, HVI recommends the following guidelines for minimum recommended flow rates for exhaust fans when designed to operate in continuous mode and intermittent mode.

Location	CFM/ Continuous Type Fan	CFM/ Intermittent Type Fan
Kitchen	60	100
Bathroom	20	50

Sound

Noise prevents many people from operating fans. Low sone ratings are less important for remote-mounted fans. However, you should use sound absorbing fan mounting and duct connections to prevent sound transmission into living areas. Choose as quiet a fan as you can afford.

Table 9.4: ASHRAE 62.2-2004, Prescriptive Duct Sizing

Duct Type	Flex Duct				Smooth Duct			
Fan Rating CFM @ 0.25 inch wg (l/s @ 62.5 Pa)	50 (25)	80 (40)	100 (50)	125 (65)	50 (25)	80 (40)	100 (50)	125 (65)
Diameter in. (mm)	**Maximum Length ft. (m)**							
3 (75)	X	X	X	X	5(2)	X	X	X
4 (100)	70(27)	3(1)	X	X	105(35)	35(12)	5(2)	X
5 (125)	NL	70(27)	35(12)	20(7)	NL	135(45)	85(28)	55(18)
6 (150)	NL	NL	125(42)	95(32)	NL	NL	NL	145(48)
7 (175) and above	NL	NL	NL	NL	NL	NL	NL	NL

This table assumes no elbows. Deduct 15 feet (5 m) of allowable duct length for each elbow.
NL = No Limit on duct length of this size.
X = Not allowed. Any length of duct of this size with assumed turns and fitting will exceed the rated pressure drop.

Energy Efficiency

The efficiency or efficacy of a residential fan is expressed as cubic feet per minute per watt (CFM/W). It is determined by dividing the volume of air that the fan moves by the amount of energy used. Efficient small-bathroom fans—less than 76 CFM—will have a minimum efficacy of 1.4 CFM/W. Better large bathroom fans—76 CFM and over—as well as range hoods will have a minimum efficacy of 2.8 CFM/W. Remember: the larger the efficacy number, the better!

Remote or "In-Line" Fans

In-line fans are duct-mounted, remote fans that can provide ventilation or boost airflow with little detectable noise. They provide a solution to noisy or ineffective bathroom fans, ineffective dryer exhaust, and recirculating range hoods.

Many ceiling- or wall-mounted exhaust fans can be adapted as in-line blowers located outside of the living area, such as in an attic or basement. Manufacturers also offer simple single-port or versatile multiport in-line fans that can be used to supply ventilation for most single-family residential applications. A multiport design allows one fan to provide ventilation for multiple rooms, such as two bathrooms and a laundry (Figure 9.3).

Ducts

The most efficient ventilation ducts are smooth, short, straight, and properly sized. Smooth sheet-metal ducts offer low airflow resistance. Because corrugated (flex) ducts have greater flow resistance, it is important to keep them as short as possible—stretch the corrugated material to its full length and cut off the excess. Minimize the number of elbows. Provide adequate support. Use mechanical fasteners and sealants (preferably duct mastic) at all joints. Ducts located outside the conditioned space should be insulated.

Duct Terminations

Ducts that exhaust water vapor or other pollutants must exhaust directly to the exterior—never into attics or crawlspaces. Use wall caps with flap dampers, screens, or both to deter access and to reduce air infiltration. Unless they are already integrated into the system (e.g., wall cap with flapper), equip ventilation ducts with backdraft dampers at or near the insulated building boundary. Note: Roof jacks could cause problems because of condensation within the duct or icicles created by melting snow.

System Controls

Ventilation system controls range from simple to complex. People are not generally reliable ventilation controllers, so you shouldn't count on a manual switch as the primary ventilation control. An automatic control is essential. However, people should be able to activate or disable the system when necessary. So, most systems require at least two controls wired together.

Here are a few control options that would work with most types of ventilation systems:

- Timers
    - Twenty-four hour timers allow the occupants to set certain times for ventilation. Set the timer to run the fan at least eight hours per day.
    - Twist timers, also called interval timers, allow occupants to turn on the fan whenever it's needed. Twist timers can be set for up to 60 minutes and are generally located in bathrooms, utility rooms or kitchens.

- Sensors
    - Indoor air quality sensors activate a fan when they detect carbon monoxide, formaldehyde or other pollutants.
    - Dehumidistats engage the fan on rising humidity. They work well when relative humidity accurately indicates the need for ventilation. By setting the dial at 40, you are telling the dehumidistat to operate the fan whenever the humidity is 40 percent or higher. Unfortunately, relative humidity isn't always a reliable indicator. Climates with low humidity might never reach 40 percent, so the fan would never turn on. In wet climates the fan might never turn off during mild weather. Dehumidistats aren't used as much as they once were because of this problem.
- Speed controllers allow the fan to operate at low speed for background ventilation with a manual high-speed boost.
- Continuous operation simplifies the controls, but you should at least install an on/off switch. It's a good idea to locate the switch out of the way to reduce the chance that someone will accidentally flip it off.

Indoor Air Circulation

Indoor air must be free to flow between supply and return ports of whole-house ventilation systems. If a supply and return port is not installed in every room, then through-the-wall transfer grills should be installed above doors in rooms with doors that are often closed, or the doors should be undercut to facilitate air flow.

Commissioning a System

Once the installation is complete, the installer should visually inspect the components in the system, correct any deficiencies, and then start up the system and check its operation.

Test procedures will vary depending on the complexity of the system, but the goal is to be confident that the system will operate as designed, providing adequate airflow, proper operational control, and adequate distribution of ventilation air while avoiding pressurization or depressurization problems

- Measure airflows to rooms
- Balance supply and exhaust airflows
- Check controls
- Clean all filters and core
- Clean outside supply air intake
- Compatibility with combustion appliances

Occupant Information

Controlled ventilation systems are new to most home buyers. It's your job to educate the occupants.

- Label all components, including the fan, controls, and ducts.
- Provide building owner an operation and maintenance manual with a brief description of the system that explains the principles of operation, control strategy and maintenance. This manual should include the installer's name and phone number, product literature for all components, ventilation system model and serial number, ventilation airflows, and the operation and maintenance schedule.
- Show the occupants the location of each component and how to operate the system.

Good information is essential because even the best ventilation system needs to be operated and maintained properly.

Summary

Good ventilation must be effective at maintaining reasonable indoor air quality and building durability. When done right, mechanical ventilation can improve air quality and protect the building. When done wrong it can cause many problems including poor indoor air quality. You should understand basic design and installation principles that will help ensure adequate airflow, proper operational control, and adequate distribution of ventilation air while avoiding pressurization or depressurization problems.

A properly ventilated home is designed to provide:

- local or spot ventilation to remove moisture, odors, and other pollutants at the source;
- whole-house ventilation for supplying fresh air to remove contaminants by dilution; and
- control of airflow through building so air can't carry contaminants into and around the house.

A successful ventilation system, from the simplest to the most complex, must be acceptable to the occupants and they must be willing and able to maintain it. It must be unobtrusive, quiet, comfortable, simple and affordable to operate, and easy to maintain.

Below is a checklist of steps to follow in order to have success in each of your projects.

❑ **Be sure that the home is tightly constructed.** Conduct blower door testing, if possible, to determine natural air infiltration levels.

❑ **Be sure the duct system is also tightly sealed**, especially if the ventilation system will use the central air handler.

❑ **Work with a knowledgeable HVAC contractor** to design and select a ventilation system that is appropriate for the home and the climate.

❑ **Consider the loads induced by the ventilation system** when sizing heating and cooling equipment.

❑ **Consider wiring and controls** for the ventilation system.

❑ **Test and adjust** the ventilation system, as necessary.

❑ **Educate the homeowner** on the proper operation and maintenance of the system.

BUILDING IN ALASKA

Indoor Air Quality and Ventilation Strategies for Cold Climates

EEM-00450

INTRODUCTION

What constitutes the designation cold climate? For the purposes of this informational publication and to emphasize some of the difficulties with mechanical ventilation control strategies, we will use the lower limit of 8000-Fahrenheit heating-degree-days as the level above which we consider the climate cold. The climate of Fairbanks, Alaska, far exceeds this 8000 degree-day lower limit, with an average heating index of 14,300-14,400 Fahrenheit heating-degree-days annually. This designation includes all but the very southernmost portions of Alaska in its definition and much of the northern tier of U.S. states and Canada. This location provides a unique natural laboratory setting in which to not only discover difficulties with ventilation control and the general control of indoor air quality in cold climates, but to also suggest and test new strategies from our research utilizing existing, inhabited homes in our community. This is the source of our most recent research results reported in this paper. The 8000 Fahrenheit-degree-day boundary for classifying cold climates also provides a large reference zone for most regions of the planet north of 60 degrees latitude.

Residential Ventilation–Why Do We Need It?

With the emphasis in modern cold climate housing on air-tightness and energy efficiency, a house is typically lacking adequate air exchange without the addition of mechanical ventilation. In addition, traffic noise, particulate pollution (such as forest fire smoke in the north during the summer), pollen (a problem for asthmatics and highly allergic people), and the maintenance of a healthy level of relative humidity can be better controlled with mechanical ventilation. A range of humidity considered both achievable and healthful in northern housing is the range from above 30% to 50%. Although relative humidities a bit higher are still considered healthful, our present ability to prevent condensation on colder surfaces is limited by modern window technologies. Keeping windows free of condensation at our most extreme periods of cold is not feasible with windows of R-values of 4 or

10-04/RS/1000 October 2004

COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF ALASKA FAIRBANKS

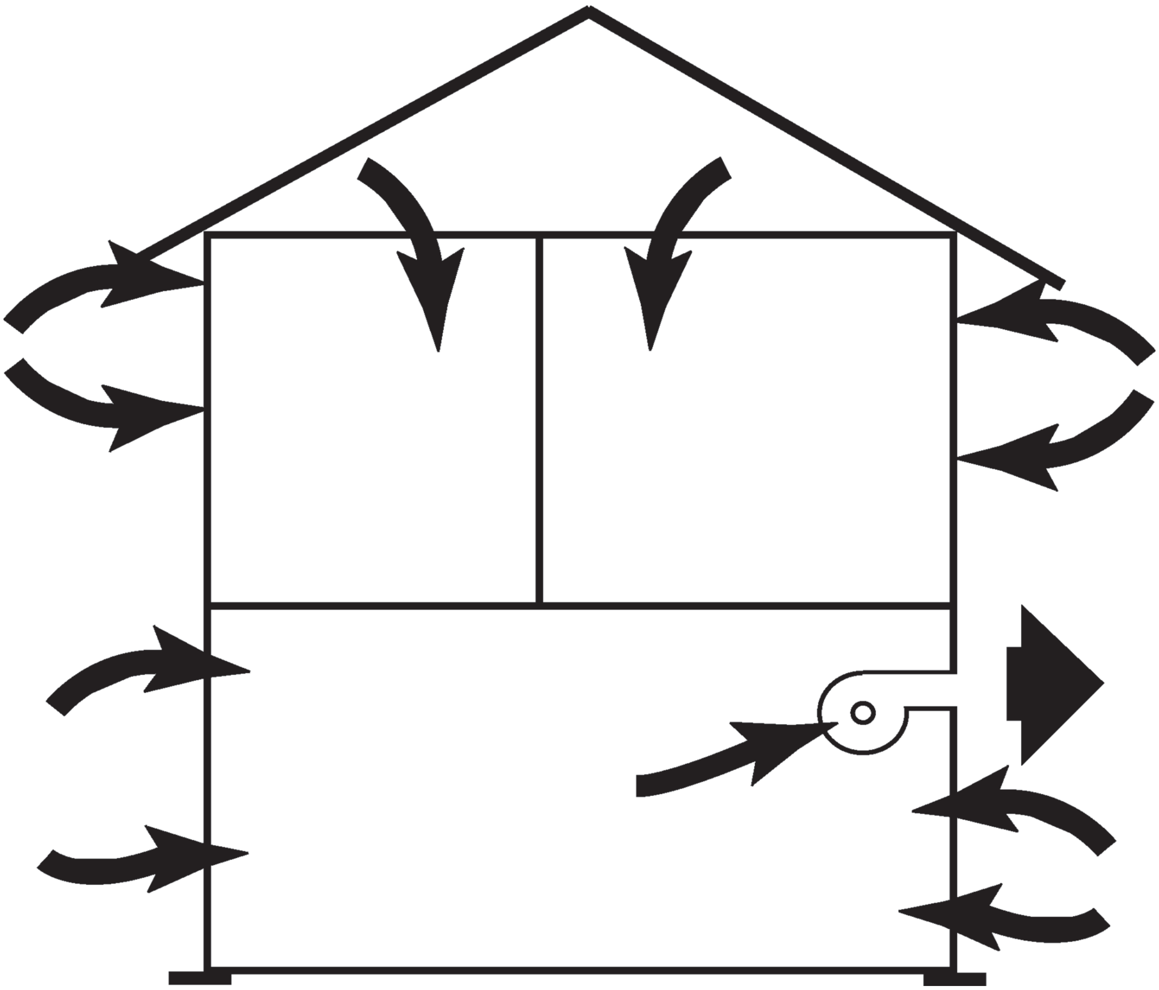


Figure 1: An exhaust-only ventilation system (Alaska Housing Manual, 2000). Although not shown in this figure, exhaust-only systems typically provide for supply air by small inlet vents, such as the Fresh 80, a brand name tubular plastic duct with an external louver to provide inlet air to make up for the air being exhausted. No heat exchange takes place, and the exhaust-only system not only induces air at the outdoor temperature, but also puts a negative pressure on the entire house, possibly leading to induced pollutants, such as radon.

less. Finally, the air quality in homes can often only be ensured by mechanical ventilation, designed for that home.

COMMON VENTILATION SYSTEMS FOR RESIDENTIAL USE

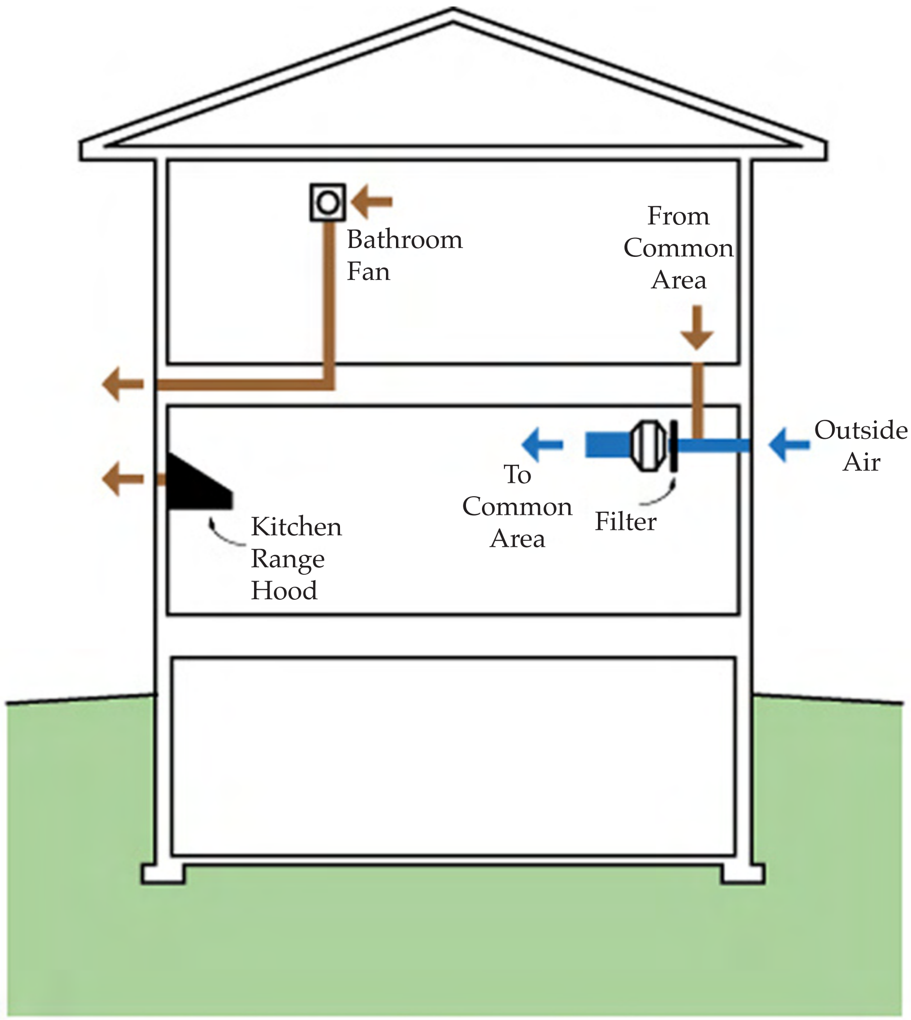
It is appropriate to review the common technologies in use for residential ventilation to understand the options for control that they afford. These systems include:

1. **Unbalanced Mechanical Ventilation Systems–Exhaust-Only**

This type of system typically employs a single fan, hopefully strategically placed, to exhaust air from a residence, with air inlets placed in rooms typically requiring supply air, such as bedrooms (Figure 1–supply ducts not shown in figure). Placement of the inlets is crucial because of the pressure dynamics of the building. This is particularly so in cold climates because the temperature differentials are larger and the consequent pressure differentials across the building shell are enhanced. Exhaust-only systems also induce a constant negative pressure inside the building–with respect to outdoors–and induce radon from below grade walls along with other soil gasses. For these important reasons, most building scientists in northern regions have rejected exhaust-only technology for cold climate ventilation.

A second type of unbalanced mechanical ventilation–supply ventilation with point source exhaust–is shown and described in Figure 2.

2. Balanced Heat Recovery Ventilation (HRV)
For approximately two decades, improvements in balanced heat recovery ventilation have resulted in steadily gaining adoption



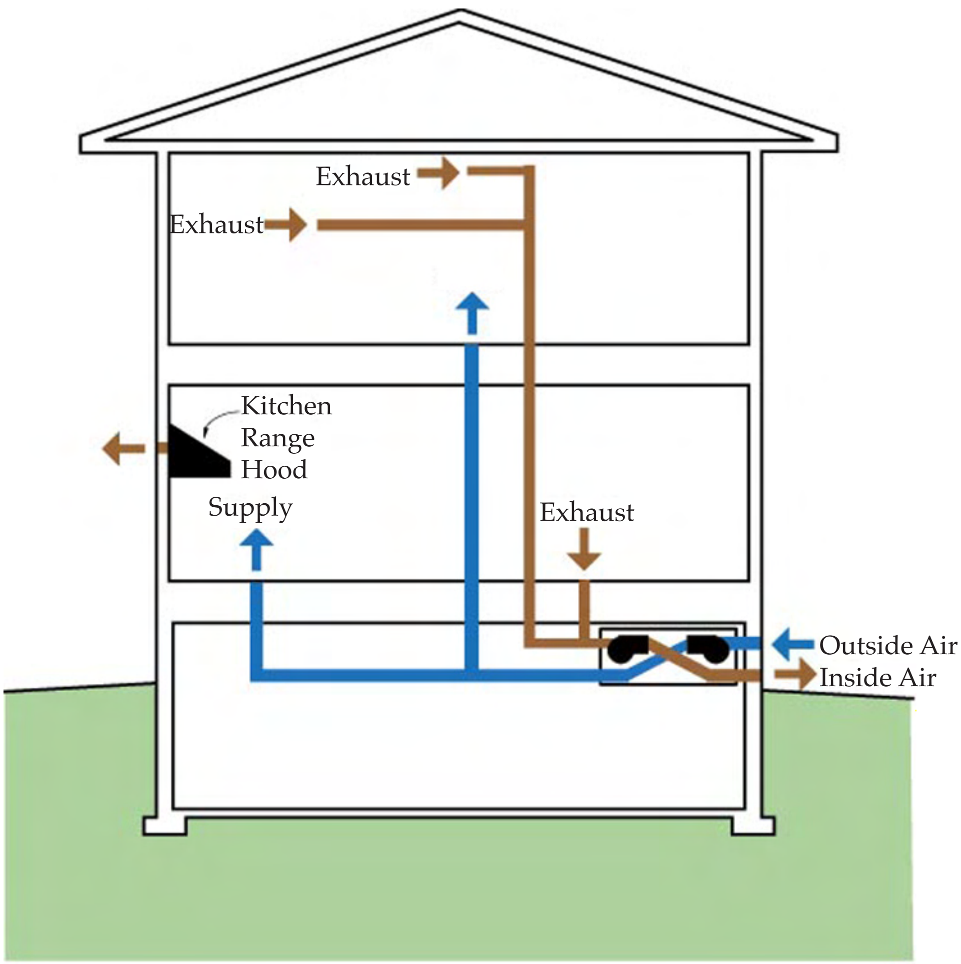
Supply Ventilation System with Point Source Exhaust

- Supply fan brings in outside air and mixes it with air pulled from a common area (living room, hallway) to provide circulation and tempering prior to supplying to common area.
- Run time is based on time of occupancy.
- In supply ventilation systems, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.
- Kitchen range hood provides point source exhaust as needed.

Figure 2: Non-integrated supply and multi-point exhaust ventilation system (uncommon in the north, but could be adapted here). Credit: Building Science Corporation, 2004, used with permission.

of this mechanical ventilation option (Figure 3). A generic cross-sectional view of a heat recovery ventilator (also called an air-to-air heat exchanger) is shown in Figure 4. These systems have been particularly useful in Canada, Alaska and the northern United States. The biggest barriers to wide adoption seem to be initial cost and a satisfactory control strategy. Cost of installation is nearly always less for new construction, as the duct distribution system and design integration into the structure are much simpler to include at the time of construction. But satisfactory performance of these systems is not always certain due to immature control technologies.

3. Heat Wheel HRV with latent heat recovery. This third type of heat recovery ventilation system uses a rotating heat transfer surface, which transits between the outgoing exhaust and the



Balanced Ventilation System with Heat Recovery via an Air-to-Air Heat Exchanger

- The ventilation system has a separate duct system not integrated with the heating and A/C system.
- Run time based on time of occupancy.
- Exhausts are typically from bathrooms and supplies are typically to bedrooms.
- In supply ventilation system, and with heat recovery ventilation, pre-filtration is recommended as debris can affect duct and fan performance reducing air supply.

Figure 3: A Heat Recovery Ventilation System. Credit: Building Science Corporation, 2004, used with permission.

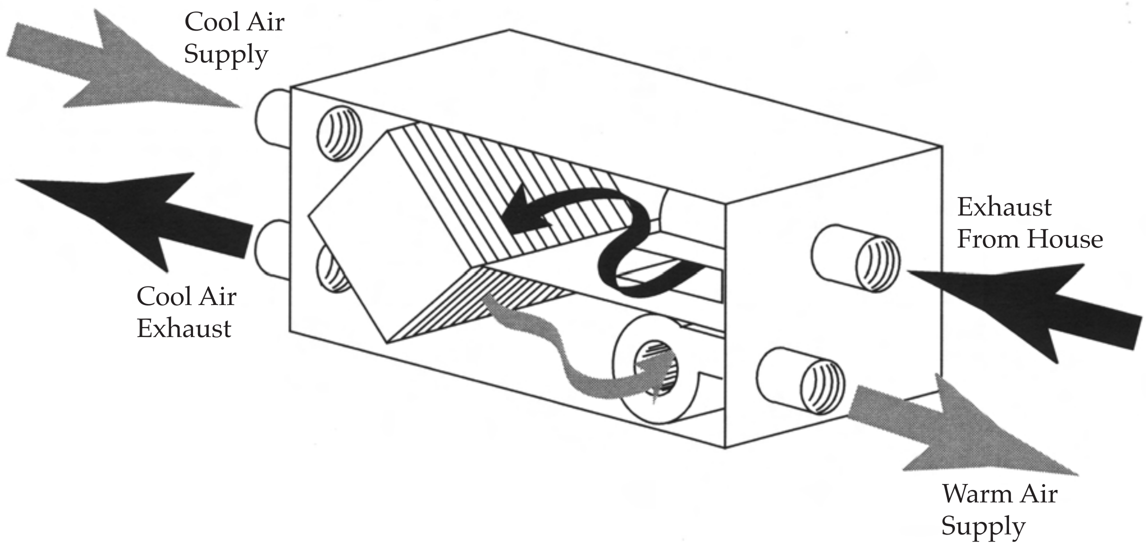


Figure 4: A cut-away view of a typical Heat Recovery Ventilator, single core. Credit: Alaska Housing Manual, 2000.

incoming cooler, dryer air. Consequently there is cross pollution of the air streams. This type of system is not recommended even though it solves the condensation and humidity issues in some instances.

How Much Ventilation Do You Need?

ASHRAE 62-2 is a residential ventilation standard. This standard recommends 7.5 cubic feet per minute (cfm) of ventilation air per person based on the number of bedrooms in the house plus one. In addition, an ASHRAE compliant design must add .01 cfm for each square foot of floor area. As an example:

A three bedroom 1500 sq. ft. house would take:

7.5 x 4 plus 1500 x .01 = 45 cfm

This could be supplied in many ways, and we'll talk about the control mechanisms for doing so.

RESIDENTIAL VENTILATION CONTROL STRATEGIES

Either by inference or by consensus of engineering, we have agreed to reproduce indoors the outdoor climate of the tropical savannah. These conditions are typified by a relative humidity range from 30 to 60 percent and the temperature between 65° to 70°F (18° to 21°C). There are probably many reasons why this design strategy and set point condition were agreed upon. But it's hard to imagine that our evolutionary emergence from the tropical savannah was not a strong influence in this resulting agreement.

Residential control strategies have consequently been developed to try to keep the relative humidity in the range of 30 to 60 percent. In Alaska we have to slide toward the dry side of this range and not exceed 50 percent relative humidity indoors. Present window technologies do not allow us to tolerate indoor relative humidities higher than 50 percent.

All cold weather ventilation strategies are inherently dehumidification processes. In a heating climate, warm moist air is being exhausted and replaced by cooler drier outside air.

Another aspect of indoor air quality affected by ventilation strategy is radioactive radon gas. When present in the soil gas, radon infiltrates into a house driven by the same mechanisms that cause the infiltration of cool dry outdoor air into a house. Transport of radon into a house is primarily due to air leakage (air containing radon) caused by differential pressures between the house and soil[5]. Infiltration can take place anywhere there are pressure differences and openings in the building envelope. Houses typically leak air in low and out at the top of the building.

The ventilation rate of a house at any given time is a function of the openings in the structure and the forces causing air to move through the house. The effect of the air buoyancy is often referred to as the stack effect and this effect is significant during the heating season in Fairbanks.

First, let's look at some research:

During the winter of 2000, researchers at the University of Alaska Fairbanks did a series of experiments and research tests to study the results of various ventilation systems and their controlled operation on the indoor air quality of several homes in the Fairbanks area.

They recorded indoor radon concentrations, indoor temperatures, and outdoor temperatures at two Fairbanks homes for the period between the spring of 1999 and the spring of 2000. They also measured differential pressures across the basement slab at one of the houses during the winter months. The purpose was to demonstrate the seasonal variability of indoor radon concentrations, the variation of indoor radon concentrations with outdoor temperature and the effectiveness of subslab depressurization systems in the Fairbanks area. TSI instruments were also used to acquire data consisting of relative humidity, carbon monoxide, carbon dioxide, and indoor temperature measurements in twelve different homes in Interior Alaska. In all but a very few periods of measurement, homes were occupied and in routine use. Houses were measured for two-week intervals for each season, typically rotating through a data collection interval every 10-12 weeks for nearly three years. Radon data was typically gathered simultaneously with a Sun Nuclear radon monitor and supplemented with various radon test kits for corroboration. Air leakage tests were typically done during the autumn or winter, and a mix of blower door tests and carbon dioxide dilution tests were utilized to measure air leakage under various outdoor conditions.

RESEARCH RESULTS

Figure 5 is a plot of indoor relative humidity and the simultaneous indoor/outdoor temperature differential in two different houses. However, the time periods are contiguous and the contrast in sustained indoor relative humidity levels between the two houses is an important indicator of the importance of air leakage. House R-S has 50% more natural air leakage than House R-A. The temperature differential during the period of measurement for House R-S was markedly greater indicating it was much colder outside during that time period.

The latter half of the measurement period for House R-A (1/28 to 2/8) compares somewhat closely to the period (1/13 to 1/28) for House R-S. The relative humidity in house R-A is consistently 15-20% higher, and in a healthful range (ca. 45%). Air leakage is an important controlling factor in this difference. The blower door leakage rates for the two houses were 2.5 ACH_{50} for House R-A and 3.7 ACH_{50} for House R-S (ACH_{50} means the Air Changes per Hour at 50 Pascals pressure difference. 50 Pascals is a common test pressure for blower door tests). This 50% greater air leakage appears to exceed a crucial boundary since House R-A is able to sustain healthful humidity levels, and House R-S is not able to do so.

A strong correlation was found between the indoor radon concentrations and differential pressures across the slab at House R-A (Figure 6). It is generally accepted that pressure driven flow dominates as a radon entry mechanism. This demonstrates the correspondence between the pressure differences across the building envelope and the entry of radon bearing soil gas assuming that the soil gas radon concentrations remained stable. In House R-A

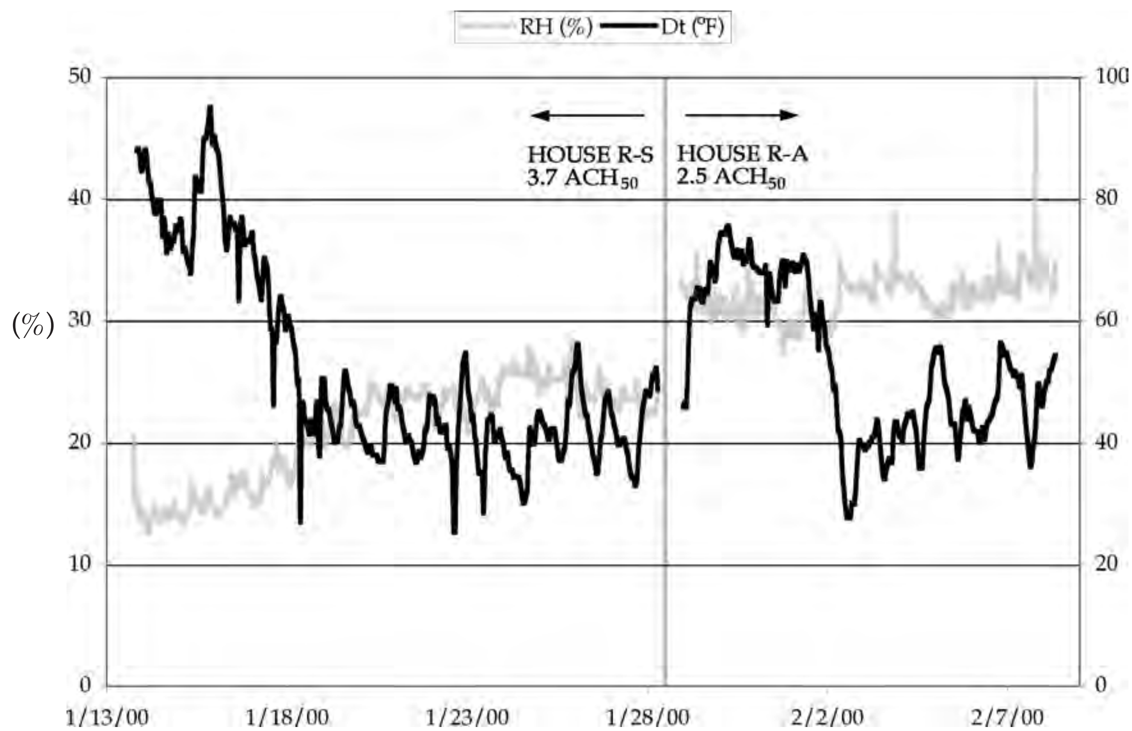


Figure 5: Relative Humidity (%) indoors is directly related to the outdoor-indoor temperature difference and the "leakiness" of the house. A leaky house, such as house R-S here, cannot maintain a healthful level of relative humidity at low outdoor temperatures. "Dt" here means temperature difference.

there was no positive correlation between indoor-outdoor temperature differences and the radon concentrations. This was unexpected. In work with other homes, strong correlations were observed between the indoor-outdoor temperature differences and indoor radon concentrations. In a study of passive ventilation in a house in Sapporo, Japan, Fukushima noted that the leakage rate of an average size airtight house increases with indoor-outdoor temperature difference[7]. It was expected that the temperature differences would be a good indicator for the pressure differences across the basement slab and also an indicator of soil gas infiltration.

The infiltration rates of the other houses tested in this study were between 0.3 to 0.6 air changes per hour (ACH) as measured by tracer gas measurements at temperatures less than 19.4°F (-7°C) and blower door measurements. Tracer gas measurements indicated the infiltration rate of House R-A to be between 0.1 and 0.2 ACH at 19.4°F (-7°C). The range of differential pressures across the slab was from 0 to 18 Pa with only 2% of the data points greater than 10 Pa. In this house the operation of the kitchen fan, 2 bathroom fans, clothes dryer, and oil-fired boiler in various combinations could reduce the pressure in the house by as much as 11 Pa. Other confounding factors would be the opening of the garage door on the ground level and the occasional wind.

CONCLUSIONS

There are several fundamental conclusions one can draw from our results. First, the greater the temperature difference (i.e., the lower the outdoor temperature is), the greater the air leakage (infiltration) rate is likely to be, and a fraction of that infiltration will be soil gas that possibly contains radon or other pollutants. Second, the concentration resulting from radon bearing soil gas induction is very strongly

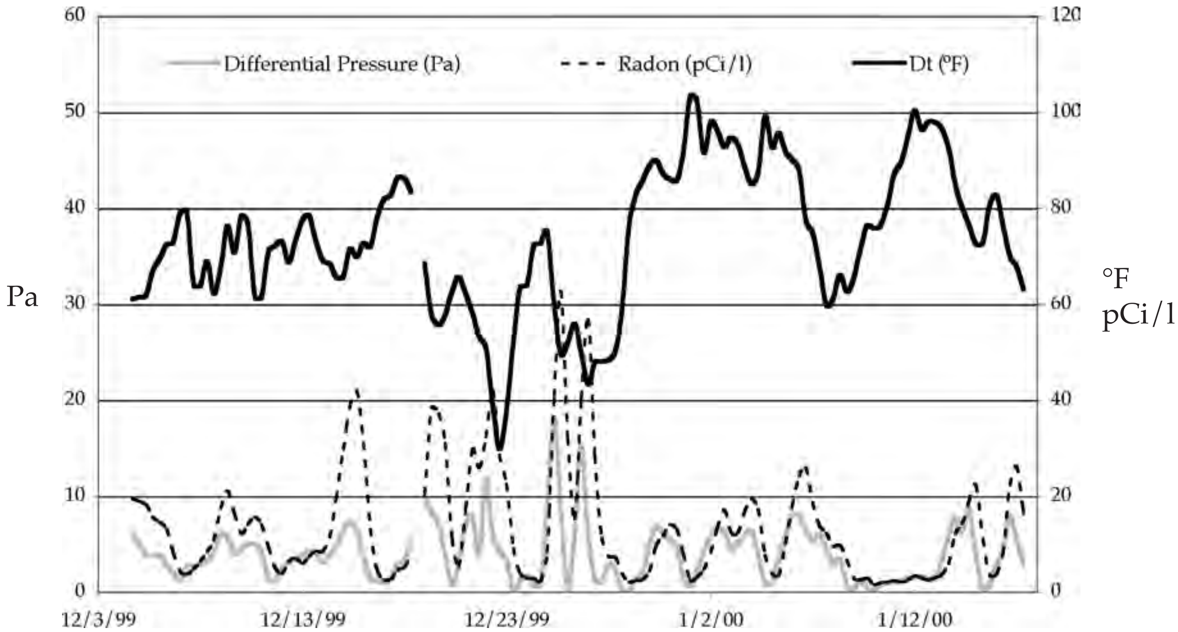


Figure 6: Radon Concentration & Pressure Differential Across Basement Slab vs Time in House R-A.

correlated to the pressure difference across the slab (Figure 6). This clearly indicates that air leakage resulting from the pressure difference is a crucial factor in radon induction. Blocking air and soil gas entry by limiting leakage from the building can go a long way toward controlling radon induction and other soil gas pollutants from entering the home.

Houses with exhaust-only ventilation show a clear tendency to induce radon. So exhaust-only ventilation is workable, but has the added risk of possibly inducing radon in dangerous amounts into the home if it is on a radon risk site. For this important reason, we urge caution in using exhaust-only ventilation systems in Alaska.

The results of this research corroborate that we have made progress toward a control strategy for ventilation systems. Very good control of air leakage, and consequent control of indoor relative humidity is important. This control of leakage makes the house less responsive to differential pressures across the building envelope. **That is what air sealing accomplishes!** Large pressure differences should not be induced on the shell of a building by ventilation systems, as this will induct soil gas, outdoor air pollutants, and would generally limit the ability to control the air flow and pressure difference across the shell. This is another major reason why most building scientists reject the concept of exhaust-only ventilation in very cold climates.

House R-A is an example of a house in which the natural infiltration is well controlled. The lack of a positive correlation between the indoor-outdoor temperature difference and the pressures across the envelope indicates that–in this house–the ventilation is driven less by natural infiltration and predominantly by operation of the various appliances in the house, and the openings of doors and windows. Ideally a house would have provisions to replace air removed by appliances to minimize the depressurization of the house. It is simply a **tight house**. Operation of appliances can cause substantial depressurization, and this has a more significant impact on this house than houses with greater air leakage rates. In interior Alaska, the predominant natural force driving air infiltration is buoyancy resulting from temperature differences. The average outdoor temperature is less than 19.4°F (-7°C) for approximately five months out of the year[1].

So what can we conclude about ventilation for Alaskan homes and how to control it? Here are some concise statements about ventilation and its control:

- Controlled ventilation REQUIRES an airtight building envelope and ducts.
- Exhaust ventilation can work, but it is difficult to control and has serious liabilities for inducting pollutants and bad outdoor air into the house.
- Balanced ventilation, which can be single point, multi-point (i.e. fans at locations where exhaust is commonly necessary), integrated with a central fan system or forced air heating system, or with Heat Recovery Ventilation (HRV) is the preferred approach. Control based on maintaining relative humidity above 25% is recommended.

Installation and selection of a ventilation system for your house is not considered expendable, and should be done by a competent ventilation contractor who is capable of designing the ductwork and certifying the system with tests. Although these services are available in Alaska, there is no certification of ventilation installers. This is regrettable, and Extension, Alaska Building Science Network, and others are working to remedy this situation. For the present, seek experienced installers and consult with your contractor, the ABSN (www.absn.com) or local homebuilders association at the time of construction.

Ventilation system cost estimates

These estimates are from Building Science Corporation for national labor rates for 2003:

- Central-integrated-fan system <u>$320</u> total: $65 fan recycling control, $65 motorized damper, $30 duct parts, $160 labor.
- Multi-point supply <u>$800</u> total: $250 supply fan with filter and two inlet ports (outside air and recirculation air) and one outlet port, $150 ducts and grilles, $400 labor.
- HRV, approximately $1.25 per square foot of building floor area, installed at the time of construction. Perhaps 20% more in retrofit.

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Mold in Homes

INTRODUCTION

This fact sheet provides information for people who have mold problems in their homes. It presents the health concerns associated with mold exposure and advice on finding and removing mold contamination.

What is Mold?
Molds are fungi. Molds grow throughout the natural and built environment. Tiny particles of mold are present in indoor and outdoor air. In nature, molds help break down dead materials and can be found growing on soil, foods, plant matter, and other items. Molds produce microscopic cells called "spores" which are very tiny and spread easily through the air. Live spores act like seeds, forming new mold growths (colonies) when they find the right conditions.

What does mold need to grow?
Mold only needs a few simple things to grow and multiply:
- Moisture
- Nutrients
- Suitable place to grow

Of these, controlling excess moisture is the key to preventing and stopping indoor mold growth.

Should I be concerned about mold in my home?
Mold should not be permitted to grow and multiply indoors. When this happens, health problems can occur and building materials, goods and furnishings may be damaged.

HEALTH EFFECTS

Can mold make me and my family sick?
Mold can affect the health of people who are exposed to it. People are mainly exposed to mold by breathing spores or other tiny fragments. People can also be exposed through skin contact with mold contaminants (for example, by touching moldy surfaces) and by swallowing it.

The type and severity of health effects that mold may produce are usually difficult to predict. The risks can vary greatly from one location to another, over time, and from person to person.

What symptoms might I see?
The most common health problems caused by indoor mold are allergy symptoms. Although other and more serious problems can occur, people exposed to mold commonly report problems such as:
- nasal and sinus congestion
- cough
- wheeze/breathing difficulties
- sore throat
- skin and eye irritation
- upper respiratory infections (including sinus)

Are the risks greater for some people?
There is wide variability in how different people are affected by indoor mold. However, the long term presence of indoor mold growth may eventually become unhealthy for anyone. The following types of people may be affected more severely and sooner than others:
- infants and children
- elderly people
- individuals with respiratory conditions or sensitivities such as allergies and asthma
- persons having weakened immune systems (for example, people with HIV infection, chemotherapy patients, organ transplant recipients)

Those with special health concerns should consult a medical professional if they feel their health is affected by indoor mold.

Are some molds more hazardous than others?
Some types of mold can produce chemical compounds (called mycotoxins) – although they do not always do so. Molds that are able to produce toxins are common. In some circumstances, the toxins produced by indoor mold may cause health

problems. However, all indoor mold growth is potentially harmful and should be removed promptly, no matter what type(s) of mold is present or whether it can produce toxins.

HOME INVESTIGATION

How do I tell if I have a mold problem?
Investigate – don't test. The most practical way to find a mold problem is by using your eyes to look for mold growth and by using your nose to locate the source of a suspicious odor. If you see mold or if there is an earthy or musty smell, you should assume a mold problem exists. Other clues are signs of excess moisture or the worsening of allergy-like symptoms.

- Look for visible mold growth (may appear cottony, velvety, granular, or leathery and have varied colors of white, gray, brown, black, yellow, green). Mold often appears as discoloration, staining, or fuzzy growth on the surface of building materials or furnishings. When mold is visible, testing is **not** recommended.
- Search areas with noticeable mold odors.
- Look for signs of excess moisture or water damage. Look for water leaks, standing water, water stains, condensation problems. For example, do you see any watermarks or discoloration on walls, ceilings, carpet, woodwork or other building materials?
- Search behind and underneath materials (carpet and pad, wallpaper, vinyl flooring, sink cabinets), furniture, or stored items (especially things placed near outside walls or on cold floors). Sometimes destructive techniques may be needed to inspect and clean enclosed spaces where mold and moisture are hidden; for example, opening up a wall cavity.

Should I test for mold?
The Minnesota Department of Health does **not** recommend testing for mold. Instead, you should simply assume there is a problem whenever you see mold or smell mold odors. Testing should never take the place of visual inspection and it should never use up resources that are needed to correct moisture problems and remove all visible growth.

Sometimes, mold growth is hidden and difficult to locate. In such cases, a combination of air (outdoor and indoor air samples) and bulk (material) samples may help determine the extent of contamination and where cleaning is needed. However, mold testing is rarely useful for trying to answer questions about health concerns.

MOLD CLEAN UP AND REMOVAL

To clean up and remove indoor mold growth, follow steps 1-6 as they apply to your home.

1) Identify and Fix the Moisture Problem - the most important step in solving a mold problem is to identify and correct the moisture source(s) that allowed the growth in the first place. Common indoor moisture sources include:
- Flooding
- Condensation (caused by indoor humidity that is too high or surfaces that are too cold)
- Movement through basement walls and slab
- Roof leaks
- Plumbing leaks
- Overflow from tubs, sinks, or toilets
- Firewood stored indoors
- Humidifier use
- Inadequate venting of kitchen and bath humidity
- Improper venting of combustion appliances
- Failure to vent clothes dryer exhaust outdoors (including electric dryers)
- Line drying laundry indoors
- House plants - watering them can generate large amounts of moisture

To keep indoor surfaces as dry as possible, try to maintain the home's relative humidity between 20-40 percent in the Winter and less than 60 percent the rest of the year. You can purchase devices to measure relative humidity at some home supply stores. Ventilation, air circulation near cold surfaces, dehumidification, and efforts to minimize the production of moisture in the home are all very important in controlling high humidity that frequently causes mold growth in our cold climate.

2) Begin Drying All Wet Materials - as soon as possible, begin drying any materials that are wet. For severe moisture problems, use fans and dehumidifiers and move wet items away from walls and off floors. Check with equipment rental companies or restoration firms to see if you can rent fans and dehumidifiers.

3) Remove and Dispose of Mold Contaminated Materials - items which have absorbed moisture (porous materials) and which have mold growing on them need to be removed, bagged and thrown out. Such materials may include sheet rock, insulation, plaster, carpet/carpet pad, ceiling tiles, wood products (other than solid wood), and paper products. Likewise, any such porous materials that have contacted sewage should also be bagged and thrown away. Non-porous materials with surface mold growth may be saved if they are cleaned well and kept dry (see step 4).

Take Steps to Protect Yourself - the amount of mold particles in air can increase greatly when mold is disturbed. Consider using protective equipment when handling or working around mold contaminated materials. The following equipment can help minimize exposure to mold:

- Rubber gloves
- Eye goggles
- Outer clothing (long sleeves and long pants) that can be easily removed in the work area and laundered or discarded
- Medium-efficiency or high-efficiency filter dust mask (these can be found at safety equipment suppliers, hardware stores, or some other large stores that sell home repair supplies) -- at a minimum, use an N-95 or equivalent dust mask

Take Steps to Protect Others - plan and perform all work to minimize the amount of dust generated. The following actions can help minimize the spread of mold spores:

- Enclose all moldy materials in plastic (bags or sheets) before carrying through the home
- Hang plastic sheeting to separate the work area from the rest of the home
- Remove outer layer of work clothing in the work area and wash separately or bag
- Damp clean the entire work area to pick up settled contaminants in dust

4) Clean Surfaces - surface mold growing on non-porous materials such as hard plastic, concrete, glass, metal, and solid wood can usually be cleaned. Cleaning must remove and capture the mold contamination, because dead spores and mold particles still cause health problems if they are left in place.

- Thoroughly scrub all contaminated surfaces using a stiff brush, hot water and a non-ammonia soap/ detergent or commercial cleaner
- Collect excess cleaning liquid with a wet/dry vacuum, mop or sponge
- Rinse area with clean water and collect excess rinse water

5) Disinfect Surfaces (if desired) - after cleaning has removed all visible mold and other soiling from contaminated surfaces, a disinfectant may be used to kill mold missed by the cleaning. In the case of sewage contamination, disinfection must be performed -- contact the Minnesota Department of Health for appropriate advice.

- Mix 1/4 to 1/2 cup bleach per gallon of water and apply to surfaces where mold growth was visible before cleaning. The solution can be applied with a spray bottle, garden sprayer, it can be sponged on, or applied by other methods.

- Collect any run-off of bleach solution with a wet/ dry vacuum, sponge or mop. However, do not rinse or wipe the bleach solution off the areas being treated -- allow it to dry on the surface.

Always handle bleach with caution. **Never mix bleach with ammonia** -- toxic chlorine gas may result. Bleach can irritate the eyes, nose, throat, and skin. Provide fresh air (for example, open a window or door). Protect skin and eyes from contact with bleach. Test solution on a small area before treatment, since bleach is very corrosive and may damage some materials.

6) Remain on MOLD ALERT - Continue looking for signs of moisture problems or return of mold growth. Be particularly alert to moisture in areas of past growth. If mold returns, repeat cleaning steps and consider using a stronger solution to disinfect the area again. Regrowth may signal that the material should be removed or that moisture is not yet controlled.

When can we rebuild?
Rebuilding and refurnishing must wait until all affected materials have dried completely. Be patient – it takes time to dry out wet building materials. A moisture meter may help measure drying progress. Contact your county Minnesota Extension Service office to see if they loan moisture meters.

Can ozone air cleaners remove indoor mold?
Some air cleaners are designed to produce ozone which is a strong oxidizing agent and a **known irritant of the lungs and respiratory system.** Studies have shown that ozone, even at high concentrations, is not effective at killing airborne mold or surface mold contamination. Even if mold was killed by ozone, the health threats would not be reduced until mold contaminants are removed through cleaning. Health experts, including the Minnesota Department of Health, do **not** recommend the use of ozone to address mold or any other indoor air problems.

Questions ?
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ENERINFO ADVISOR

February 2000

Key Points

- *Bathroom fans and range hoods can provide adequate ventilation in many older homes.*
- *Fans must be properly sized and ducted.*
- *Ventilation won't always solve mould and mildew problems. Other measures may also be necessary.*
- *Dehumidifiers help control basement moisture problems in summer.*

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Ventilation for Older Homes

Introduction

Many older homes suffer from condensation and mould growth. If serious moisture problems are ignored, permanent damage to a home's windows, interior finishes and structure can occur. Prolonged exposure to some moulds may also cause health problems.

This fact sheet examines common moisture problems and suggests possible solutions, including some simple, inexpensive, do-it-yourself projects. Low to moderate cost ventilation options for typical older homes are also discussed.

What causes moisture problems?

Condensation occurs when humid air is cooled below its "dew point." Mould growth usually occurs on any surface that remains wet or damp for a prolonged period of time. The two factors that determine whether condensation will or won't occur are the "relative humidity" of the air and temperature of the various cold surfaces (particularly windows) in the home.

Can you explain relative humidity?

The amount of water vapour air can hold depends on its temperature. For example, air at room temperature can hold over ten times more water vapour than air at –5° Celsius.

Relative humidity tells us how "wet" or "dry" the air is. As air is warmed, it expands and its relative humidity decreases, because warmer air can hold more moisture. Conversely, as air is cooled, it shrinks and its relative humidity increases. Condensation occurs when relative humidity reaches 100 per cent.

To reduce the relative humidity of the air in your home, you can:

1) increase air temperature (turn up the heat)
2) reduce the amount of moisture in the air by:
   - eliminating moisture sources (storing firewood outside, etc.)
   - diluting it with air that is drier (ventilation during the heating season)
   - removing moisture from the air (dehumidification)

Why does surface temperature matter?

Cool surfaces reduce the temperature of nearby air. If air is cooled enough that its humidity reaches 100 per cent, condensation occurs and problems begin. Condensation typically first starts on windows because they are the coldest surfaces in most homes. If indoor humidity continues to rise, condensation and mould growth may also occur on other cooler surfaces, such as outside corners, behind furniture, or in closets with outside walls.

Do I need more ventilation in my house?

It depends on your home and your habits. Every building can tolerate some moisture before problems begin to occur. And each household's cooking, bathing, and living habits are different. But if window condensation or mould growth occur frequently, it is time to take action. The "Assessing Your Home's Moisture Problem" sidebar provides suggestions on how to solve common moisture problems.

Removeable filter and grille for in-line fan or exhaust vent. Suitable for kitchen and bathrooms.

Does my existing exhaust fan work?

Check air flow at the exhaust hood by holding a garbage bag over the exhaust hood and timing how long it takes to inflate the bag. If it takes more than a few seconds, the fan system needs to be upgraded and/or replaced with a more powerful unit, or the ductwork needs to be improved.

Should I buy a heat recovery ventilator?

Heat recovery ventilators (HRV) are designed for, and work best in, a new home that is air tight. In this type of home, virtually all fresh air is distributed by the HRV.

In an older, leakier home, air continues to enter the home through cracks and holes, so the heat recovery and fresh air distribution advantages of an HRV are, for the most part, lost. It can also be expensive and difficult to properly install a fresh air distribution duct system in a finished house. A less elaborate and expensive central exhaust system can provide enough extra ventilation to control humidity in most older houses.

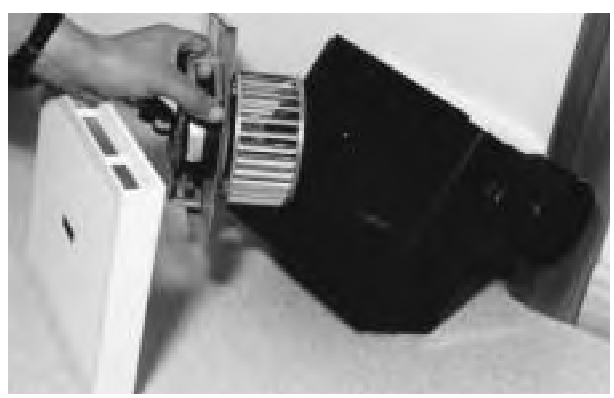
How about opening windows?

Windows are just as likely to allow outside air into the house as let inside air out—and incoming air tends to push the moist air into the rest of the home. On calm days, air may not move at all. Worse still, hardly anyone will leave windows open on cool days, when you may need ventilation the most. Fans, on the other hand, positively remove air from the building.

So what are my options?

Bathroom fans

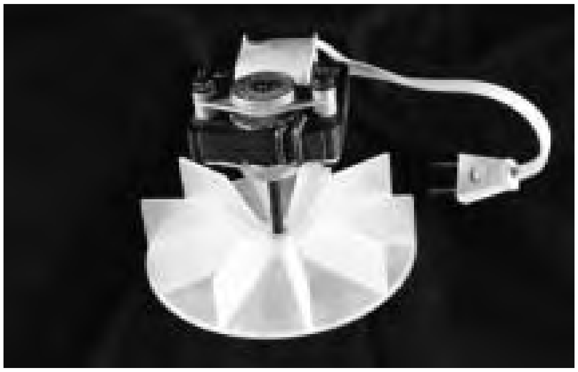
Good-quality bathroom fans can solve minor bathroom moisture problems ... if they are properly sized and installed. Look for a fan with a rated capacity of at least 100 cubic feet per minute (cfm), a minimum 4-inch (10 cm) outlet and a "squirrel cage" type blower. The



Typical higher capacity design. Note blower wheel and four inch outlet for duct. Minimum recommended.

cost of this type of fan starts at about $65. Don't buy a fan with a sone rating above four. More expensive fan units tend to be quieter (a sone rating of two or less) and better constructed. The 1995 National Building Code requires that all fans in a new house must have a sone rating of two or less.

Low-cost, low-capacity (50 to 60 cfm) bathroom fans aren't a bargain at any price. They don't exhaust air effectively, are noisy, and won't stand up to frequent use.



Typical low capacity, propeller-type design with blades. **Not recommended.**

Range Hoods

Range hoods vented to the exterior are an effective way to exhaust odours and moisture from cooking, particularly if grease or fat is present. But range hoods can't meet all of a home's ventilation requirements. The capacity, quality, and noise levels of range hoods vary greatly. Downdraft range hoods can have exhaust capacities as high as 600 cfm and may be powerful enough to pull flue gases from the furnace or wood stove into the home.

Blower-style fans are quiet and effective.

Central exhaust fans

These systems are ideal for many older houses that aren't particularly air tight but still need some extra ventilation. Most central exhaust systems have enough capacity to exhaust from several areas of the house, so they can replace several smaller exhaust units, which can help to justify their higher cost ($250–$350 plus installation). Quality central exhaust systems are quiet and suitable for continuous operation.

Assessing Yo

What should I do first?

Start by checking your home for ways to reduce moisture levels through source control. It is always better to control moisture at its source than to depend on ventilation to remove moisture that could have been prevented in the first place. After all, it costs money to install and operate a fan.

Six suggestions for reducing an older home's moisture levels are:

1) Dry and store firewood under cover outdoors.
2) Cover any exposed earth in crawlspaces or basements with heavy polyethylene to stop evaporation into the house. This is extremely important!
3) Fix basement leaks and make sure downspouts direct water away from the foundation.
4) Vent clothes dryers outdoors.
5) Operate existing fans more often.
6) Avoid drying clothes indoors.

What is the next step?

If moisture problems continue, the next step is to thoroughly examine your house to determine where and when problems are occurring. Common problems are discussed below. Possible solutions are listed from least expensive to most.

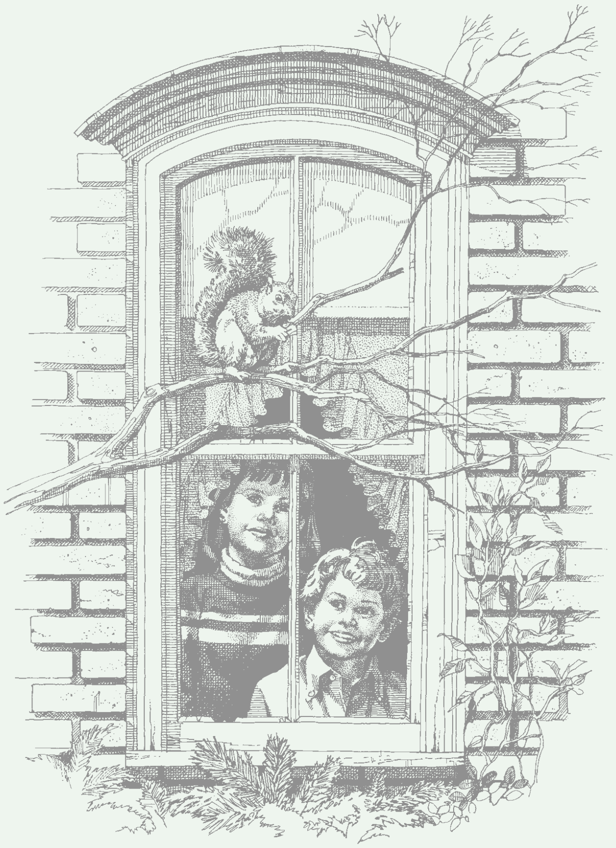
1) Problems are not widespread, and occur only in (or near) "wet" areas such as bathrooms or kitchens.

Likely cause: Moisture generated by cooking or showering isn't removed fast enough.

Possible solutions:

- Reduce moisture generation when possible. Use lids on pots, shorter showers, etc.
- Improve existing ventilation. Increase air flow by operating your existing fan longer, upgrading ducting, or replacing the fan with a more powerful unit.
- Add more ventilation. Install quality bathroom, kitchen, or central exhaust fans as appropriate.

ur Home's Moisture Problems



2) Problems are concentrated in the coldest room(s) in the house such as an unused bedroom.

Likely cause: Room is too cold. Lower temperatures increase relative humidity and reduce exterior wall and window surface temperatures. Both make condensation more likely.

Possible solutions: Add heat by

- turning up the thermostat
- opening air dampers and registers
- removing any blockages over heaters
- opening or undercutting doors to increase circulation
- increasing heat distribution system capacity to affected areas

3) Mould formation limited to a few defined areas

Likely cause: Missing insulation or large air leaks have cooled surfaces enough to cause condensation.

Possible solutions:

- If problems are found, air seal or insulate as required.

4) Your basement is damp or musty during warmer weather

Likely cause: The ground cools below-grade concrete walls and floors enough that they become the coldest surface in the building in the summer.

Possible solutions:

- *Best:* Insulate walls and floors to raise concrete temperatures (exterior insulation) or to keep humid indoor air from reaching the cold concrete (interior insulation and an air barrier).
- *Most practical in older home:* Close windows and doors to avoid bringing in more moisture-laden air, then use a dehumidifier to control basement humidity levels.

5) Window condensation on only a few windows

Likely cause: Problem windows are cooler than rest of windows in the house.

Possible solutions:

- Leave tight-fitting drapes open during cold weather to keep windows warmer.
- Weatherstrip and air seal windows and frames.
- Add a permanent or temporary storm window.
- Insure window isn't isolated from heating source.
- Replace window with an energy efficient window.

6) Widespread window condensation throughout home and some mould growth on drywall

Likely cause: Humidity levels are too high.

Possible solutions:

- Install additional ventilation. Choose quality equipment that is quiet and capable of continuous operation.

Installing a bathroom fan

To exhaust enough air to keep moisture from damaging your bathroom, you need a quality bathroom fan and a good installation. Scrimping on either the fan or exhaust ductwork usually results in an exhaust system that doesn't do the job. That's no bargain at any price.

Here are a few tips.

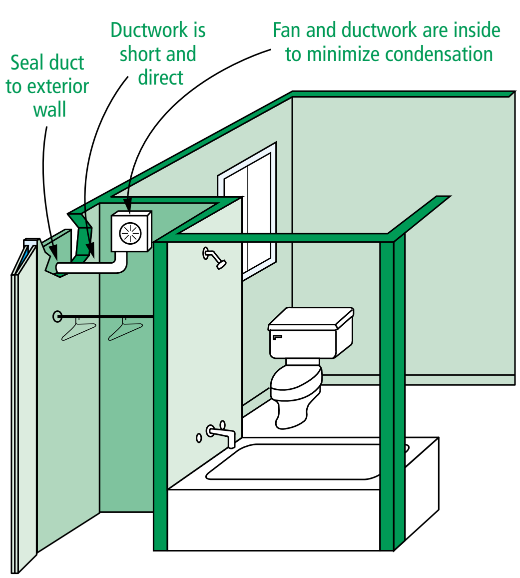
Where should I put the fan?

Most bathroom fans are mounted in the ceiling and vented out a gable end wall. In retrofit applications or when the attic isn't accessible, it may be easier to install the fan in the top of a storage cabinet or adjoining closet and run the exhaust duct out the wall below ceiling level. This also keeps the exhaust duct short and warm.

Where should the exhaust hood be?

Exhaust hoods work best when located on a wall. Terminating a duct into the roof overhang is not recommended, since incoming attic ventilation air may carry the moist bathroom air back into the attic, and the back draft damper won't work when hanging upside down. Roof-mounted vents add an unnecessary hole to your roof and if duct condensation occurs, it can drip into the bathroom through the fan.

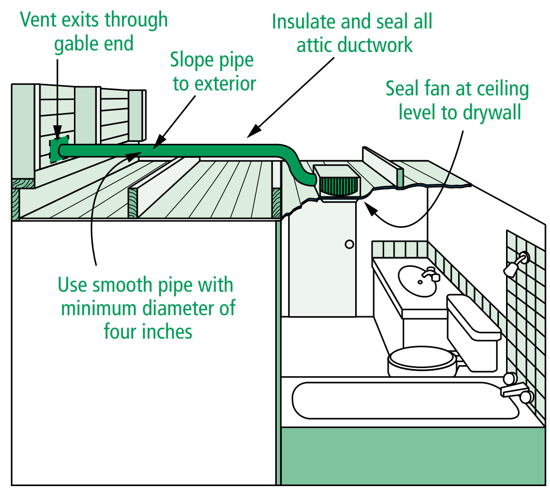
Bathroom Fan Installation Using Adjacent Storage Space



What about ductwork?

Ducts should be at least 4" (10 cm) in diameter (or no smaller than the fan's outlet if it is greater than four inches) and be as short, smooth, and straight as possible. Ducts in cold spaces should be sloped to the outside and must be sealed and insulated to prevent condensation and moisture damage to the attic. Flexible plastic dryer hose should not be used, because the duct's rough surface will restrict the fan's air flow.

Typical Ceiling Installation



Any control suggestions?

Wind-up timers (available for about $20) are useful because wet towels, shower enclosures, etc. continue to produce moisture after you leave the bathroom.

Who installs bathroom fans?

Most ventilation contractors and some carpenters or electricians install bathroom fans, but no trade specializes. Be sure to discuss the points raised in this fact sheet with prospective contractors before deciding who to hire.

Installing a central exhaust fan

Adding a central system to an older house is usually not difficult as long as either the attic is accessible or the basement isn't finished.

Quality in-line fan unit mounted in an attic. Quiet, capable of continuous operation, and has a high capacity.

In an attic installation, choose a fan unit approved for use in cold temperatures and use insulated flex ducts to prevent condensation. Nearly all work can be done in the attic or through closets without disturbing the living areas of your home.

What's the best way to control a central exhaust system?

Wind-up timers are a good choice in bathrooms or other areas with short-term ventilation requirements. If the system is also expected to control indoor humidity levels, consider a humidistat located in a central area or a 24-hour timer to automatically turn on the fan at scheduled intervals.

Attatching insulated duct fan ceiling inlet. Ensure gap around duct is sealed where it penetrates the drywall or vapour barrier. Tape ducting to duct fitting.

How does the fresh air get in?

Most older houses have enough air leakage paths through or around windows, doors, and other building components that the air exhausted by a moderate-size fan can be easily replaced. But air leaks in your home may not be located exactly where you want more fresh air, so exhaust-only systems can cause cold air drafts. Air quality throughout the home may also vary. If more fresh air is needed in a particular area, intentional holes to the outside (small ducts) can be added to bring in fresh air. These ducts must be carefully located to avoid drafts.

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Chapter 10
Retrofit

Key Points to Learn

- Retrofits have to be well planned to be cost-effective and to avoid causing more damage.
- Retrofit can be done from the interior or the exterior
- Common retrofits include upgrading heating systems for more energy efficiency, increasing insulation, replacing low-quality windows, and other improvements.
- It is critically important to solve air leakage problems and to consider each change in relation to the operation of the house as a system.

Introduction to Retrofit

Retrofit is a very complex subject. An in-depth look would require one whole book. This chapter is an overview to guide you in the right direction.

Retrofit is upgrading or repairing a building. True retrofits go deeper than replacing building components and aim to accomplish specific goals. These goals can most often be broken down into performance characteristics, such as health and safety, comfort, energy efficiency, and durability. Most retrofits are a combination of needed repairs and upgrades to the building subsystems that affect building performance.

Repairs often are necessary to safeguard the health of the occupants, and/or durability of the structure. The goal of such projects is to restore the functionality of the current design. This type of construction is not retrofit, and being less systems-comprehensive, may require little in the way of diagnostic tools and planning and may or may not provide a payback in lower operating costs.

Upgrades to the core systems of a structure start with a rigorous in-depth inspection process carried out both visually and with diagnostic equipment that reveals the strengths and weaknesses of the systems that contribute to the building's safety, energy efficiency, and durability. Upgrades to core systems are planned and prioritized to provide better performance and a payback by reducing operating costs and/or increasing appraisal value.

As indicated earlier, all building construction, including retrofits, must be planned and implemented using the building as a system concept. All parts of the building system are interrelated and interdependent; therefore any change in design, materials, mechanical systems, or construction assembly affects the performance of the other related components. Successful retrofit construction in cold climates depends on achieving balance and harmony within the building system.

Training in the building sciences, diagnostic equipment, and building performance modeling software are needed to understand the systemic changes necessary to correct core problems, and their impact on other interrelated subsystems. If you are not a professional and are planning to do your own work, hiring a professional with good references to do the assessment and retrofit design is a good investment. Just make sure the person you work with is an energy specialist with a background in the building sciences in his or her diagnostic field and has the references to prove it. This is especially true when analyzing performance in mechanical systems such as ventilation and heating, or when confronted with moisture problems, which play such a large role in health and safety, operating costs, and building durability.

The upgrades to core systems that constitute retrofit require planning to be successful, and are more expensive and labor-intensive than new construction. Generally, a demolition phase is necessary to remove damaged materials and expose thermal and structural components to prepare these systems to receive new materials and mechanical systems.

Poor construction quality and unforeseen damage is often hidden deep in building subsystems and exposed only during the demolition phase. This can cause substantial unforeseen increases in costs and delays in completing the project. But it is very common.

Retrofit planning requires extensive assessment, diagnostic equipment, flexible timelines and a substantial contingency fund. Have clear, realistic goals in mind for retrofit projects.

Triage

Some buildings are good candidates for retrofits and some are not. Specific information is necessary before planning the retrofit. For example, a conventional home built 30 or more years ago, with evidence of structural degradation, mold or other moisture problems, and a failed foundation may not be a good candidate for a retrofit. Some buildings are simply too substandard and/or degraded to ever give good quality of living for a reasonable investment of time and money. Retrofit is always more difficult and labor intensive than new construction.

On the other hand, an older building with a good foundation, little evidence of moisture damage, very little insulation, and a leaky shell may see a substantial reduction in operating costs from a well-planned retrofit that will provide a rapid payback of your investment, increase building durability, and offer years of increased comfort.

Gathering some basic information about the building is necessary to determine if further investment is justified:

- When was it built?
- Is the foundation in good shape? If not, is it repairable for a reasonable price?
- Is the building near the end of its useful lifespan or is it fairly new?
- Is most of the structure in good, fair, or poor condition?

Remember, retrofit measures need to fit the home, occupants, and climatic region. The building performance modeling software AkWarm provides a good guide for modeling retrofit effectiveness. It is not as good at telling you whether the science is right, if the materials are correct, or whether the measure will solve the problem.

In all cases, most important is do no harm to occupants or dwelling. To make the retrofit work:

- View all retrofits as system changes.
- The building science must work.
- Use appropriate materials and mechanical systems for the region and the number and lifestyle of the occupants.
- Use good construction and quality control.

Figure 10.1: A 30-year-old house in Fairbanks that was a good candidate for retrofit. It has a fine foundation; good, well-maintained exterior; and was tested for air leakage and vapor control. It does need new roofing.

Figure 10.2: Poor candidate for retrofit. This building probably has had ice damage for years and likely has internal damage.

Table 10.1: Here is a basic matrix that shows comparative suitability of homes for major retrofit:

House Selection Matrix	House I	House II	House III	House IV	House V
Has some insulation				✔	✔
Needs new appliances	✔		✔		
Needs new wiring	✔		✔		
Needs new plumbing	✔		✔		
Needs heating system	✔	✔	✔		
Needs new interior finish	✔		✔		
Needs new roof structure	✔				
Needs new roofing	✔	✔			
Needs new siding	✔	✔		✔	
Needs new foundation	✔				

source: ACHP Retrofit Student Manual

HOUSE I: Good candidate for demolition; total cost of project is prohibitive

HOUSE II: Good candidate for exterior retrofit

HOUSE III: Good candidate for interior retrofit

HOUSE IV: Marginal candidate for exterior retrofit

Assessments

If it is advisable to proceed, the planning phase of a retrofit project begins with a comprehensive inspection of the building proposed for the upgrade. This inspection is called the assessment. You must have comprehensive and accurate information to base your retrofit plan on.

The assessment is used to determine:

- How the building is currently performing to give you a baseline for the improvements
- How the building is constructed
- What building systems need repairs or upgrades
- How those repairs and/or upgrades will affect the performance of other building components
- What specifically those repairs and/or upgrades will be
- Specifically how much, and exactly what, materials need to be purchased and installed to correct the building performance problems
- How much and what damaged and undamaged materials need to be removed to gain access to the subsystems selected for upgrades in order to install the materials
- How the materials will be installed
- How long the retrofit project selected will take
- What tools you need
- How many people it will take to install the material properly
- What the project will cost in terms of materials and labor
- Specifically how the proposed project will improve the building's performance and how much it will save in operating costs

It should now be apparent that the quality of the assessment will determine the success of the project. The more in-depth and intrusive the assessment inspection, the better the diagnostic equipment, and the more well trained and conscientious the inspector, the better chance you have of having a realistic scope of work for your project.

There are several forms and checklists available commercially to help avoid omissions in the assessment process and make it easier to understand and more or less comprehensive.

One of these tools is the House Assessment Procedures Package, or HAPP. These are a mix of checklists and troubleshooting guides useful in the field as checklists, and as retrofit design and diagnostic tools. The HAPP Package is available from Energy Mines and Resources Canada. It has been reproduced in the 1992 edition of the ACHP Retrofit Manual.

Checklist

Here is a generic checklist to start the assessment process that provides a guide to action, in case other guidelines are not available:

Be sure to write down everything you know that needs to be checked, as well as every bit of information you find out about the building in as much detail as possible.

In general, every bit of information about the building in question that affects or is affected by heat, air, or moisture is an area of concern to retrofitters.

Foundation failures and moisture problems driven by air leakage and weather intrusion are common causes of failing building systems in Alaska.

Common problem areas include:

- Differential settlement in the foundation, causing leaks in the thermal envelope and/or structural failure.
- Water staining or rot at rim joists, indicating lack of vapor retarder and/or insulation or back-splash problem

- Water staining at soffit or gable vent, indicating moisture problem in the attic (Figure 10.6).
- Insulation in the attic contacting both attic floor and roof.
- Water staining or mold at the attic access, indicating an air leak and/or no insulation.
- Water staining on floor bottom cap on exposed floor systems.
- Wet insulation at rim joist or foundation pony wall.
- Water staining, rot, or mold at window and door openings.
- Evidence of leaks at plumbing walls, sinks, showers, tubs, and toilets.
- Cracks and air leakage at additions and at plumbing wall penetrations.
- High or low indoor relative humidity.
- Mold or condensation behind furniture, in corners, and at top and bottom plates (Figure 10.3).
- High stack temperatures of boilers and furnaces
- Evidence of soot tracking at inspection plates and barometric dampers on boilers or furnaces
- Heater output that does not match building conductive and convective heat loss.
- Poor heat distribution
- Leaky heat distribution ducting

No matter how careful you are, you will find you have omitted some critical detail or observation. The trick is to check and recheck your data, conclusions, physical makeup of the building, square footages, etc., and catch your errors and omissions before ordering the materials and commencing work.

Diagnostic equipment is necessary to accurately gather information during the building inspection. For example, blower doors (Figure 10.7), thermo hygrometers, digital monometers, and moisture meters are essential to determine indoor air quality, air tightness, back drafting potential, measure pressure imbalances, and moisture content of building materials. A more complete list of tools is included later in this chapter.

A good method of assessment is to do the physical inspection of the building starting from the ground or bottom up, outside to inside. Use the same methodology for each building type each time. Rate each of the critical areas as good, needs work, or needs replacement, with pertinent notes.

Note the square footage of each assembly, the materials it is made of, how they are fastened, and the sequence of construction. Then take pictures. Use tags in the photos, so later you will know what you are looking at. If pertinent, use a yardstick or other measuring device in the photo for scale or quantity.

Review all of your notes before leaving the job site. This is your first and best chance to correct omissions while the building is fresh in your mind.

Even if the majority of the building subsystems are not considered for retrofit, knowledge of their function and performance is necessary to the systems approach. All building systems are interrelated and interdependent. The more information you can gather about the building the better chance of a successful project.

Case Study: Poor Retrofit Planning

Sadly, many retrofits have left buildings in far worse shape than before. In addition, the retrofit may have created health and safety issues where none existed before. Several years ago, an investigation into water damage in a subdivision in one of the hub cities in Alaska was contracted to a building science consulting firm. Out of the 34 homes investigated, 33 had been recently retrofitted under a government program.

Problems began in the 33 homes that were retrofitted when 12 to 14 inches of

Figure 10.3: Mold on interior walls on an outside corner of the house

Figure 10.4: Opening up this wall reveals a poorly detailed vapor retarder but good dry studs and insulation.

Figure 10.5: Sometimes in Alaska, the building is simply not finished. This 4-mil polyethylene film was all the ceiling there was in this utility room. This and a bathroom fan vented directly into the attic allowed an extreme buildup of frost in the attic.

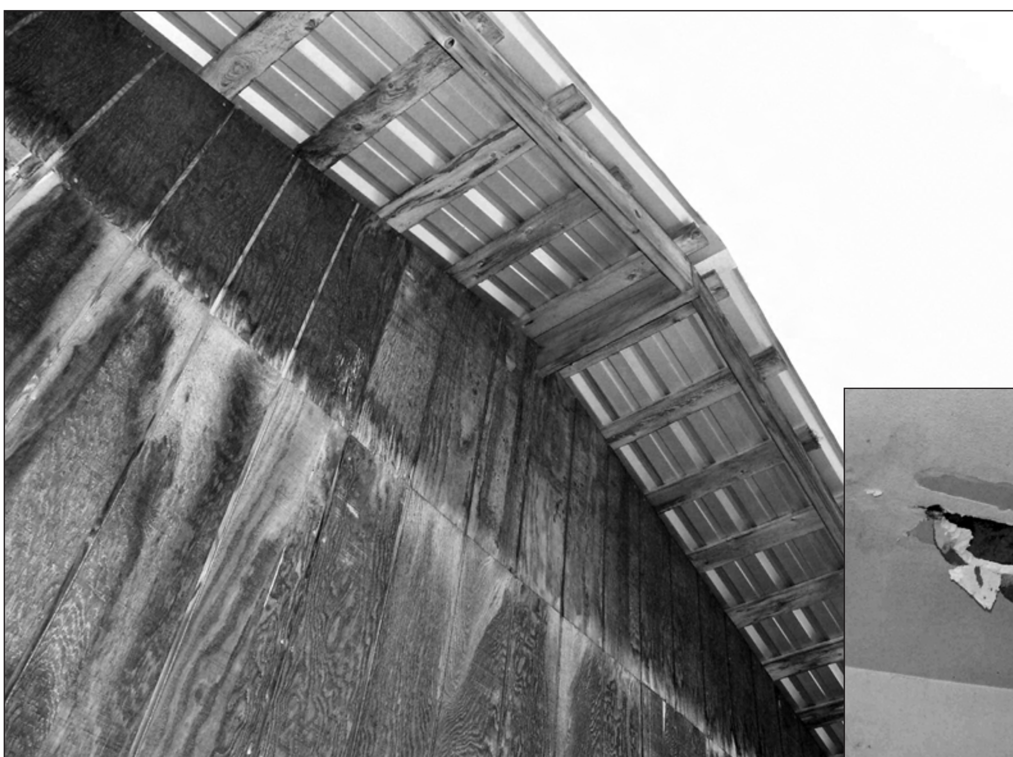

Figure 10.6: These streaks of lighter color are water stains from melting attic condensation and frost.

Inset: Ceiling damage from condensation buildup in the attic melting.

loose-fill cellulose was blown into the attic spaces over the top of six inches of fiberglass batts.

When the consulting firm performed the inspections, it was winter. All attic spaces in the retrofitted homes were cold; fiberglass batts were frozen solid to the ceiling and truss bottom chords. The whole attic space was covered in a thick layer of frost, including the roof sheathing, trusses, gable end vents, and protruding fasteners. Ceilings and floors inside the homes were water stained, water damaged, and growing mold.

These homes had suffered substantial degradation in the two years since the conclusion of the retrofit project and were rapidly becoming uninhabitable. The attic space in one house, however, had not been touched. It was very hot up there. There was no water damage to any of the building systems in number 34, no rot, and no mold. What happened?

Figure 10.7: Using a blower door to measure air leakage.

When the retrofitters increased the R-value in the attic space, they failed to take into account how that change decreased attic temperature. (Remember, all building subsystems are interrelated and interdependent: any change in performance in one system affects the performance of other related systems.)

Before the retrofit, much heat was transferred to the attic by conduction due to the low R-value of the ceiling insulation and poor fitting of those degraded fiberglass batts. This heat loss made the attic a warm space. Warm, moisture-laden air exfiltrating into the attic through the leaky ceiling air-vapor retarder never reached the dew point temperature before exiting the attic through the gable end vents and other leakage sites, therefore there was no liquid moisture to cause damage.

Adding insulation to the attic brought the temperature in that space below the dew point temperature for much of the heating season, without significantly reducing the air leakage. The low attic temperature caused the water vapor to condense to liquid before it had a chance to exit the building through the gable vents, saturating the attic space, creating an ideal environment for molds, mildew and bacteria. The accumulation of water weight in the ceiling system was also the cause of impending structural failure. The responsible parties failed to think their project through, and so ruined the homes they tried to help.

Understanding how the proposed changes will affect the rest of the building system is critical to the success of any retrofit. The house as a system matrix in the next section can help you understand these interactions.

House as a System Matrix

The house as a system matrix is a tool to visualize how proposed changes to one part of the house may affect how the system as a whole operates. For an example of how to use the chart, look at proposed air sealing. Air sealing minimizes convective Heat loss. Now consider the effects of air sealing on the envelope, mechanical systems and occupants.

Whatever methodology you use for building assessment:

- Make up or obtain a good checklist that suits your goals and skill level to document existing conditions in the home to be retrofitted.
- If this is your house, start by writing down what you know of existing problems. Check this information against a physical inspection. If this is not your house, start with an inspection of the exterior, then a client interview.
- Inspect all subsystems that make up the building thermal envelope from the outside and the inside to check for evidence of moisture damage and water staining that signal that the weather barrier, vapor retarder, or other components of the thermal envelope may be damaged.
- Inspect all mechanical systems for capacity and evidence of performance problems.
- Look at building performance from a system perspective to pinpoint deficiencies in core systems and determine the scope of work for retrofit projects. For example, even if a leaky home's air-tightness is greatly improved by air-sealing, perhaps no substantial operating savings will result until a smaller or more efficient heating system is installed.
- The same air-sealing that results in lower heat loss and a substantial savings in operating costs may cause moisture problems and poor indoor air quality if mechanical ventilation is not added to control air exchange quantity and quality.

Remember, if you are not visually inspecting and using diagnostic tools for testing, you are guessing. Guessing is not good enough to stake your health and money on.

There are a number of good diagnostic tools available to help you determine what is going on beneath the surface of these subsystems. Use diagnostic equipment as necessary to look deep into the system. Diagnostic tools used in retrofit include infrared cameras, moisture meters, velocity and infiltration meters, fiber optic visual inspection tools, blower doors, duct blasters, combustion efficiency and safety testing equipment, as well as various building diagnostic or performance modeling computer software. Most of these tools are prohibitively expensive for amateur retrofitters and some require extensive training to operate and analyze the data. However, these tools can reveal short-circuiting of insulation from poorly fitted batts, low-density insulation settling, and voids in thermal blankets. A blower door can detect air leaks through the thermal envelope and pressure imbalances that drive moisture and heat loss.

The better your diagnostic equipment, the less intrusive this detection process needs to be. Where you need to be intrusive to look for water damage, construction quality, evidence of prior retrofits, etc., look for places to hide the holes you will need to make. Go to closets to make holes in ceilings and look behind outlet and switch covers and in crawl spaces. You can also remove or enlarge gable end vents to get into the attic.

Where working around electrical wiring, use nonconductive instruments and probes. When cutting holes or drilling into walls and ceilings, barely cut through the surface materials and then probe and inspect for wiring. Remember: safety first.

Remember:

- No home is worth retrofitting unless the foundation is in good shape or it is cost effective to repair or replace it.
- Structural damage must not be covered up with the installation of new materials.
- No new materials should be added to or placed over wet or rotten materials. Systems must be dry, rot free, and moisture problems must be permanently solved, at least conceptually, before installing new materials.
- All repairs and upgrades must be made as system repairs or upgrades and not as stand-alone measures.

	HEAT Conduction Convection Radiation	**AIR** Stack Wind Chimneys Fans	**MOISTURE** Air Leakage Vapor Pressure Gravity Capillary Action
ENVELOPE Walls, ceilings, windows, doors, floors			
MECHANICAL SYSTEMS Appliances used for heating, cooling, ventilation, humidification			
OCCUPANTS			

Figure 10.8: The house as a system matrix

Retrofit Goals

All retrofits have one or more common goals. In general, these are to

- restore harmony and balance to the building system,
- safeguard occupant health,
- lower operating and maintenance costs,
- increase the value of the home,
- increase comfort, and
- increase the lifespan of the home.

Retrofit Design Basics: Guide to Performance

Remember, the key to attaining good building performance in cold climates is to use good cold climate design and construction techniques. This is true for new construction and retrofits alike. In general, cold climate designs need:

- High levels of insulation: use BEES to determine minimum levels, computer modeling software (AkWarm) to determine optimum payback
- Airtight construction
- Controlled mechanical ventilation
- Appropriate materials, durable and efficient mechanical systems
- Attention to solar design

"Must Do" List

A stable foundation system: Racking and twisting of the building due to differential settlement or other foundation failures causes excessive heat-loss and moisture damage as well as structural failure. The building floor system must not have excessive movement or retrofit measures will be in vain.

The vapor retarder, insulation, and outside weather barrier must all be in contact or adjacent to each other. They must all be continuous with no breaks or voids, and they must **completely enclose the conditioned space of the building**. This is very important! Not following this rule is the root cause of many poorly performing buildings.

Insulation must be installed according to the manufacturer's instructions. Low-density insulations must be installed dry and remain dry.

If not building PERSIST method, all exterior stud cavities must be completely full of insulation with no voids. Voids allow thermal bridging, short-circuiting of the insulation, convection looping, and stimulate overall airflow.

Remove any existing moisture problems and prevent future ones.

Exterior retrofit design must provide a drainage plane in the wall and roof assemblies on the outside of the structural sheathing to redirect liquid water penetrating the weather barrier and cladding back out of the system (placement depends on the design).

Provide a drying space between the cladding and the sheathing to prevent trapping moisture in the walls or roof.

Use other water management strategies as appropriate, such as an air-weather barrier, flashings, overhangs, rain gutters and down spouts, perk pipe, and proper grading of surrounding terrain. The goal is a comprehensive strategy to keep the structural part of the building dry and allow it to dry if it becomes wet.

Ensure good indoor air quality by air-sealing homes as close as possible to .5 air changes per hour at 50 Pascals so air is supplied primarily by the ventilation system. Also, retrofit assemblies must be airtight before installing more insulation to prevent moisture damage from condensation through uncontrolled air movement.

Install a ventilation system. A whole-house, pressure-balanced ventilation system with a supply and exhaust is the preferred method for cold climates. Ducted heat recovery ventilation is the most cost-effective system currently available.

Retrofit Techniques: Interior or Exterior

All retrofit goals are attained by working on the inside of the building (interior retrofit), or by working from the outside (exterior retrofit). These are the two main categories of retrofit. Some retrofit projects combine both strategies.

After determining that the home is suitable for retrofit, the first question that needs to be answered in the assessment process: Is this home more suitable for an interior or exterior retrofit?

Major retrofits require adding framing, continuous vapor retarders, insulation, and finish or weather-proof surfaces. Destroying, demolishing, or replacing functional systems can drive the cost of retrofits up to where a payback for the conservation measure is reduced or nonexistent. Therefore, look first to do major retrofit work where finish or weather surfaces are nearing the end of their useful life spans and renovation is needed anyway.

For example, if the siding is new but the home interior needs remodeling, an interior retrofit is recommended. If the home has a nice interior, the siding is in poor shape, and the floor system is accessible from underneath, an exterior retrofit is indicated.

There are other considerations: is the home occupied, how many hours per day, by how many people? Do they have anywhere to go while you are working, or will you have to work around them? Are there special architectural features of the building that need to be preserved? What obstructions exist on the inside to make installing a continuous vapor retarder and adding insulation a problem? (For example, partition walls, chases, and cabinets.) What obstructions exist on the outside to have to work around? (Arctic entries, electrical stub in, doors, windows, other utilities.)

Generally speaking,

- It is more labor intensive and difficult to do a comprehensive retrofit from the inside of the building because there are more obstructions to work around, limited space to work, possibility of breakage, and a higher standard of work space cleanup.
- The biggest problem in doing an exterior retrofit is the weather. Retrofit materials need be kept clean, dry, and above 32° F. Rigging temporary shelters over retrofit materials and workspace for the duration of an exterior retrofit is often necessary.

Following in the interior and exterior retrofit sections are a few typical retrofit techniques.

Interior Retrofit

Here are some typical interior retrofit techniques. Start by assessing the problems to implementing the scope of work decided on.

- Does electrical penetrate the vapor retarder?
- Are penetrations a problem: air leakage, moisture damage?
- What is the condition of interior cabinets and finish?
- How many partition and other interior walls are there?
- Plumbing and vent chases
- Insulation levels in floor, ceiling, and walls
- How do the existing insulation levels and cavity sizes help determine the best method of achieving the selected energy target?
- How many hours per day of occupancy, and how many occupants
- What about furniture and other personal belongings?
- What time of year is it and what is the weather?

The advantages of an interior retrofit are that work is out of the wind, rain, and dirt and it can be temperature controlled. It is easy to keep materials clean and dry. The drawbacks are that space is limited, air-sealing work is usually more difficult, and it is often necessary to work around personal belongings and occupants with the possibility of breakage of personal and household items. Preventive measures to limit dust, debris, and poor air quality as well as cleanup standards are more rigorous when working inside an occupied home.

Here is a look at some interior retrofit techniques to achieve common retrofit goals.

Air Sealing

Air sealing in retrofit is done for specific reasons:

- to prevent moisture migration through air transport
- to increase winter comfort levels
- to increase energy efficiency
- to control pressure imbalances
- to enhance air quality by increasing ventilation system effectiveness
- to keep interior condensing surfaces above the dew point temperature

Achieving air tightness can be a problem with an interior retrofit because interior partition walls, cupboards, chases, and cabinets can create leakage bypasses that are difficult to seal. Air sealing work is done with a blower door before and after, or during, to find leaks and verify that air sealing was effective. The more sophisticated your testing is, the easier to define your scope of work.

Air Sealing Interior Partition Walls

For an example, suppose standard blower door testing reveals that a house is very leaky: > 9 air changes per hour at 50 Pascals (Pa). Air sealing in this house on interior surfaces such as door and window trim, floor wall intersections, ceiling wall intersections and utility penetrations yields marginal results, reducing air leakage only a nominal amount, down to 7 air changes per hour at 50 Pa.

Zone-to-zone air tightness testing reveals several very leaky interior partition walls and that the leaks are mostly to the attic space, with some leakage to the exterior wall, not to the floor system. This is very useful to know when planning to seal those leaks. This is also typical for a platform-framed building

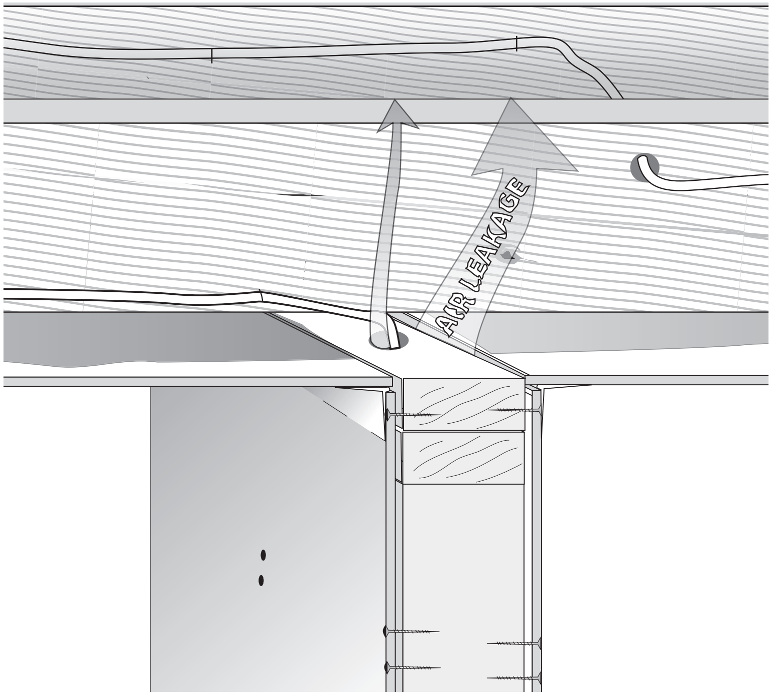

Figure 10.9: Air leakage at the junction between interior partition walls and the attic

with partition walls framed up before the vapor retarder was installed.

In this example, a trip to the attic is the next step. Set the blower door to pressurize the house. This will force warm air into the attic and you can trace it back to the source of the leak while in the attic space. Before moving insulation to find the source of the leak, look for discolored, blackened insulation, a sign of air leakage. Low-density insulations such as fiberglass batts or blow-in fiberglass are not air-sealing materials, rather they act as filters as the air moves through them driven by stack or sucked out of the conditioned space by venturi effect. The dirt in the air is deposited in the fiberglass.

Another tell-tale sign of air leakage is water staining on the framing or the insulation and shrunken or matted batts or blow-in insulation. Remember air leakage is a primary transport mechanism for moisture. Water vapor migrating into spaces or contacting surfaces below the dew point temperature turns to liquid water.

A physical inspection in the attic reveals that the partition walls are fastened to the truss bottom chords with no vapor retarder or wall top plate.

Temporarily pressurizing the house (spot checking) while working in the attic space makes leaks easy to find and seal. If you plan to run the blower door fan for a while to pressurize the building, be sure to turn the whole fan around rather than running it backwards, otherwise the fan will not cool the fan motor well, and the blower door may overheat.

To air seal the top plates of the partition walls, cut plywood or rigid insulation to fit into place at the thermal boundary in the attic space over the top of the walls, seal and secure into place with caulking sealant. Be sure to seal the existing vapor retarder to the patch. To do this, cut the patch big enough to cover the partition wall top and lap over or under the existing vapor retarder. Use acoustical sealant and a compression seal to stop airflow. When using the patch under the vapor retarder, a piece of lathe or strip of plywood is used to create the compression seal of the vapor retarder and sealant between the patch and lathe or strip. For nonexistent or very discontinuous vapor retarders, consider spray-in or roll-in vapor retarders.

To air seal the partition wall exterior wall intersection from the inside of the building, use a sawsall or small circular saw to cut the finish material on the partition wall to the middle of the first stud back from the end stud, on each side of the wall. If the finish is paneling, it is in good shape, and it looks like you can save it, punch the finish nails through the paneling with a small punch and remove the piece of paneling intact. Next, remove the finish pieces and/or sheetrock on either side of the partition wall nearest the exterior wall intersection (Figure 10.10).

With your sawsall, cut the nails securing the end stud to the top and bottom partition wall plates. Using a nail puller, pull the nails securing the end stud of the partition wall to the exterior wall, and remove.

If you had an air leak here to the exterior, the vapor retarder, sheetrock and/or other finish material does not extend behind the partition. Cut the sheetrock or finish material on the exterior wall back at least 1½ inches from either side of the partition wall. Do not cut all the way through the sheetrock, as you do not want to damage the vapor retarder on the exterior wall. Cut to, but not through, the paper backing on the sheetrock. Bend and work the sheetrock pieces you have cut to break the pieces loose with or without the paper backing. If you have fragments of paper backing, bend them towards you, using a razor knife cut the paper backing against the sheetrock edge. Be very careful not to cut the vapor retarder. This is very important. The object of this fix is to make the air-vapor retarder continuous.

Cut a piece of Visqueen (vapor retarder tab) that will extend from cut sheetrock to cut sheetrock between the partition wall and the existing exterior wall. Use vapor retarder tape to seal the vapor retarder tab to the existing vapor retarder at nailers on either side of the partition wall, to the vapor retarder or top plate at the ceiling, and to the exterior wall bottom plate at the floor. Cover with a sheetrock patch; retest the building for air leakage and physically spot check repair. If there is also an air leak to the attic space, air-seal from the attic.

Figure 10.10: Cutting back the sheetrock on an interior partition wall

Air Leakage at Top or Bottom Plates on Exterior Walls

Some buildings with discontinuous air-vapor retarders have leaks at the top and bottom plates of the exterior walls. These leaks can usually be sealed using one-part polyurethane sealant or a low-expansion one-part foam. When using sealant, be sure to tool it into the crack. Remember that spray foams provide insulation and can effectively seal air leaks, but for the most part are not effective vapor retarders. Foam products must be sealed with a sealer or waterproof caulk such as a one-part polyurethane. If you find leakage at top or bottom plates, and the leak is coming from behind baseboard, cove, or crown molding, it is best to remove it, seal and replace.

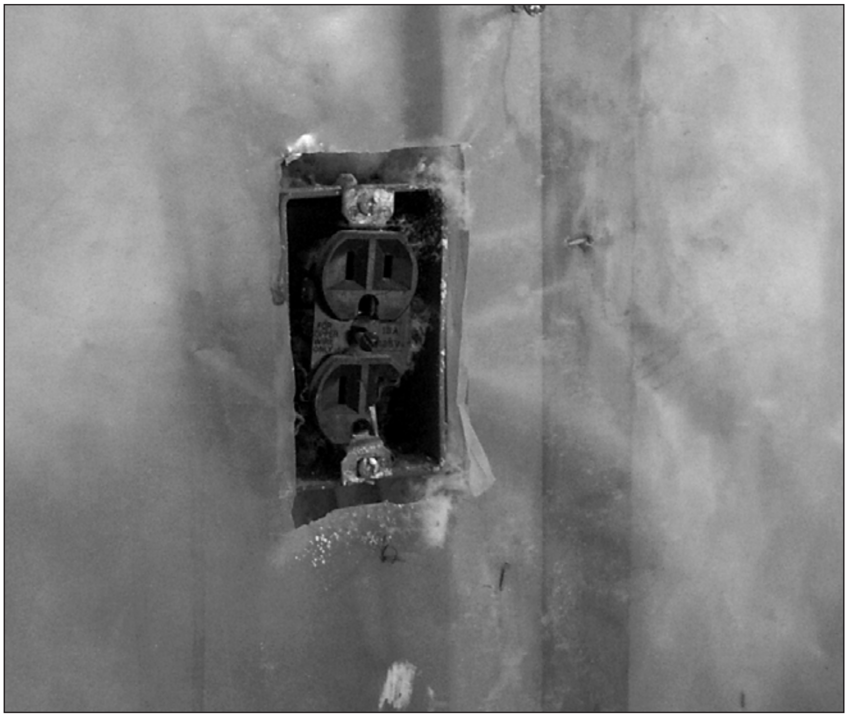

Figure 10.11: A prime site for air leakage around an outlet where the vapor retarder is not sealed.

Air Leakage at Switches and Outlet Covers

If air leakage is detected at switch and outlet covers, it is a sign that the vapor retarder is not sealed at the electrical box penetration. Replace standard switch and outlet covers with gasketed, insulated covers with spring-loaded closure, if major retrofit to replace vapor retarder or increase R-value to the interior is not considered. "Care Covers" are an example of a product that works well in this application. This is an easy way to cut off most of the airflow through those leakage sites, and provide a thermal break.

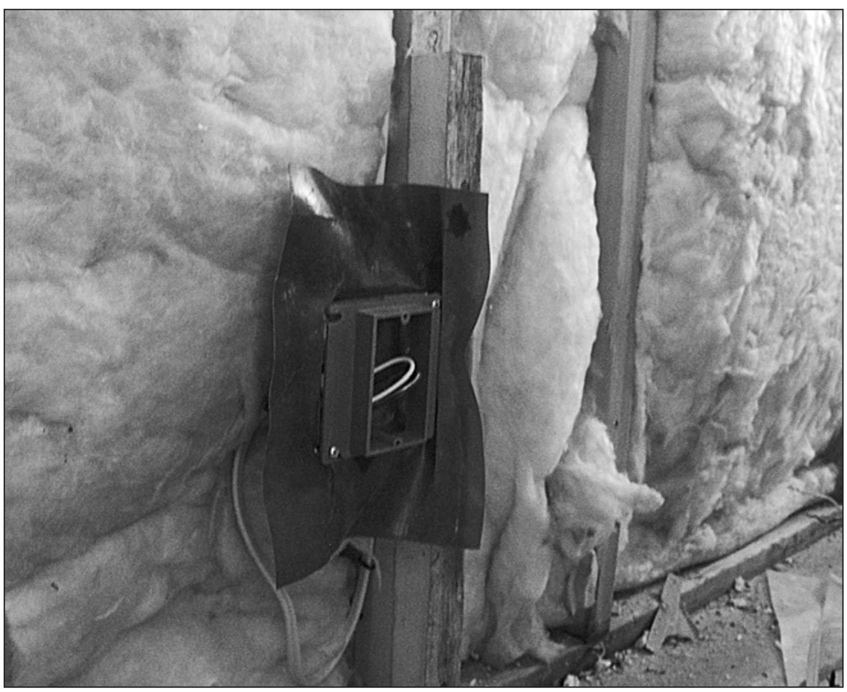

Figure 10.12: A poly pan is used to seal behind an outlet. Foil-backed foam will be installed on the inside of this wall so the outlet is fastened to the furring.

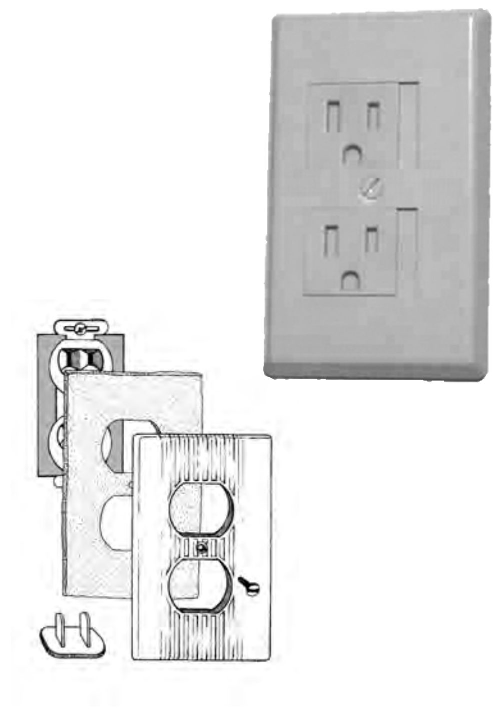

Figure 10.13: Care Covers and switchplate gaskets prevent air leakage at outlets

Air Leakage at Windows

Figure 10.14: A replacement window with the vapor retarder ready to tie into the wall vapor retarder.

Leaks between the rough opening and window or door frames are stopped by removing the interior trim, filling the void with spray foam to provide insulation, and air-sealing in that space. This measure will bring the inside surface temperature up, prevent convective leakage, and provide backing for a vapor sealer. Note: do not fill the space to full width of wall in one application with foam or the jamb will buckle. Spray to a depth of no more than one inch with room to expand in at least one direction. Allow to cure before building up another layer. Repeat as necessary to fill cavity.

Fiberglass is also used to insulate these cracks and cavities; however, the R-value of fiberglass is not as high as spray-in one-part foams. It is also not an effective air-vapor retarder, nor does it provide solid backing for one. Do not pack fiberglass tightly into these cavities because that reduces R-value. Insulate as you would in any standard cavity, allowing the insulation to loft while completely filling the crack or cavity.

Remember, an air-vapor retarder is necessary on the warm side of added low-density insulations. Do not put fiberglass in cracks or cavities where the weather barrier is broken and water leaks occur.

Leaky opening windows are a result of broken hardware or out-of-plumb or out-of-square windows. Inspect all hardware, including weather stripping, closely for functionality. Some windows are repairable with generic materials available off the shelf at hardware stores. If the window name brand, size, and model are known, parts may be available from the manufacturer. It is worth a trip to the manufacturer's web site to find contact information and check.

Storm windows may be added to window exteriors to bring inside glass surface temperature above the dew point, or magnetic storm windows may be installed to the glass interior to add R-value to the window system.

Whatever system is used, be careful not to restrict egress in case of an emergency. Magnetic storm windows are easily removed with a slight tug. When installing storm windows with fasteners, use care to fasten them to the opener itself so as not to restrict egress.

If window water leaks or condensation cannot be controlled by caulking, foam, storm windows, or replacement parts, new windows must be installed. Chronic moisture presence on windows or in window openings is a cause of wall system failures and promotes mold growth that may affect occupant health.

Remember, when installing or reinstalling windows, a good flashing and use of spray foam and sealants between the rough opening and window casing are your primary defense against weather intrusion.

Caulking the trim to prevent water and air leaks is largely ineffective.

Adding Insulation to Building Interiors

Adding enough insulation to the interior surfaces to meet your energy target without demolition to remove the existing vapor retarder can also be a problem. Vapor retarder placement and continuity is critical to retrofit success in cold climates.

The vapor retarder should always be placed so that the temperature at the vapor retarder is above the dew point on the coldest anticipated day of the year, to prevent condensation in the building assembly. The more insulation placed to the inside of the vapor retarder, and the colder the exterior temperature, the colder the vapor retarder will be. Therefore, before adding insulation to the inside of the vapor retarder, the dew-point temperature and thermal gradient of the building assembly you are adding insulation to, must be known, as well as local weather data to determine how much R-value is allowable to the inside of the vapor retarder.

There are several ways to calculate this; however, only methods based on local temperatures are accurate enough to be useful in Alaska for retrofit purposes. (See the discussion of dew point calculation in the Building Science chapter.) Here are methods to add insulation to floor, walls, and ceilings from the interior. Adding insulation to the ceiling on the interior of buildings is done only when necessary, because there is less access to space for lower cost, lower density insulations. But it can be necessary in instances such as hot roofs or very low-pitched roofs with very little working area in the attic.

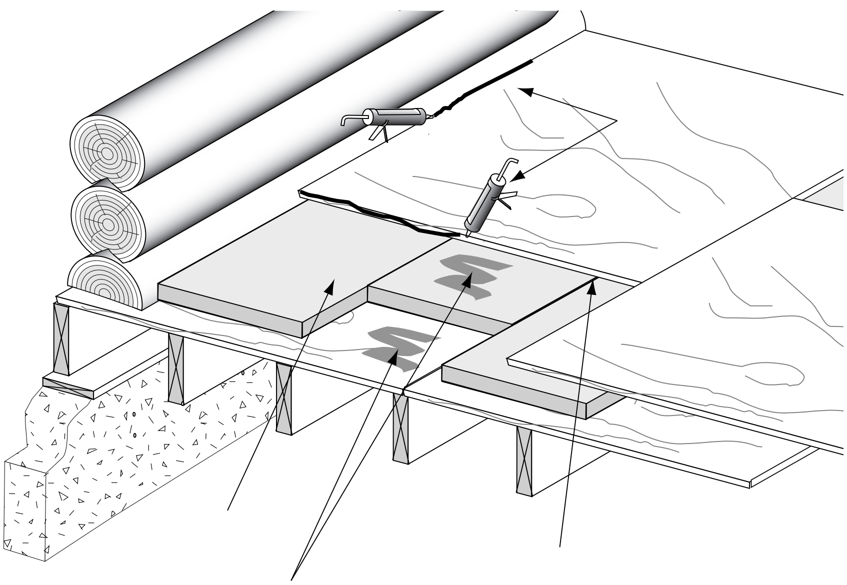

Figure 10.15: Adding insulation to the floor from the inside

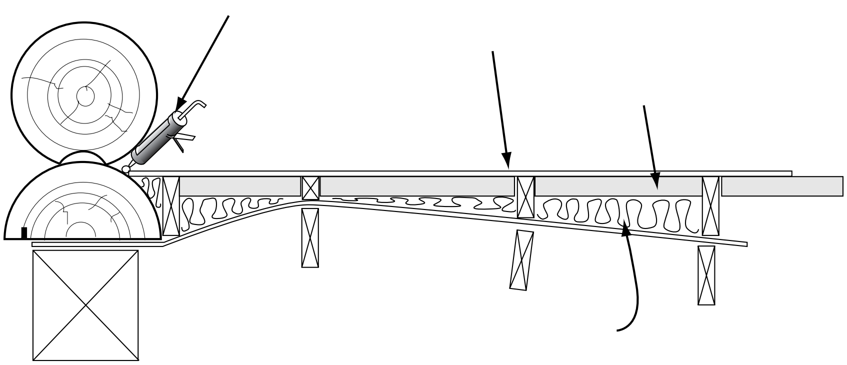

Figure 10.16: If the existing floor is not level, compensate for it when adding insulation on top to create a level floor

Adding Insulation to Floor Systems from the Interior

Extruded polystyrene or other high-density closed-cell foams are the rigid insulations of choice to increase the R-value of a floor system from the inside. They resist the flow of both liquid water and water vapor, have a relatively high R-value per inch, and are not easily damaged by foot traffic.

The first thing to check if you're going to enhance the thermal properties of the floor system from the interior is to see if you can raise the floor system by approximately 2 ½ inches and still have sufficient headroom to meet code. With this measure, 1 ½ inches of foam can be added to the floor system and framed in with 2 x 2 inch lumber to add an additional R-7.5.

Next, make sure that either you will meet your energy target for the floor system with this measure, or this measure is a necessary step in meeting that target.

Remove all existing cabinets, baseboard trim, furniture, and anything else removable that contacts the floor. Frame in the entire floor perimeter with 2 x 2s. Be sure to grade your 2x2s. Floor framing that is not well secured may result in a loose, squeaky floor. Use construction adhesive or sealant to help prevent floor framing from working loose over time. Secure these to the existing floor alternately with 16-penny galvanized nails and 3-inch sheetrock screws. If you have trouble with splitting, you may have to predrill. Include partition walls in this perimeter framing.

Remove all interior doors. When a particular door cannot be cut down, remove the frame as well. Remove exterior door if it swings in. The starter strip will be a different width than the foam installed in the field, to accommodate the sub-floor extending to the outside edge of the perimeter nailer.

On your table saw rip strips of the rigid insulation to 21½ inches wide for the starter pieces, and fill in the first row along the perimeter wall. At the butt ends of every sheet of rigid insulation, you will need a nailer to secure the subfloor properly. Kick 2 x 2s solidly against the exposed edge, nail and glue them down, and put down the next row of foam.

An alternative is to leave out the nailers so the insulation layer is continuous without a thermal break, if you have solid bearing for fastening down and sealing the new floor coverings without them. For this method, use rigid structural screws for the fasteners.

When using the nailer method, if the home has enough headroom to sacrifice the additional space, a thin layer of foam, usually one inch, can be laid over the framed-in layer to provide a thermal break and continuity. Run this layer perpendicular to the first layer. Use construction adhesive and a few screws to temporarily fasten this foam into position while working. Be sure to mark the position of the nailers before covering them up. The floor decking will hold this layer permanently in position once it is installed.

If Visqueen (polyethylene) is used as the new air-vapor retarder, it must be installed over the floor decking to provide solid backing to prevent sagging. The Visqueen must be installed directly under the subfloor, on the warm side of the insulation, so trapped water can dry to the inside.

Once the exposed floor is insulated, it is time for the new floor coverings. Use at least ⅝-inch thick AC grade exterior plywood to cover the insulation. Decking must be tongue-and-groove to interlock for air and moisture sealing. Each plywood sheet must be air and moisture sealed to the next sheet and to the existing walls with one-part polyurethane caulk or the equivalent to prevent air or moisture leaks.

Approaching the perimeter of the room with the new plywood, you will get to spots where there is no clearance for the tongue. At this point cut the tongue off with a Skilsaw. Be sure to cover these intersections well with sealant to prevent leaks. Floor air and moisture sealing is done with a good-quality construction adhesive or polyurethane caulk. The goal is a warm, air-tight, and moisture-proof floor system.

Insulating Wall Systems From the Inside

When adding rigid insulation to the exterior wall from the inside, work proceeds similar to insulating the floor system. Foam may be installed with horizontal nailers on 2-foot centers and at perimeters, or the nailers may be omitted according to preference, providing you are confident of fastening the new wall board to the existing framing.

When omitting the nailers, remember that the further away from the existing framing you get, the more difficult it will be to hit the existing framing with the fasteners, so mark the studs well. Long screws are used to secure the sheetrock through the foam to the studs.

If there is existing paneling over the firebreak, it is usually unnecessary to remove it before proceeding to install the new foam. You need only a smooth plane to back up the new material.

Remember if there is an intact existing vapor retarder in the system, there is a limit to the amount of insulation that can go to the warm side of it.

If there is not an existing vapor retarder, continuously installed extruded polystyrene can be used as the new vapor retarder, as it has a low perm rating. Be sure to tape all seams with a good vapor retarder tape. Installing the new firebreak directly over the foam will provide the compression seal necessary to prevent the tape from coming off.

If blower door testing and visual inspection reveal that the existing air-vapor retarder is functional, any kind of insulation may be used to meet your limit allowed to the warm side of the existing vapor retarder, providing you are willing to sacrifice the space. You need only frame accordingly.

If the wall system is not framed with adding rigid insulation to the interior in mind, it will be difficult to secure nailers in the corners for the nailer method. Extra long fasteners, such as 5-inch sheetrock screws, can be driven in at an angle to reach the corner framing. Or fasten corners of horizontal nailers together before installing on the wall to provide a strong nailer there.

All doors and windows must be perimeter framed. Window and door furring is extended to cover the increased wall depth; this can be done by adding to, or furring over the existing jambs.

If the additional finish gets in the way of openers or the desired finish look cannot be achieved, the windows and doors may need to be removed and reinstalled with extended jams.

Switch and outlet boxes are extended to accommodate increased wall depth. In some cases this can be difficult due to tight wiring, and short tails may need to be wire-nutted to existing wiring to reset switches and outlets to the new surface. Switch, outlet, and junction box extensions are available at electrical supply stores. Remember, outlet, switch box extensions and extended jambs need to be installed before installing the new added rigid insulation.

Adding Insulation to the Ceiling

Adding rigid insulation to both the ceiling interior and floor systems as a retrofit, or new construction is not desirable in rooms with an 8-foot ceiling, because adding significant amounts of insulation to the interior space reduces headroom.

Attic spaces generally provide enough room to add low-density, low-cost insulation to meet a good energy target in a more cost-effective way. Exceptions to this are when attic access is limited or there is no attic access, such as a hot roof.

In these specialized cases, adding rigid insulation to the interior can proceed in the same way as floor and wall systems, except that with this method, nailers need to be stronger to hold heavy sheet goods up. Therefore 2 x 4 nailers are recommended on the ceiling, with the nailers running perpendicular to the roof truss bottom cords and well fastened to them with rigid structural screws.

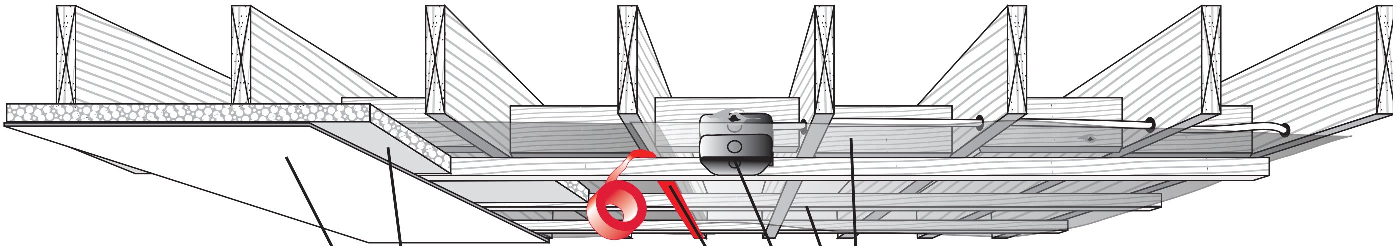

Figure 10.17: Adding foam insulation to a ceiling.

Junction boxes will need to extend to accommodate the increased depth of the ceiling system as in the wall retrofit method.

You cannot add insulation to any part of the thermal boundary without air sealing to prevent moisture problems. The more insulation added to the cavities, the colder the outer portions of the cavities will be. Moisture in a vapor form contacting these cold cavities will be prone to condensation during the heating season in Alaska.

Attics are especially prone to moisture damage from air leakage because they are usually cold spaces located where moist air is rising out of the building.

Exterior Retrofits

Goals of an exterior shell retrofit are:

- Repair or replace the air-vapor retarder as necessary according to the assessment, to make the wall or ceiling system air tight as possible.
- Enhance thermal performance (resistance to heat loss) by adding as much insulation as is affordable. See AkWarm for maximum payback or BEES for minimum levels to meet AHFC standards. (Appendix A)
- Provide a drainage plane at the appropriate place in the assembly.
- Provide an air-weather retarder outside the exterior of the insulation and sheathing.
- Provide flashing at all penetrations, drip edges, door and window openings, and valleys as a part of the overall weather barrier strategy.
- Provide a drying space between weather barrier and cladding.

Adding Insulation to the Floor System from Underneath

There are several ways to increase R-value in a floor system from the exterior. Here are some rules of thumb:

- If the insulation is in the floor framing cavities, these cavities must be completely full of insulation with no voids.
- Use the flow-through principle when sequencing installation of materials. Do not put rigid insulation under the floor trusses or joists, as this will trap water in the floor system
- Do not use a weather barrier such as Tyvek or Typar under the floor trusses or joists for the same reason. Remember these products will not pass liquid water.
- An exposed floor system must have an air-vapor retarder and bulk water barrier to the inside or warm side. If one does not already exist, one must be added before insulating.

Adding Insulation to the Exterior Wall

Remember, adding insulation to the thermal boundary anywhere in the building system, in this case, the exterior of the exterior walls, is contingent upon air-tight construction to avoid damage to the system from air-driven moisture migration. Therefore, you need to repair or replace the existing vapor retarder if there is a problem with air tightness.

If you have chosen an exterior retrofit, it means you are prepared to salvage or sacrifice the existing siding. There are several ways to go about repairing and replacing vapor retarders from the exterior and adding insulation from the exterior. If the intent is to use only the existing cavities for insulation, the best way to ensure a good job is to strip the wall from the exterior.

In some cases, this will not be cost effective because the demolition phase is labor intensive. However, if the siding needs replacement anyway, this is the best way to ensure a quality job. Remember, most interactions in these systems are invisible to the naked eye and are buried within the system. Total access can ensure that construction is done with good quality control, no voids in the cavities, and with proper sequencing of insulation and materials. See the illustrations on the next page of an exterior insulation retrofit on a 30-year-old 2 x 4 stud house.

Stripping Walls

If you do not need to strip the old sheathing and other materials from the wall, by all means avoid the wasted

Figure 10.18: A house in the midst of an exterior retrofit. This approach uses narrow wood studs in a wide all-weather wood plate. The top of the wall is attached to the soffit above.

Figure 10.19: This is the east wall of the house before the exterior insulation and finish siding are installed.

Figure 10.20: A high resolution infrared photo of the house in Figure 10.18. Note the whiter portions, which are indicating high temperatures and high heat loss, and the darker areas which are cooler and indicate they are better insulated. This is a marvelous tool for retrofit, but is even better when used in combination with a blower door.

labor. But if you must remove the materials for an exterior retrofit, to ensure structural stability, strip walls in 8-foot sections. If there is any question of shear strength of the exposed structural assembly, use bracing or structural steel tape nailed to the existing framing at a diagonal angle as a brace. Remove the siding and discard or salvage as practical.

Remove sheathing with nail pullers; do not destroy it. Unless it is rotten or excessively nailed, the sheathing may be reused. This should expose the insulation. If there is Tyvek or Typar, cut it back and remove.

Remove the insulation. If it is dry, still retains its loft, fills the cavities completely, and is undamaged, bag and store it safely. If it is wet, discard it. If it is dry but appears to have lost some loft and does not tightly fill the cavities, bag it and put to the side for use in the attic space or for piecing into the cavities.

Repair

You will now be able to see clearly to the interior of the wall system. Let's assume the vapor retarder was leaky. Now we have an excellent chance to repair it.

For vapor retarder repair, you can use a United Coatings product, Elastron 858 (two component, fire retardant, polymerized, butyl rubber, vapor retarder coating), or an equivalent spray-in capable vapor retarder. The Elastron 858 product is only an example. It is resistant to the passage of liquid water and water vapor, due to its low molecular structure.

Elastron 858 cures by chemical reaction to form a highly impermeable elastomeric membrane, which is also chemical resistant.

Elastron 858 may be applied by brush, roller, or conventional or airless sprayer. Airless spray is the preferred method for most applications, as it is quick and provides good coverage with the right nozzle. For small jobs or problem areas, a brush or roller may work fine. An airless sprayer capable of a minimum of one gallon per minute output at 2500 psi, tip size of .021 inches to .035 inches, and a 40 to 50-degree fan angle is recommended for the spraying application.

Before spraying, check the wall cavities for holes to the interior that need to be sealed, such as penetrations for electrical switches and outlets. In the case of conventional electrical boxes, the holes or cutouts in the back of the boxes, along with any large holes around the boxes, must be sealed prior to spraying. For this step I use a one-part low expansion foam. One example of such a product is Hilti Foam. If batt-type insulation is to be used to insulate, take care not to create irregular shapes in the cavities when sealing holes.

After the obvious holes are sealed you are ready to spray in the new vapor retarder. The Elastron 858 or equivalent can be applied directly to the outside surface of the existing vapor retarder to seal defects. If there is no vapor retarder, the new vapor retarder can be applied directly to the exterior surface of the sheetrock, paneling, or sheathing. Be sure to cover well at all perimeters and intersections, and electrical boxes, as well as in the field. Spray the intersections of studs, vapor retarders, and finish surfaces well to prevent leakage around studs. A two-coat total thickness of at 18 to 22 dry mils is recommended.

Once the vapor retarder is well sealed and dry, the rest of the thermal blanket can be installed. If there is still any question of vapor retarder integrity, or framing cavities are not wide enough to accommodate enough low-density insulation to meet your energy target, here are some options.

Have a contractor come in and spray foam from the exterior (the attic floor in the case of a ceiling), to the outside of the inside surface (if it is a wall). This foam layer can be a flash coat of one inch to the interior surface, or can entirely fill the cavities according to your energy target and budget.

The flash coat method acts to stop air leaks, increase R-value, and follows the flow-through principle of cold climate construction. The flow-through principle is important to place the high density, more impermeable insulations closest to the vapor retarder, and lower density, more permeable materials towards the outside. This is to allow any moisture passing the vapor retarder to be able to wick or evaporate out of the system without becoming trapped and causing damage.

If the existing fiberglass batts are reusable, they are reinstalled to the exterior of the flash coating. These batts will now be compressed, slightly reducing the R-value of the batts but ensuring that no voids occur to promote short-circuiting of the insulation, which is more important.

Spraying these cavities full of urethane foam is a relatively expensive but highly desirable retrofit method. Urethane costs are generally $1 per square ft., per inch. The overspray can be cut to the stud plane, leaving completely full cavities. This is a nice finished product. Urethane has a long term R-value around R-6 per inch, almost twice that of fiberglass batts. It has the added advantage of providing integrity to loose rickety structures, air-sealing, and conforming to any irregular shaped cavities.

There are other foams also suited for this application that are nontoxic and have air-sealing properties; however, urethane has one of the highest R-values, so if you have conventional framing and do not wish to deepen these wall cavities by adding framing, urethane can add significant thermal performance to existing spaces that were formerly full of fiberglass batts.

In cases where wall framing is deep enough to accommodate enough low density insulation to meet your energy target, reinstall the insulation of your choice. If the original insulation fits cavities well and is undamaged, it can be reused. However, in many cases, problem walls have damaged insulation that should not be reused in the wall cavities.

Water damage is easy to spot even in dry fiberglass batt insulation, because moisture promotes matting together of the tiny fibers, reducing loft and slightly shrinking batt widths and depths. Measure batts or trial fit to cavities to spot this problem.

Damaged batts that are totally dry can be reused in a second insulation layer in the attic space, where they can be laid contiguously and perpendicular to the truss bottom chords.

We prefer blow-in cellulose where new insulation is needed, because it is less labor intensive to install than batts, less toxic than fiberglass, conforms to any size or shape cavity, does not itch,

Figure 10.21: This is a view of a side wall with the siding partially placed and the Tyvek installed to the level at which the cellulose is ultimately blown in.

and can be sprayed to a high enough density to resist settling and air movement (approximately 4 pounds per cubic foot when confined in a cavity).

Rock wool is also a good insulation of about the same R-value as cellulose, around R-3.1 per inch. Although not as popular in the USA as some other insulations, rock wool has the same basic insulative properties as cellulose, with the added advantage of resistance to moisture damage and fire resistance. It is also not very comfortable to work with.

When insulating walls or hot roofs, follow these guidelines:

- Fill cavities completely to avoid short-circuiting, convection looping, and low R-values.
- Insulation may be slightly compressed; however, the more compression (density), the more reduction in R-value. Better higher density than allowing any voids.
- Systems must be dry before insulating.
- Air-vapor retarder and air-weather retarders must be completely sealed air and weather-tight before and after insulating.
- When finished the thermal blanket must follow three-C rule: Continuous, Contiguous, Complete.
- Most older homes requiring retrofits lack the deep wall and floor framing necessary to achieve high R-values with low-density insulations. In these cases additional framing can be added to enclose high levels of insulation.

Larson or Standoff Truss System

When retrofitting existing walls with a Larson truss system, standoff wall, or insulated panels, it is desirable to either construct such walls with an integral vapor retarder, or add a vapor retarder type membrane to the exterior of the building sheathing, in cases where the existing vapor retarder is nonfunctional.

When a vapor retarder and insulation is added to a building's exterior, use one of Stuart's vapor retarder placement formulas to ensure the added vapor retarder will not become a condensing surface. The one third-two thirds rule applies in retrofit as well.

The Larson truss, ladder truss, or standoff wall are all variations of the same thing: a nonstructural insulated wall is added to the outside of an existing wall system to bring the R-value up to the retrofit energy target. The advantages of this system are:

- Working from outside the building where space is not an issue.
- Any amount of low density, low cost insulation may be added to the wall system above the amount needed to keep any added vapor retarder above the dew point at the outdoor mean January temperature.
- Walls may be built on the ground, and raised into position with manpower, wall jacks, or equivalent

This system is constructed by building a light double wall constructed of a series of ladders with the two uprights as the inside and outside studs. This type of wall is not intended to support the structure, only itself, the insulation, and cladding. The "rungs" are installed at opposing diagonals, connecting the inner and outer walls rigidly. The two walls can be as far apart as necessary to accommodate the desired amount of insulation.

If the existing vapor retarder is nonfunctional or nonexistent, an air-vapor retarder is added to the inside surface, the insulation is installed between the ladders, a weather barrier is added outside of the insulation, then furring strips to create a drying space, then the cladding. If more than one wall is done, install weather barrier continuously around all walls at once, or leave a tab on each wall to connect to the next.

The added wall system is generally suspended from the soffit or truss or rafter tails at the top and held up at the bottom by a ledger board installed at the rim joist of the building.

Stud tails protrude at the top of the wall to connect to the joists or rafters. The added wall top plate must be protected by the existing roof overhang, or more overhang must be added to the existing roof system. Flashing and cladding must completely cover the roof–wall intersection.

Wall bottom plates can be constructed of ¾-inch to 1⅛-inch plywood if the width is too great to use standard dimensional lumber. Use care to seal wall intersections and door and window openings well.

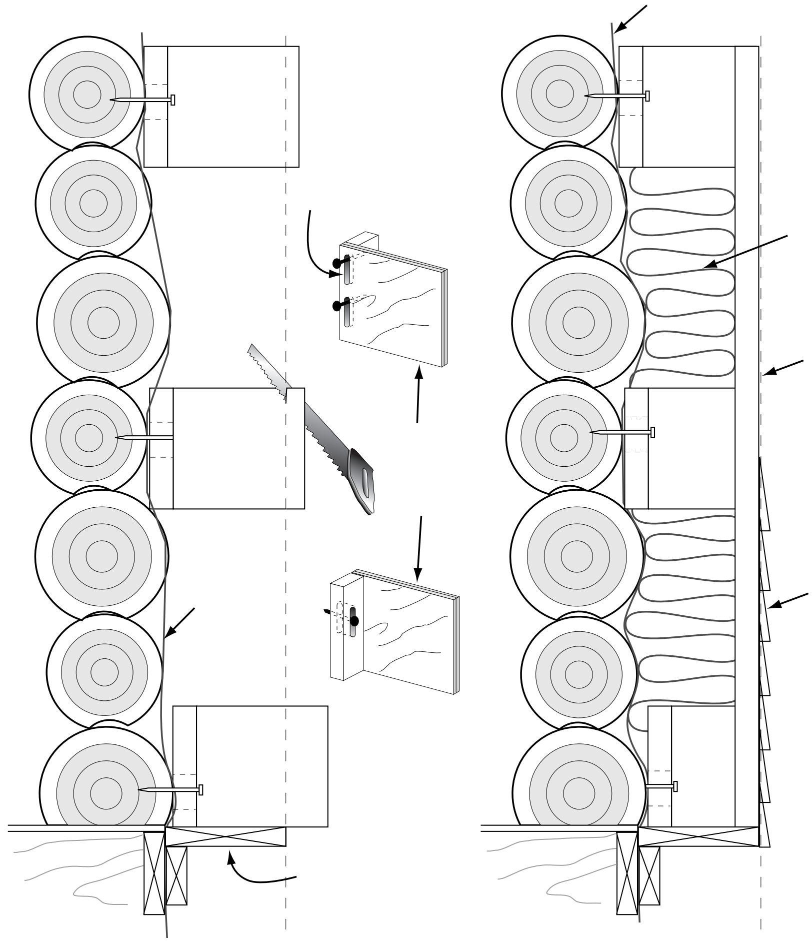

Figure 10.22: A standoff truss system applied to a log wall

Adding Insulation to Attics

As always, don't add more insulation to the existing attic insulation without first determining that the boundary between the insulation and the conditioned space is airtight. Otherwise there is a real potential for moisture damage. Remember moisture damage is one of the leading causes of premature building degradation. Do not build moisture problems into your retrofits! To determine the integrity of this boundary, do overall air-tightness tests for whole house and zone-to-zone testing of the main living area to attic space.

If your vapor retarder needs repair at the attic floor, here are some tips: for problems involving penetrations, pressurize the house with the blower door. Warm air will blow into the attic from leaks in the vapor retarder, allowing you to find the leaks.

In cases of a mostly intact vapor retarder with leaky penetrations such as junction boxes, five-sided covers are cut from rigid insulation and the pieces are pinned and caulked together to form airtight insulated boxes when

Figure 10.23: A stand-off wall exterior retrofit, showing details around a window opening. In this case the retrofit used a plate at the bottom that was lag-screwed into the original wall plate and then 1 x 4 studs were used as the framing of the new wall.

caulked around the junction box to the attic floor. Notches are cut in the box to accommodate the wires entering and leaving the box. These holes are caulked or foamed to provide the air seal. Determine that existing recessed lighting is rated to be air sealed and insulated before using this repair with recessed lighting.

If the vapor retarder should be located at either the attic floor or rafters, but there is no vapor retarder or the vapor retarder is ineffective, you'll have to replace it.

Vapor Retarder Added to Attic Floor

If you have enough headroom, redoing the entire ceiling vapor retarder from the attic space is a good way to ensure vapor retarder integrity. I will generalize a strategy to replace this vapor retarder that can work well in many applications.

First of all, doing a major project in a confined attic space makes the project harder than it really needs to be. First step is to open the space up, as a means to let in fresh air and light, as well as making cleanup and materials stocking much easier. To that end, I start by removing siding and sheathing covering attic space at gable ends, or at least at the downwind end. Hang and anchor reinforced Visqueen over the openings to prevent wind-driven rain from entering the attic space while still allowing enough airflow.

Remove the existing insulation through the openings. If the existing insulation is batt-type, bag the dry, undamaged pieces and store for reuse.

If the existing insulation is blow-in type, a shovel and shop vacuum may be the best option to remove it. Use a shop vacuum to clean attic floor of debris. This surface must be clean and dry.

If condensation from exfiltration has wet the attic floor and the perimeter framing, after the insulation is removed these surfaces should warm rapidly, allowing them to dry if heat is maintained at normal temperatures.

After cleanup is complete, Elastron 858 or equivalent is sprayed, rolled, or brushed over the attic floor in a continuous layer, applied in two coats, to form the new vapor retarder. Two applications totaling around 22 mils provide plenty of protection.

Special attention needs to be given to potential problem areas such as intersections between truss bottom caps and the attic floor. Any large holes need to be repaired before coverage with plywood, rigid insulation, spray foam, Visqueen, or whatever is the most practical solution. In general, it is difficult to apply a continuous membrane of manufactured sheet goods to the attic floor area, because of built-in obstructions such as truss bottom caps and webbing.

Attic Space Insulation

- If the vapor retarder needs to cure, wait until it is dry, then reinsulate the attic floor continuously to the R-value for your energy target
- Keep the insulation contiguous to the new vapor retarder.
- When using batt-type insulation, install at least two layers perpendicular to each other to provide full coverage and the needed thermal break.
- When using blown-in insulation, insulate past the truss bottom cap. Prevent air intrusion and insulation migration in high wind areas by covering the insulation with Tyvek. Staple in place between truss webbing or chords or rafters if these obstructions are present.
- Use insulation dense enough to avoid excessive air intrusion.

- Protect the insulation from air intrusion with blocking and rim joist at perimeters.
- In conventional cold roof applications, attic ventilation is necessary to ensure moisture transport through the attic system. This is ensured by gable end vents and button or continuous soffit vents.
- Take advantage of natural convective loops to vent where possible.
- Use screen to keep pests and trash from entering space. Use insulation baffles to keep insulation from filling the whole space between the attic floor and the roof. Back vent screen with ½ inch hardware cloth ("rabbit hutch wire cloth") to keep out rodents. This is especially effective against squirrels.

Whatever ventilation strategy you employ:

- Ensure liquid moisture will not be transported into the system from outside
- Ensure the boundary between the attic and conditioned space is as tight as possible, less than 200 cfm of air leakage at a forced pressure difference of -50 Pascals before adding insulation to the attic.
- Ensure moisture will be transported out of the attic space before it accumulates.

Avoid attic access from inside the conditioned space such as through trap doors, because of the potential for chronic air leakage. If an attic access hatch is located in the conditioned space, it should be gasketed, insulated, and compression sealed.

Attic access is ideally provided from the exterior of the building at a gable end. This can be accomplished by mounting a gable end vent on a hinged panel large enough for access or by constructing an exterior door to gain access.

There are many building types and retrofit techniques and we don't have room to list all problems and fixes here. Do a good, accurate assessment and use building science, and you will do no harm and have an excellent chance to attain your retrofit goals.

BUILDING IN ALASKA

Tips on Insulating an Existing House

EEM-04452

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As a "first cut" evaluation in deciding what items are most worthy for energy efficient retrofits, start with the **"Low-Energy Retrofit-Priority Checklist"** which is adapted from the Environmental Building News (July 2007.)

This checklist assumes that you are starting with a fairly standard existing house relative to energy features: for example, an uninsulated basement: 2x4 walls insulated with R-11 fiberglass; a flat ceiling insulated with R-19 fiberglass; insulated-glass windows or single-pane windows with storm windows; a relatively leaky 5-7 air changes per hour at 50 pascals (ACH50), and an atmospherically vented furnace or boiler. Within each category, the checklist starts with easy, low-cost measures, and includes progressively more costly or difficult measures. Note that some later measures obviate the need for earlier measures, so this should not be considered a step-by-step action list. When the starting conditions are different—a better-insulated house or a house with no insulation at all—the cost-effectiveness of different measures will differ, but many of the strategies will still be applicable.

COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF ALASKA FAIRBANKS

HOUSE ENVELOPE	
Air-seal foundations and attic	Identify and seal major holes in the foundation and attic; patch holes in ducts through unconditioned spaces.
Fix moisture problems and insulate basement walls	Identify and repair any moisture problems (including drainage and site-moisture probems) in the basement or crawl space and, insulate walls (R-15 to R-20) if walls are suitably flat, with high-density EPS or XPS board insulation. Cover insulation with non-paper-faced drywall if the basement space is being finished, or other durable protective surface.
Air-seal the house	Hire a weatherization contractor or energy auditor to locate (using a *blower door*) and seal cracks and leaks in the house envelope, especially at floors and ceilings. Weatherstrip windows and doors. Note that tightening a house often causes higher moisture levels indoors that may have to be dealt with. Radon levels should also be closely monitored.

Add insulation in attic	Air-seal the attic first! Install additional insulation (e.g., cellulose) on top of existing insulation in the attic floor. Depending on existing conditions, it may be necessary to remove the attic floor to expose joist cavities to fill with insulation. In general, it is cost-effective to add more insulation than can fit in the joist cavity; additional insulation can be added on top of the floor, or the floor can be raised using cross joists to increase cavity thickness. If existing insulation is removed prior to installing new insulation, air-seal the exposed ceiling from above prior to insulating.
Upgrade windows	Replace existing windows with tight-sealing, double- or preferably triple-glazed, low-e windows or storm windows on either the interior or the exterior of the prime windows. When upgrading windows or adding storm panels, address moisture control and drainage. Consider different glazings for different orientations to exclude some of the unwanted solar gain.
MECHANICAL SYSTEMS	
Tune heating and air conditioning systems	Tune up equipment and inspect controls to ensure that mechanical systems are working at top efficiency. Replace air filters in furnaces and heat pumps.
Insulate water heater	Insulate storage-type water heaters, even newer models, with an insulation blanket. Electric water heaters can be covered more completely; gas water heaters require that areas be left uninsulated to provide for combustion air supply. Also insulate hot-water pipes to slow the cooling of hot water in the pipes.
Reduce hot water demand	Install low-flow showerheads and faucet aerators to reduce hot water demand. When there are long hot-water piping runs, install on-demand recirculation systems to reduce losses.
Replace furnace or boiler	Replace atmospheric-venting furnaces or boilers with new, sealed-combustion (or power-vented) high-efficiency models.
Install mechanical ventilation	Many energy retrofit measures will increase airtightness to the extent that poor air quality and condensation problems from excessive indoor humidity may occur. To remedy this, install a mechanical ventilation system or a heat-recovery ventilator to capture heat from the exhaust air stream.
HOUSE INTERIOR	
Replace incandescent lights	Install fluorescent or LED lighting as an energy-saving alternative to incandescent. Compact fluorescent lamps (CFls) easily replace incandescent light bulbs; linear fluorescent fixtures (specify electronic ballasts and T-5 or T-8 lamps) can provide indirect lighting. Lighting energy savings can also be achieved with better controls, including occupancy sensors, and task lighting that replaces area lighting.
Upgrade appliances	Buy a plug-in energy-use meter to judge the efficiency of appliances, and replace inefficient equipment. A new refrigerator, for example, may use just a third as much electricity as one from the 1980s. Recycle old refrigerators rather than keeping them for back-up use. Some utilities in Alaska make these energy use meters available to customers.
Turn off the TV	Really turn it off. Many—but not all—televisions and other entertainment equipment continue to use power even when "turned off." To be sure that the equipment is really off, put it on a power strip and get in the habit of switching that off when equipment is not being used. When buying a new TV, consider both the standby and the operating power consumption. Be aware that digital recording devices, such as TiVo, tend to draw significant power (25-35 watts) even when not recording, and they are typically left on 24/7 to be ready for reset recording.

Turn off cable modems and routers	Internet connection equipment, including cable modems and wireless routers are significant electricity users in many homes—often surpassing even televisions. If doing so will not interrupt crucial services like phone service, plug these devices into power strips and switch them off at night and when the house is unoccupied.
Practice a low-energy lifestyle	Homeowners should be encouraged to alter their lifestyles in ways that reduce energy use by limiting water use, turning off lights when not in the room, making use of task lighting, etc. Also, carefully consider the need for any proposed addition and its impact on the occupants' total energy consumption.

Once you have selected those items from the priority list, you may want to seek a professional energy audit to get a better idea of the energy use at present and the value of the energy savings. A list of energy raters is available at the Alaska Housing Finance Corporation Web site: www.ahfc.state.ak

Before proceeding to do energy efficient retrofits, carefully review the following sections by building element to be sure you understand the necessary details required to do a "best practices" job. Sequencing of vapor barriers, placement, careful installation of insulation to eliminate voids, use of appropriate caulks and sealants, selection of materials, and material compatibility are all crucial details which when done right ensure a very satisfactory energy efficient result.

Understanding of the house as a system is very important to taking the correct and effective steps in a retrofit. A good review of building science concepts describing how a house works can be found in Chapter 2 "Building Science" of the *Alaska Residential Housing Manual* (© 2007 AHFC), which is available in either hard copy or CD from the Cooperative Extension Service 474-5211. Important cautions are knowing where to place vapor barriers to prevent moisture problems, understanding heat flow, and properties of various insulations. All these concepts and properties are covered well in the *Alaska Residential Housing Manual*.

Ceiling

Lack of ventilation and vapor barrier in the ceiling is often evident by moisture stains and water leaking out of electrical outlets during the spring thaw. Glaciering at the eaves is another sign that warm air is leaking into the roof cavity or that it is inadequately insulated.

The following steps should be taken if additional insulation is installed in the ceiling.

1. Lift the existing insulation and check for the existence of a vapor barrier. The vapor barrier usually consists of a clear sheet of polyethylene (Visqueen). Older houses may have a double sheet of rosin paper cemented to an asphalt coating. Sometimes the rosin paper may be coated on one side with a thin sheet of aluminum foil. The vapor barrier must be securely fastened under the ceiling joists to be effective. The aluminum foil cemented onto a rock lath is not adequate because the joints are not sealed. All air sealing should be completed BEFORE any new insulation is added to the attic.

2. If there is no vapor barrier evident, then a vapor barrier must be installed before placing any type of insulation. Vapor barriers may be installed using the following guidelines.

   a. There is no satisfactory technique for installing and sealing a polyethylene sheet between the joists. If urethane is used without an additional vapor barrier, specification of water vapor permeability of the urethane should be provided by the applicator in writing. It is best to use a polyethylene vapor barrier for urethane foam applications.

   b. If any loose fill (cellulose, mineral wool, fiberglass) insulation is used, a 6-mil polyethylene sheet must be installed on the underside of the ceiling and sealed along the seams and edges with non-hardening caulking compound. Then, 1 inch x 2 inch nailers should be installed under the vapor barrier. These may be covered with acoustical tile or sheet rock.

c. Where possible, all openings around plumbing vent stacks, plumbing walls, electrical wiring, lighting fixtures and chimneys should be tightly sealed against water vapor and air migration into the roof cavity. Recessed lighting fixtures should be removed and the opening tightly sealed against warm air and water vapor leakage. Inspect exhaust fans located in the attic before installing insulation. Replace if needed (very likely).

d. All access openings and stair wells from the interior of the house into a cold roof cavity or attic should be tightly sealed against migration of warm air and water vapor. Access openings into a cold attic should be placed in the gable ends of the roof rather than in the ceiling.

e. When placing additional insulation in the roof cavity, special precautions must be taken not to restrict air movement over the insulation at the eaves, particularly with trusses constructed of 2 inch x 4 inch top and bottom chords. It may be desirable to place a 2 inch x 24 inch strip of rigid urethane under the eaves instead of blanket, batt or fill insulation. New products are available for this purpose, also.

f. The plate (top) of interior partitions should be vapor proofed with vapor resistant paint and the edges sealed with caulking, when no other vapor protection has been provided.

Stud Frame Wall

Lack of insulation in a wall may be evident by blistering of paint on exterior siding, frost or condensation behind furniture and drapes, or staining of sheet rock nailheads.

Follow the steps listed below to insulate an existing wall.

1. Remove a section of exterior siding and sheathing in several locations and determine if the wall is insulated and/or vapor proofed. No insulation should be blown into the wall until it is properly vapor proofed.

2. The wall may be vapor proofed by installing a 6-mil polyethylene sheet over the existing interior wall covering. The vapor barrier should be sealed at all edges and seams. The polyethylene may be covered with sheetrock or paneling.

Cont'd on page 5.

Figure 1. This photo shows several aspects of a house, which is poorly insulated at the studs such that you see condensation and mold not only at the top of the wall where the wall plate is, but also in the corner and at each stud. This is an extreme example of a phenomenon called "ghosting of the studs" where the surface of the wall on the inside of the stud is cooler and therefore condenses out moisture and other vapors on the cool surface first. In the case shown, the problem is fairly horrible with the resulting mold on every cool surface of the inside of the building. Retrofit would solve this by insulating on the exterior or the interior and using good vapor barrier sealing to keep moisture from getting to cold surfaces. The existing condition may also be a result of a fairly tight air seal causing exceedingly high relative humidity levels in the building. Photo by Scott Waterman.

Figure 2. A photo by the author of his own house retrofit showing both the exterior wall being framed in and a new superinsulated window being installed in the rough opening of the old wall. Both of these are examples of how to retrofit both windows and walls with more insulation and a better performance window. The superwindow is described in the Fall 2005 issue of the *Alaska Building Science News*. It is a fiberglass framed quad-pane, krypton-fill window, 10 feet wide and 5 feet high with a measured R-value at approximately -20°F of 13.25 over a 36-hour period.

Figure 3. Shows another detail of the author's home in the final retrofit stages. The wall is being covered on the exterior with Tyvek© homewrap and the siding then installed such that cellulose insulation can be sprayed in the wall cavities and below the windows as the siding is attached. The finished wall is then sealed and the insulation is contained by the Tyvek© on the exterior. This system worked extremely well but it only worked well because the new window openings were sealed with foam sealant and the vapor barrier caulked to the inside of the window frame. The vapor barrier itself was of good quality, and had the confidence of the retrofit team that it did indeed stop most of the moisture at the inside wall. These two photographs (Figures 2 and 3) are indications of one way to amply retrofit a wall of a house to achieve a good result. The wall shown in Figure 3 resulted in approximately an R-27 wall when it was originally about R-11. This nearly tripled the insulating value of the wall.

3. The interior of the wall may also be vapor proofed by a vapor resistant wallpaper. Regular vinyl wallpaper may be waterproof and washable, but not necessarily vapor proof. The permeability should be specified by the manufacturer and not be greater than 0.750 perms.

4. After the wall has been properly vapor proofed, mineral wool or cellulose may be blown into the wall through 1½-inch to 2-inch plugs cut through the exterior siding and sheathing in every cavity between the studs. Cavities under windows should also be insulated.

5. A more expensive and drastic method is to remove all interior wall covering, place 3½ inches of insulation between the studs, cover with 6 mil polyethylene and then install new gypsum board or paneling.

Basement

An uninsulated basement can cause a large portion of the heat loss in a house. Heat loss may be evident by melting of snow along the foundation wall.

The following steps may be taken to insulate a basement of an existing house.

1. It is always more effective and less likely to cause basement moisture problems if the basement is, and can be insulated on the outside of the wall, and below grade (below the soil surface). There are excellent extruded polystyrene rigid board insulations which are ideal for this application. Insulating basements and heated crawlspaces from the outside prevents moisture problems, and keeps inside wall surfaces warmer and dry. It is highly preferable to any interior insulation on basement walls, and should be the preferred option whenever possible. Always protect the outside surface from physical damage and insects with a permanent protective sheathing.

2. The basement of an existing house may be insulated from within by installing 2 inch x 4 inch nailers at 16-inch centers on the wall. Place 2 or 3½ inches insulation between the nailers. Over this place a 6 mil polyethylene vapor barrier. The vapor barrier may be covered with gypsum board and suitable paneling.

3. Foamed plastic may be sprayed between the nailers. However, a polyethylene vapor barrier should be placed over the insulation and nailers. Also, rigid foam plastic insulation board may be used.

Closed Crawl Spaces

A masonry crawl space of a home can account for 45 per cent of the heat loss depending on the temperature required to maintain a warm floor surface temperature. Heat loss is often evident by melting of snow along the foundation wall.

The guidelines below may be used to insulate a closed crawl space.

1. Excavate a trench along the wall to the depth of the footer for placement of insulation. Attach 2 or perhaps 3 inches of rigid polystyrene or urethane board on the interior of the masonry or concrete foundation wall depending on the severity of the climate. Sprayed-on urethane may also be used on the exterior of the foundation, as can extruded

polystyrene. Spray on foams need durable protective sheathing to keep from damaging the foam.

2. The foundation vents should be replaced with permanent closures.

3. For additional comfort and fuel savings, the floor of the crawl space may be covered with a 2 inch layer of rigid polystyrene. A 6 mil polyethylene vapor barrier should be placed under the insulation. The insulation should be covered with 4-to 6-inches of sand and gravel. This system also can aid in reducing radon induction into a crawlspace or basement.

Floors Over Unheated Crawl Spaces

A floor over an unheated crawl space should be provided with as much or greater insulation than the ceiling, since it is the closest surface upon which we work, play and relax during waking hours. However, it is still not possible to attain an ideal floor temperature without installing insulated skirting around the foundation, which must be done with extreme caution in permafrost zones.

Slab-On-Grade

Slab-on-grade is not recommended for Alaska except in a basement. Insulating the floors and foundations of a house with a concrete floor is difficult at best. Ideally, in a new home, the perimeter of the floor area should be insulated with at least 2 inches of polystyrene or urethane, with a 48 inch strip laid around the perimeter. It is very costly to provide sufficient heat to raise the floor surface temperature comparable to room air temperature. A cold floor results in stratification of air such that the thermostat must be set at 75° F to maintain a comfortable temperature at the floor. This can result in temperatures near the ceiling as high as 85° F. (See also the *Manual on Frost Protected Shallow Foundation Systems* noted on page 4.)

The following steps may be taken to insulate the foundation wall of a slab-on-grade house.

1. Excavate a trench around the perimeter of the house and install 2 inches vapor resistant extruded polystyrene high density board. The insulation should extend at least 32 inches below the surface. Foamed-in-place urethane is excellent, but it necessitates excavating a 4 foot wide trench to assure uniform foaming of insulation by the applicator. A rigid urethane or polystyrene board only requires a 1 foot wide trench to place the insulation. The foam plastic insulation above grade should be plastered or in some way protected against deterioration by ultraviolet light of the sun and mechanical damage by rodents, dogs and other pests.

2. A floating slab should be insulated by placing rigid insulation along the edges.

To insulate an existing concrete slab-on-grade, the following steps may be taken.

1. Install 2 inch x 3 inch or 2 inch x 4 inch treated (all weather wood) sleepers over the existing slab. A ¾ inch space should be left at the ends of sleepers to allow for possible expansion due to moisture adsorption.

2. The space between the sleepers may be insulated with 2 inches of polystyrene or urethane rigid board or foamed-in-place urethane.

3. A wood subfloor and/or finish flooring should be placed over the nailers. A ¾ inch clear space should be left around the perimeter of the subfloor and finish flooring to allow for possible expansion. A ¼ inch opening should be left behind or under the base molding to facilitate natural removal of water vapor that may condense out under the floor, particularly during summer when the heat may be turned off.

Exterior Retrofit of Vapor-Sealed Insulation

Insulation products with low water-vapor permeability are used for exterior retrofit of insulation. These insulations include closed-cell polystyrene foams and foil-faced plastic foams which are usually available in 2 foot x 8 foot or 4 foot x 8 foot sheets. Both types of insulation are excellent vapor barriers and, therefore, must be applied with special precautions to the exterior of structures. Otherwise, moisture could accumulate in the wall and be trapped by this new exterior vapor barrier.

Refer to manufacturer's recommended installation procedures whenever you use these types of insulation, and contact the Cooperative Extension Service at 1-800 478-8324 for further information.

The following Cooperative Extension Service publications are suggested:

EEM-00258, *Heat Loss Coefficients of Building Material*

HCM-00559, *Attics & Roofs for Northern Residential Construction*

HCM-00952, *Special Considerations for Building in Alaska*

HCM-01552, *Retrofit Insulation in Wood Roofs*

HCM-01553, *Retrofit Insulation in Concrete and Masonry Walls*

HCM-01554, *Retrofit Insulation in Existing Wood Walls*

EEM-01252, *Caulks and Sealants*

Reference

Environmental Building News, Vol. 16, Number 7, pp.18-19. July 2007.

See also Chapter 10, "Retrofit," of the latest Alaska Housing Manual, copyright AHFC, 2006.

BYGGFORSK

NBI: A525.403

RETROFIT INSULATION in WOOD ROOFS

ALASKA BUILDING RESEARCH SERIES HCM-01552

Introduction

This publication is one of nine that has been translated from Norwegian. They are taken from a series of publications produced by the Norwegian Building Research Institute (NBI) series, "Byggdetaljer," which literally translated means "building details." It is hoped that Alaskan builders will be able to glean useful ideas from these publications. The translations were done by Dr. Nils Johanson and Richard D. Seifert of the University of Alaska Fairbanks with the cooperation and permission of NBI, Oslo, Norway. The financial support for the translations and printing came through the Alaska Department of Community and Regional Affairs, from USDOE Grant DE-FG06-80CS6908. The publications use the original index code of the Norwegian "Byggdetaljer" series so that specific translations can be directly cited. All questions on these translations should be directed to Richard D. Seifert, Cooperative Extension Service, P.O. Box 756180, University of Alaska Fairbanks, Fairbanks, Alaska 99775-6180. Phone: 907-474-7201

0 GENERAL

01 This bulletin describes how wooden roofs can be retrofitted with additional insulation to improve the thermal efficiency of the house. Suggestions are provided for suitable ways to retrofit wooden roofs, the various insulation methods available are outlined, and U values (heat transmission coefficient) for various insulation thicknesses are given.

02 Retrofitting insulation in roofs with poor thermal insulation (high U value) reduces the heating cost, reduces the tendency for ice formation on the roof, and provides a more comfortable internal climate. In order to estimate the appropriate insulation thickness and determine the best insulation method, consider the climate, construction, architectural design, need for replacement of internal ceiling, historical value of the building, and the types of surrounding buildings.

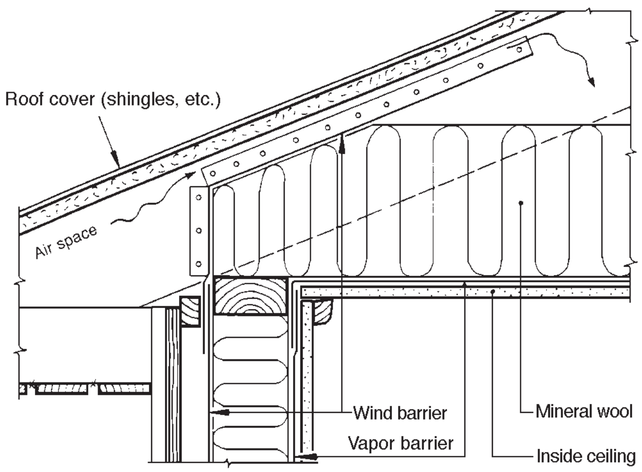
For many houses it is especially economical to insulate the ceiling or roof. The ceiling often has a larger surface area than the walls and it is usually simpler to improve. Retrofitting insulation in roofs must, however, be considered along with the possible need for insulating floors and walls and improvement or replacing poor windows.

03 Ventilated wooden roofs are usually constructed in the following order (from the outside to the inside):

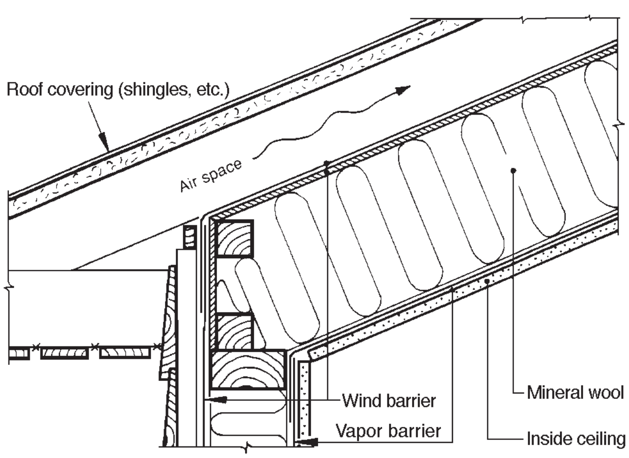
a. Roof cover (typically shingles)
b. Air space
c. Wind tight cover (building cardboard or wind tight sheathing)
d. Thermal insulation
e. Air and vapor barrier (polyethylene)
f. Ceiling finish material

The structural system varies.

Older roofs are as a rule not constructed in this manner. The insulation must therefore fit the actual construction of the existing roof and be coordinated with other work that is necessary or desirable to do at the same time. To avoid damage or poor results, it is important to consider that the retrofit insulation and ceiling will alter the temperature conditions in the roof. Parts of the roof that were warm before can be cold, intensifying condensation problems. The danger of condensation is greatest above rooms with high relative humidity, such as bathrooms, kitchens, or rooms which are cyclically heated and have insufficient ventilation. In houses with good ventilation and low relative humidity, there is little danger of condensation, provided no air leaks from the living area into the roof cavity.



a



b

Figure 03
Correctly constructed ventilated (cold) wooden roof
a) w/ horizontal ceiling
b) w/ cathedral ceiling

1.0 MATERIALS

1.1 Wood materials

The wood must be dry, straight, and without cracks. Wood that will be subjected to moisture for long periods should be preserved.

1.2 Thermal Insulation

Use rigid foam plastic boards or fiberglass batts. The standard width, 570 mm (23 in), fits between nailing boards and beams or rafters that are 600 mm (24 in) center to center. The length can vary from 870 mm (34 in), fitting between nail boards that are 900 mm (36 in) center to center, to 1200 mm (48 in) and longer. Use fiberglass without paper backing. Hollow spaces can also be filled by blowing in shredded mineral wool.

1.3 Windbarrier

Sealing against wind penetration now done with Tyvek® or equivalent air barrier materials.

1.4 Vapor barrier

As a diffusion break, use polyethylene plastic or foil-covered cardboard with a vapor diffusion number of 0.01 g/m^2 h mm mercury. This is equivalent of a material with a “perm” rating of 1.0 or less. For polyethylene, the recommended thickness is at least 6 mil so that the foil will not be torn during construction.

2.0 EXECUTION OF WORK

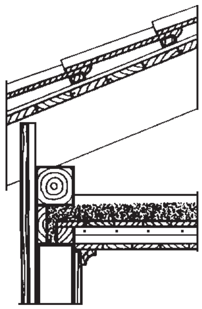
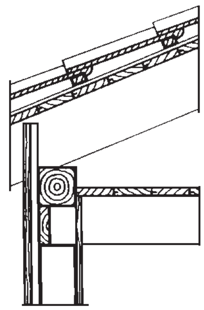
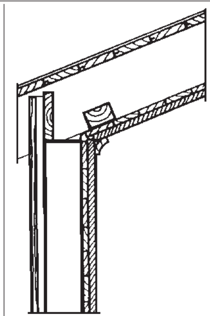
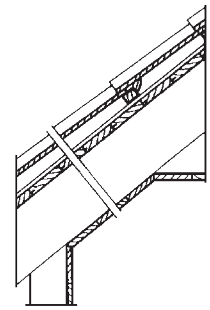
Table 2 shows U values for various roof types with retrofit insulation with mineral wool. Details of older roof construction can vary depending upon local building customs and the age of the building. The given U values are approximate.

2.10 Attic joists

An example of joists with insulation is shown in figure 2.10.

2.11 Insulating from the outside (topside) will cause minimal changes on the inside and will allow continuous insulation over the entire roof. Avoid reducing the attic ventilation, and insure that there are no air leaks from the warm side of

Table 2
U values (W/m²-°C) (BTU/hr-ft²-°F) for roofs using different methods of retrofit.

Insulation method	Mineral Wool thickness in mm (in)	 Open beams w/ various fill insulation in cold attic*	 Beams w/o fill insulation in cold attic	 Roof w/sloped interior ceiling	 Roof w/ partially warm attic
As before	—	1.46	2.54	1.40	2.09
Insulation from the outside	50mm (2 in) 100mm (4 in) 150mm (6 in)	0.60 0.37 0.26	0.67 0.39 0.28	— — 0.33	— — —
Insulation from the inside	50mm (2 in) 100mm (4 in) 125mm (5 in) 150mm (6 in)	0.54 0.27 0.37 —	— 0.42 0.29	0.52 0.35 —	— — —
Pneumatically placed mineral wool	50mm (2 in) 100mm (4 in) 150mm (6 in)	0.66 — —	— — —	— — 0.33	— — —

* 50 mm clay

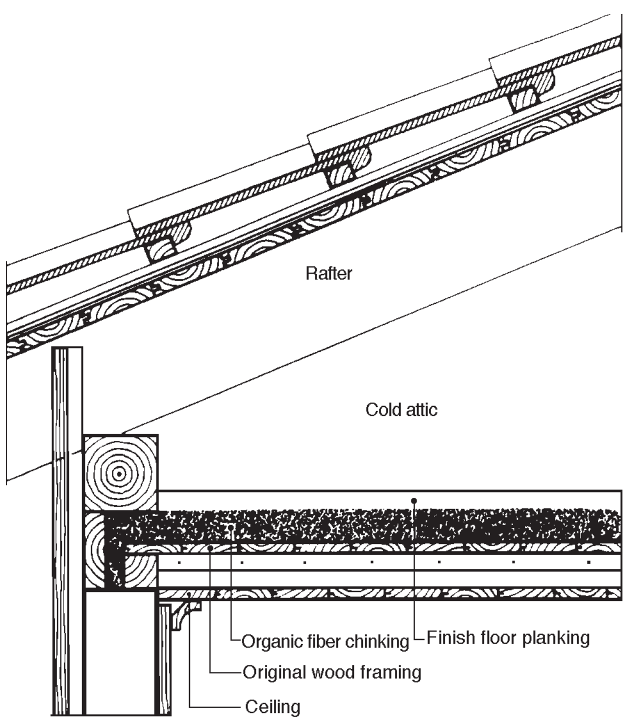


Figure 2.10
Attic beams with organic fiber chinking (the space between the beams forming the attic floor).

the ceiling. The original insulation between the joists can either be removed and replaced with mineral wool which will fit the joist spacing, or mineral wool can be placed over the existing insulation. In either case, consider whether the ceiling is sufficiently air and vapor tight to avoid condensation. Carefully seal areas where perforations occur. If there is doubt about the integrity of the internal sealing, install a new vapor barrier and a ceiling (Figure 2.11).

Insulation can be placed directly on the attic floor if it is not being used. It is advisable, however, to install a walkway over the insulation along the middle of the attic.

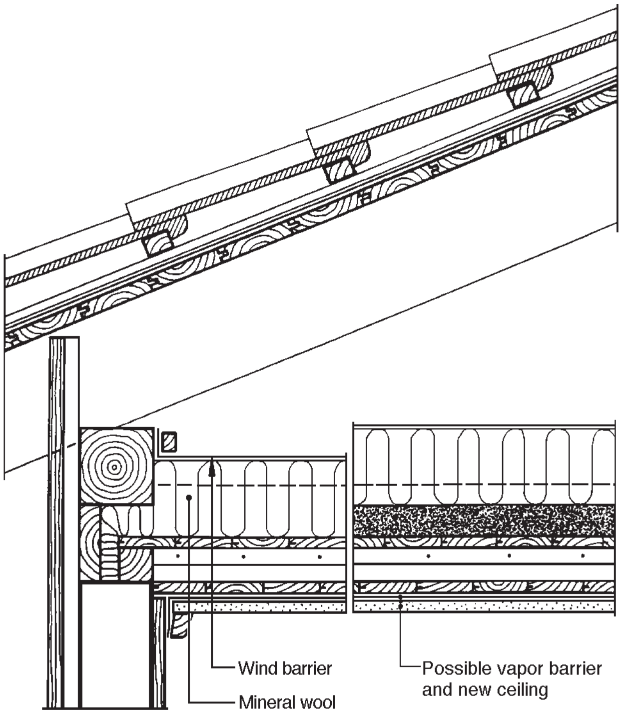


Figure 2.11
Attic floor joists insulated from above.

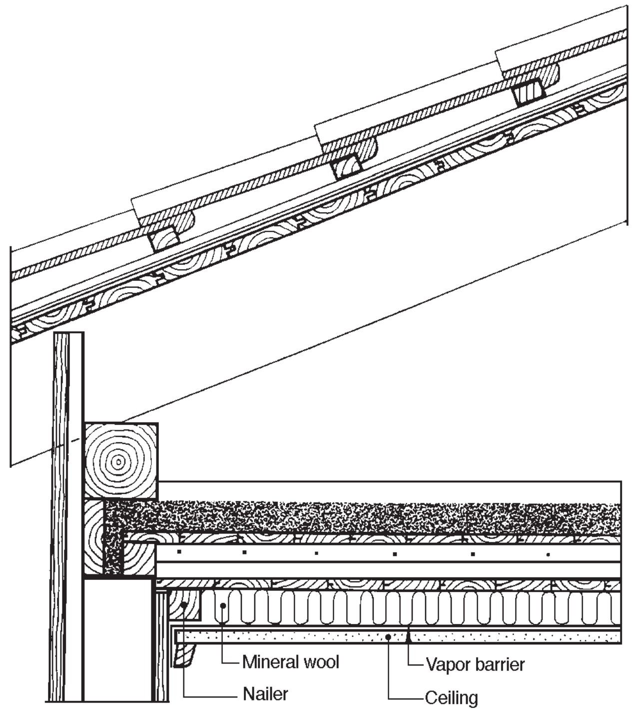


Figure 2.12
Attic floor insulated from below.

2.12 If insulation is being done one room at a time, or if a new internal ceiling is being installed, mineral wool can be placed between nailers 600 mm (24 in) center to center. The nailers should be attached directly to the old ceiling. Finally, a new vapor barrier with sealed joints and a new ceiling should be installed (Figure 2.12).

2.13 If the space between the existing ceiling and the attic is at least 50 mm (2 in), it may be possible to blow mineral wool into the hollow space (Figure 2.13). Before doing so, however, an expert should look over the condition of the roof to avoid damage. The pneumatic placement of mineral wool must be done by special companies employing trained professionals.

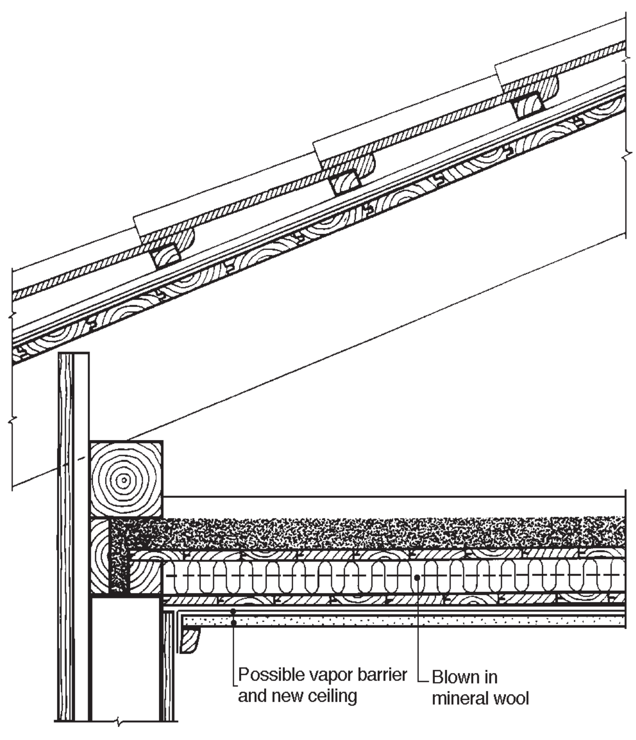


Figure 2.13
Attic floors insulated with blown in mineral wool. If the existing ceiling is sufficiently tight with respect to air leaks, a new vapor barrier is not necessary.

2.20 Attic floor (without insulation)
An example of a floor with tongue and groove boards is shown in Figure 2.20.

2.21 If exposed beams are desired, the attic floor can be insulated on the top side. First, install a vapor barrier over the entire ceiling. The vapor barrier must be joined and sealed tightly along the outer walls. If a floor is needed, install nailers 600 mm (24 in) center to center and place mineral wool between them. If the attic will not be used, the mineral wool can be placed directly on the attic floor. Install an air barrier over the insulation. See point 2.11.

2.22 The floor can be insulated from the underside by placing mineral wool in the space between the floor joists. Sheets or batts of mineral wool must be cut to fit so that they are 20 mm (1 in) wider than the space between the joists. If this is done properly, the mineral wool will stay in the space between the beams until a vapor barrier and ceiling is installed.

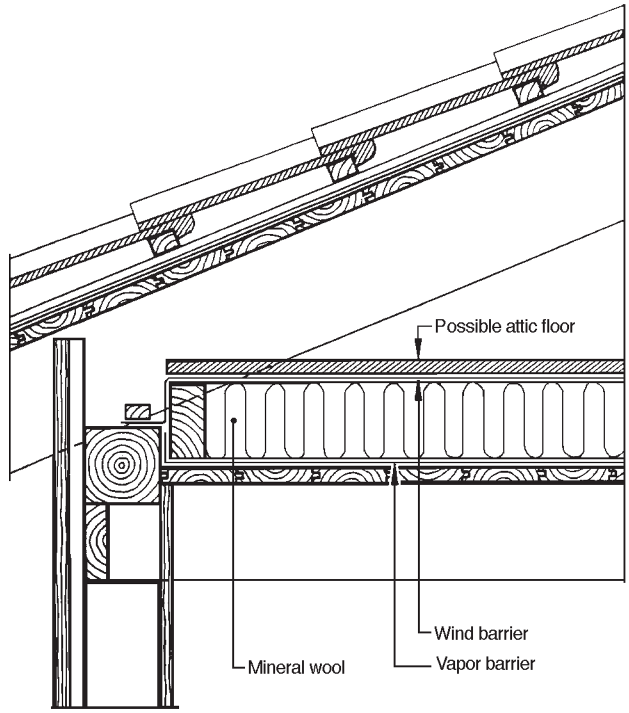


Figure 2.21
Beams without organic fiber chinking insulated from above.

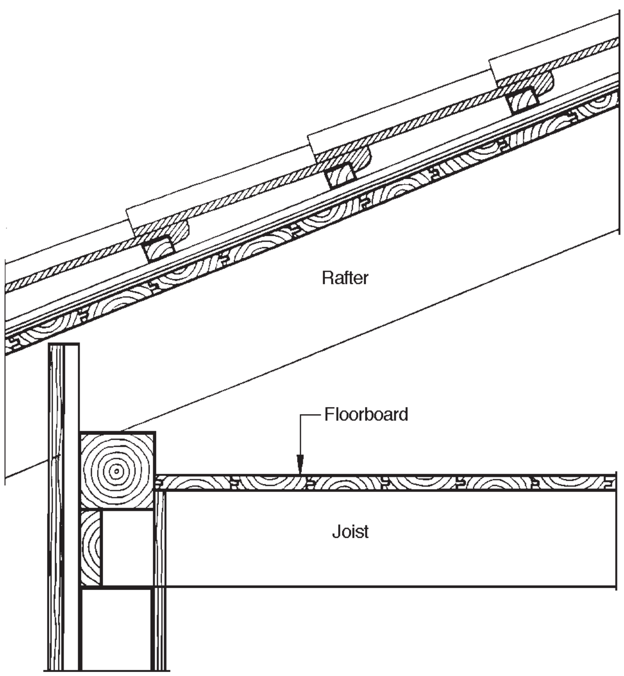


Figure 2.20
Attic floor with no insulation

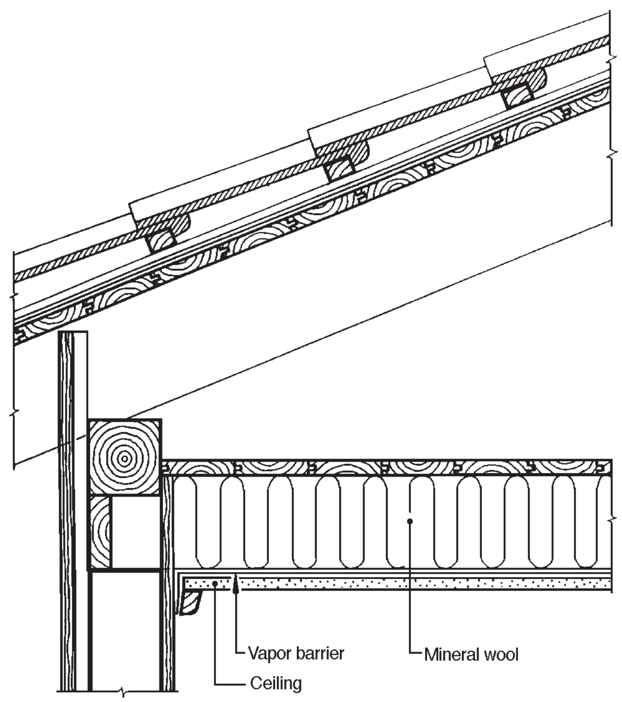


Figure 2.22
Attic floor insulated from below.

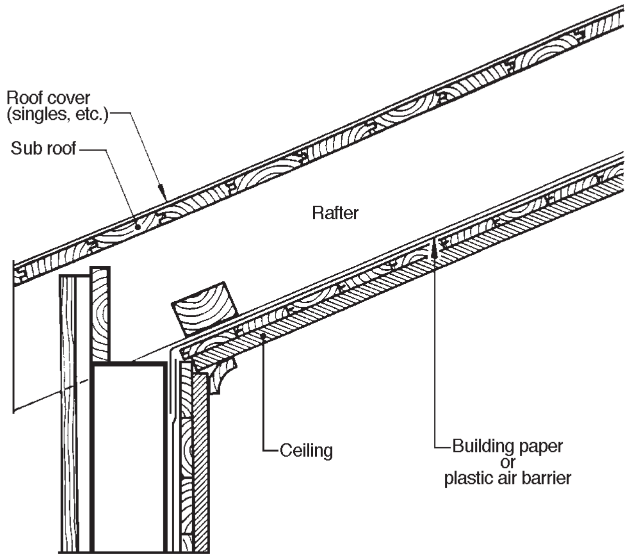


Figure 2.30

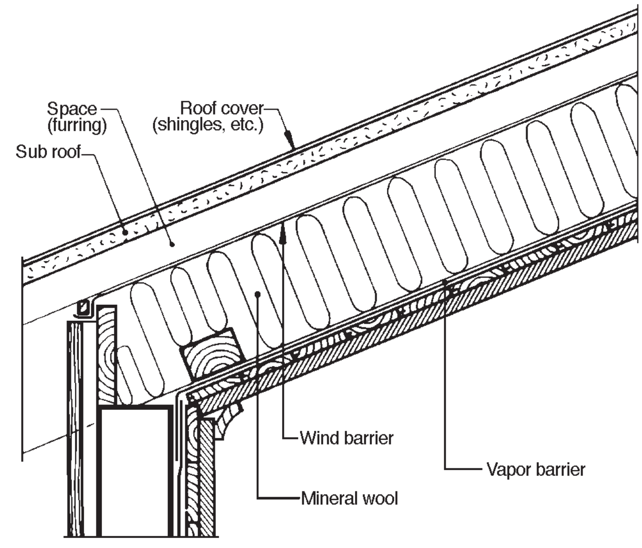


Figure 2.31
Roof with cathedral ceiling insulated from above.

2.30 Roofs with cathedral ceiling
An example of an uninsulated roof with cathedral ceiling is shown in Figure 2.30.

2.31 Special design considerations for preventing snow melt are needed when adding insulation from the outside of the roof The old roof must be opened from above and new mineral wool must placed in the area between the rafters. A wind barrier must be installed over the mineral wool. The new roofing must then be shimmed up 50 to 100 mm (2 to 4 in) to ensure sufficient ventilation (Figure 2.31).

2.32 When insulating from the inside, the mineral wool must be placed between nailers 600 mm (24 in) center to center. The nailers should be fastened directly to the old ceiling. Install a vapor barrier with sealed joints, and finally, a new ceiling.

2.33 By building up a new roof on the old roof it is possible to insulate by blowing mineral wool into the hollow space. See Figure 2.33 and Point 2.13.

2.40 Roof over an attic space in 2 story house. An example of such roof construction is shown in Figure 2.40.

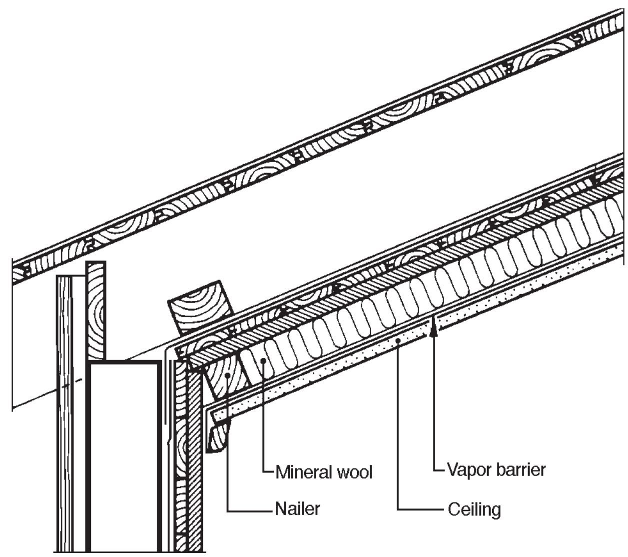


Figure 2.32
Roof with cathedral ceiling insulated from below.

2.41 In older buildings, when insulating the roof between a knee wall and a horizontal ceiling, fill the entire hollow area between the internal paneling and the roof with mineral wool. It may, however, be difficult to place the insulation. In many cases it must be threaded in from above or pushed up from below. In other cases it is necessary to break up the internal paneling or wall covering to gain access. If walls are damaged, install a vapor barrier before a new internal covering is put on.

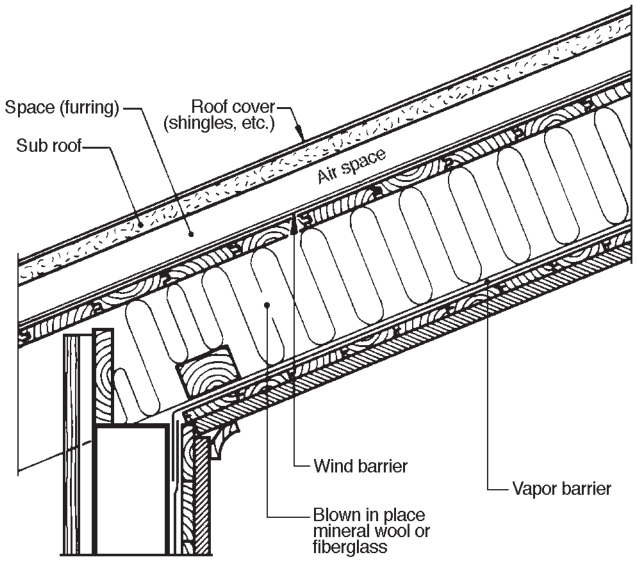


Figure 2.33
Roof with sloping ceiling insulated with pneumatically placed mineral wool.

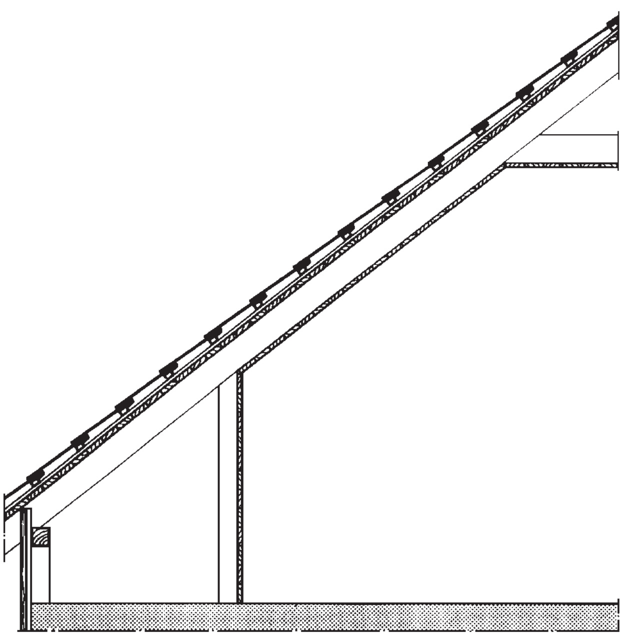


Figure 2.40
Roof over attic or finished room in 2 story house

2.50 Joists: To avoid reduced insulation performance, drafts, and condensation it is important that all wind and vapor barriers are tightly sealed against the adjoining framing. The joints must always be pressed between two solid backing layers. The mineral wool must completely fill the space into which it is placed.

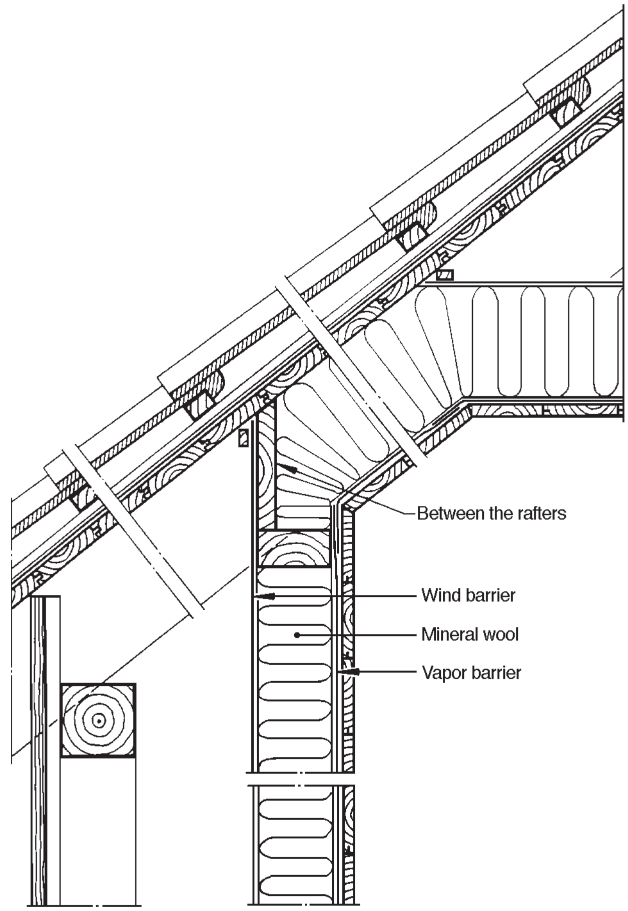


Figure 2.41
Insulation of room in a 2 story house.

3.0 REFERENCES

3.10 This bulletin was developed and edited by Knut I. Edvardsen. The editing was completed in September 1977.

Translated into English by Dr. Nils Johansen and Richard D. Seifert, University of Alaska Fairbanks, November 1989.

Revised and reviewed February 1997, by Axel R. Carlson, professor emeritus, University of Alaska Fairbanks and Dr. John P. Zarling, Department of Mechanical Engineering, University of Alaska Fairbanks.

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(Publications with corporate authors are alphabetized by the title of the publication for easier location)

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Additional information available at:

Cooperative Extension Service
U. S. Department of Agriculture
University of Alaska Fairbanks
P.O. Box 756180
Fairbanks, Alaska 99775-6180
Phone: (907) 474-7201
or 1 (800) 478-8324
www.uaf.edu/coop-ext/faculty/seifert/energy.html

Appendix 1
Alaska Building
Energy Efficiency Standard

New Alaska Building Energy Efficiency Standard
Effective April 1, 2007

The Alaska Building Energy Efficiency Standard, Second Printing, January 1, 2002 will be replaced on April 1, 2007.

Residential housing constructed on or after April 1, 2007* must meet the new Alaska Building Energy Efficiency Standard of April 1, 2007 which consists of:

1. The International Energy Conservation Code (IECC) 2006, Second Printing, which includes
2. ASHRAE Standard 62.2-2004 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings with
3. **Alaska-Specific Amendments to the IECC 2006 and ASHRAE Standard 62.2-2004 adopted November 8, 2006** by Alaska Housing Finance Corporation (AHFC)

The International Energy Conservation Code (IECC) 2006, Second Printing is available for purchase from the International Code Council at 1-800-786-4452 (www.iccsafe.org), or through local or on-line bookstores.

The ASHRAE Standard 62.2-2004 is available for purchase from American Society of Heating Refrigerating and Air-Conditioning Engineers at 1-800-527-4723 (www.ashrae.org), or through local or on-line bookstores.

Alaska-Specific Amendments to the IECC 2006 and ASHRAE Standard 62.2-2004 adopted November 8, 2006 is available from Alaska Housing Finance Corp. at 1-800-478-4636 0r 330-8164 (Anchorage).

•AHFC considers construction to have begun if the pilings, footings, or foundation has been started.

Please note:

- Energy ratings will continue to be utilized as a method of meeting thermal compliance of the energy standard.
- ASHRAE 62.2-2004 will be the only option for meeting ventilation compliance of the energy standard.
- A new version of the AHFC PUR-101 form will be utilized to show compliance with the new standard.

For specific questions on new requirements contact:

Scott Waterman
Alaska Housing Finance Corporation (AHFC)
PO Box 101020
Anchorage, AK 99510-1020
800-478-2432 (Alaska)
907-330-8195 (Anchorage & Outside Alaska)
907-338-1747 fax

Alaska Housing Finance Corporation

Alaska-Specific Amendments to the IECC 2006 and ASHRAE Standard 62.2-2004

November 8, 2006.

This document is a list of Alaska-specific amendments to the International Energy Code 2006, Second Printing, May 2006 (IECC 2006) and the ANSI/ASHRAE Standard 62.2-2004, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, (ASHRAE 62.2-2004) that were adopted by reference in 15 AAC 155.010 on November 8, 2006. It is meant to be read in conjunction with the IECC 2006 and ASHRAE Standard 62.2-2004, which may be purchased at local bookstores. The amendments are numbered and organized by the chapter and section numbers found in the IECC 2006 and ASHRAE 62.2-2004, respectively. Immediately following are amendments to IECC 2006, the ASHRAE amendments are in IECC subsection 403.7:

Chapter 1 – Administration.

101.4.3 Additions, alterations, renovations or repairs.

Applicability of the IECC and Alaska Specific Amendments shall be limited to new construction only for the purposes of this document, and shall not apply to additions, alterations, renovations, or repairs.

101.4.4 Changes in Occupancy.

For the purposes of this document, this section is deleted.

CHAPTER 3 - Climate Zones

301.1 General.

IECC 2006 Figure 301.1 and Table 301.1 shall be replaced with Table A301.1, below. To determine the IECC Climate Zone for a community, find the community in the climate region list below, note the climate region number, and then find the corresponding zone in Table A303.1. Zones for urban communities may be read directly from Table A301.1.

Table A301.1 - Climate Zones for Alaska

IECC zones for Alaska	HDD[a] Range (IECC)	BEES Climate Regions	HDD[a] Range (BEES)
Zone 6	7200 - 9000	Region 1	7000-10,700
Zone 7	9000 -12,600	Region 2	8600-13,500
Zone 8_{urban}	12,600 -16,800	Region 3&4 – Fairbanks Borough	11,300-17,700
Zone 8_{rural}	12,600 -16,800	Region 3&4 – non-urban Interior, Southwest, & Northwest	11,300-17,700
Zone 9	16,800 -21,000	Region 5 – Arctic Slope	16,900-20,300

a. HDD = Heating Degree Day

Climate Region Lists

For consistency, these are the same regional lists as in the previous standard (BEES). In cases where the HDD for a community is significantly outside of the HDD range for the assigned IECC zone, the community may request to be placed in a more appropriate zone. Note, however, that the rural sub-zone for Zone 8 has been created to allow for the higher cost of energy away from the Fairbanks North Star Borough.

REGION 1
SOUTHEAST
Alder Cove
Angoon
Annette
Annex Creek
Auke Bay
Baranof
Beaver Falls
Bell Island
Canyon Island
Chenega
Chichagof
Coffman Cove
Craig
Edna Bay
Eldred Rock
Elfin Cove
Five Finger Lt
Glacier Bay
Gull Cove
Gustavus
Haines
Hollis
Hoonah
Hydaburg
Hyder
Juneau
Kake
Kasaan
Ketchikan
Klawock
Klukwan
Kupreanof
Metlakatla
Myers Chuck
Lincoln Rock
Litl Port Walter
Moose Valley
Ocean Cape
Pelican
Petersburg
Port Alexander
Port Baker
Port Protection
Saxman
Seclusion Hbr.
Sitka
Skagway
Smuggler Cove
Snettisham
Tenakee Spgs
Thorne Bay
View Cove
Wrangell
Yakutat

REGION 2
SOUTHCENTRAL, ALEUTIAN, KODIAK
Adak
Afognak
Akhiok
Akutan
Anchor Point
Anchorage
Anderson
Atka
Attu
Belkofski
Big Lake
Cape Sarichef
Caswell
Chickaloon
Chignik

Chignik Lake
Chiniak
Chulitna
Clam Gulch
Cold Bay
Cold Harbor
Cooper Lndg
Cordova
Curry
Diamond Ridge
Driftwood Bay
Dutch Harbor
Eklutna
Elmendorf
English Bay
False Pass
Fort Glenn
Fort Richardson
Girdwood
Homer
Hope
Houston
Ivanoff Bay
Kachemak
Kaguyak
Karluk
Kasilof
Kenai
King Cove
Knik
Kodiak
Kulis ANGB
Larsen Bay
Latouche
Mat. Ag. Exp.
Middleton Is.
Moose Pass
Naptowne
Nelson Lagoon
Nikiski
Ninilchik
Nikolski
Old Harbor
Ouzinkie
Palmer
Perryville
Petersville
Pillar Mountain
Portage
Port Graham
Port Heiden
Port Lions
Port Moller
Portlock
Rabbit Creek
Salamatof
Sanak
Sand Point
Sawmill
Seldovia
Seward
Shemya
Skwentna
Soldotna
Squaw Harbor
Starisky Creek
Sterling
Summit
Susitna
Sutton
Talkeetna
Tatitlek
Tahneta Pass
Thompson Pass
Trappers Creek
Tyonek
Unalaska
Unga Island
Valdez
Wasilla
Whittier
Willow
Women's Bay
Yakataga Bay

REGION 3

INTERIOR, SOUTHWEST

Akiachak
Akiak
Alakanuk
Aleknagik
Allakaket
Anderson
Aniak
Anvik
Atmautluak
Aurora
Beaver
Beaver Creek
Bethel
Bettles
Big Delta
Big Mountain
Bill Moore's
Birch Creek
Black Rapids
Boundary
Canyon Creek
Cap.Newenham
Cape Romanzof
Cathedral Rpds
Cantwell
Central
Chalkyitsik
Chandalar
Chandalar Lake
Chatanika
Chauthbaluk
Chefornak
Chena Hot Spg
Chevak
Chicken
Chistochina
Chitina
Chuloonawick
Circle
Circle Hot Spgs
Clark's Point
Clear
Coldfoot Camp
College
Copper Center
Crooked Creek
Delta Junction
Dillingham
Donnelly
Dot Lake
Dry Creek
Eagle
Eek
Egegik
Eielson
Ekuk
Ekwok
Emmonak
Ester
Eureka
Evansville
Fairbanks
Farewell
Ferry
Flat
Fort Greeley
Fort Wainwright
Fort Yukon
Fox
Gakona
Galena
Gerstle River
Georgetown
Glennallen
Gold King Cr
Goodnews Bay
Grayling
Gulkana
Hamilton
Harding Lake
Healy
Healy Lake
Holy Cross
Hooper Bay
Hughes
Huslia
Iguigig
Illiamna
Indian Mtn
Kalskag
Kaltag
Kanatak
Kasigluk
Kennicott
Kenny Lake
King Salmon
Kipnuk
Knob Ridge
Kohkanok
Koliganek
Kongiganak
Kotlik
Koyukuk
Kwethluk
Kwigilingok
Lk.Minchumina
Lime Village
Livengood
Lower Kalskag
Lower Tonsina
Manley Hot Sp
Manokotak
Marshall
Ma Creek
McCallum
McCarthy
McGrath
McKinley Park
Medfra
Mekoryuk
Mentasta Lake
Minto
Mountain Vil.
Murphy Dome
Naknek
Napakiak
Napamiute
Napaskiak
Nebesna
Nenana
Newhalen
New Stuyahok
Newtok
Nightmute
Nikolai
Nondalton
North Pole
Northway
Northway Jct
Nulato
Nunapitchuk
Ohogamiute
Ophir
Oscarville
Paimuit
Paxson
Paxson Lake
Pedro Dome

Pilot Point
Pilot Station
Pitka's Point
Platinum
Port Alsworth
Quinhagak
Rampart
Red Devil
Richardson
Russian Mission
Ruby
Saint George
Saint Mary's
Saint Matthew
St. Paul Island
Salchaket
Scammon Bay
Shageluk
Sheldon Point
Slana
Sleetmute
Slide Mountain
South Naknek
Sparrevohn
Stevens Village
Stony River
Suntrana
Summit
Takotna
Tanacross
Tanana
Tatalina
Telida
Tetlin
Togiak
Tok
Toksook Bay
Tonsina
Tuluksak
Tununak
Tuntutuliak
Twin Hills
Ugashik
Upper Kalskag
Usibelli
Unkumiute
Venetie
Wiseman

REGION 4

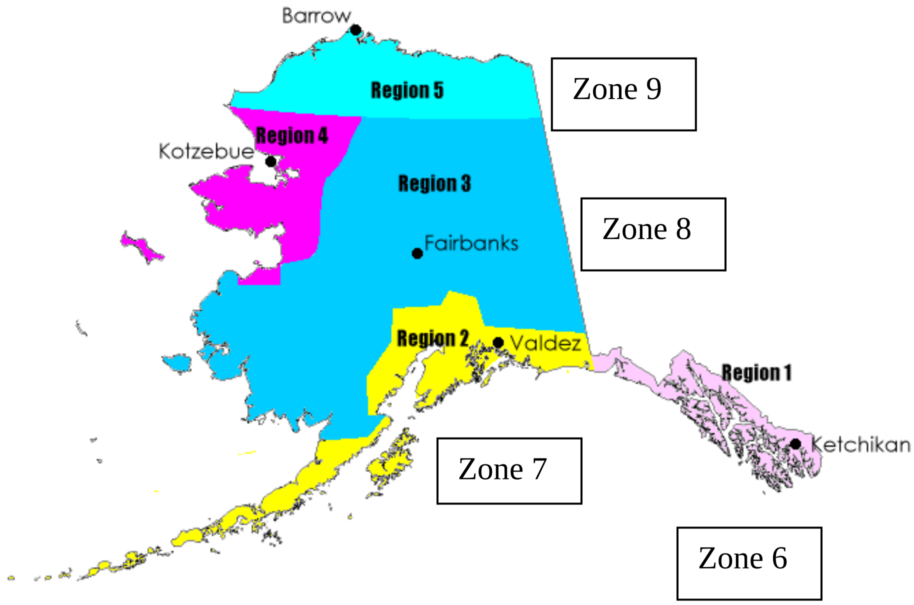
NORTHWEST

Ambler
Anvil Mountain
Brevig Mission
Buckland
Candle
Council
Deering
Diomede
Elim
Gambell
Golovin
Granite Mtn
Haycock
Kalakaket Cr
Kiana
King Island
Kivalina
Kobuk
Kotzebue
Koyuk
Mary's Igloo
Moses Point
Noatak
Nome
Noorvik
Northeast Cape
North River
Savoonga
Selawik
Shaktoolik
Shishmaref
Shungnak
Solomon
Stebbins
St. Michael
Teller
Tin City
Unalakleet
Wales
White Mountain

REGION 5

ARCTIC SLOPE

Anaktuvuk Pass
Arctic Village
Atqasut
Barrow
Cape Lisburne
Deadhorse
Kaktovik
Nuiqsut
Oliktok
Point Hope
Point Lay
Prudhoe Bay
Sagwon
Umiat
Wainwright


Barrow
Region 5
Zone 9
Region 4
Kotzebue
Region 3
Zone 8
Fairbanks
Region 2
Valdez
Region 1
Ketchikan
Zone 7
Zone 6

CHAPTER 4 - RESIDENTIAL ENERGY EFFICIENCY

402.1 General. (Prescriptive).

IECC 2006 Sections 402.1 through 402.3 describe the prescriptive method for compliance and establish minimum thermal envelope insulation requirements for buildings. Exceeding these minimums is encouraged. IECC 2006 Tables 402.1.1 and 402.1.3 shall be replaced with Tables A402.1.1 and A402.1.3, respectively. In these replacement tables, only the zones applicable to Alaska are given (i.e., 6-9). These zones are defined in Chapter 3. When using the Prescriptive Method as the means of compliance, all mandatory measures specified in Section 403 shall also be accomplished.

Table A402.1.1 Insulation and Glazing Minimum R-values by Component

Climate Zone	Windows & Skylights	Ceiling[a]	Exterior Frame Wall	Floor	Below Grade Wall[b]	Slab[c] & Depth	Crawl Space Wall[b]
6	3	49 or 38	20	30	15/19	15, 4ft	15/19
7	3	49 or 38	20	30	15/19	15, 4ft	15/19
8U	4	49 or 38	25	38	15/19	15, 4f	15/19
8R	4.5	49 or 38	30	38	15/19	15, 4f	15/19
9	5	65 or 52	35	43	NR	NR	NR

a. The smaller value may be used with a properly sized, energy-heel truss.
b. The first R-value applies to continuous insulation, the second to framing cavity insulation; either meets the requirement.
c. R-5 shall be added to the required slab edge R-values for heated slabs.

Table A402.1.3 Insulation and Glazing Maximum U-factors by Component[d]

Climate Zone	Windows & Skylights	Ceiling[a]	Exterior Frame Wall	Floor	Below Grade Wall[b]	Slab	Crawl Space Wall[c]
6	0.33	0.020	0.053	0.033	0.067/0.053	0.067	c
7	0.33	0.020	0.053	0.033	0.067/0.053	0.067	c
8U	0.25	0.020	0.040	0.026	0.067/0.053	0.067	c
8R	0.22	0.020	0.033	0.026	0.067/0.053	0.067	c
9	0.20	0.015	0.029	0.023	NR	NR	NR

a. The larger factor of 0.0263 (0.0192 for Zone 9) may be used with a properly sized, energy-heel truss.
b. The first U-factor applies to continuous insulation, the second to framing cavity insulation; either meets the requirement.
c. See below grade wall factors.
d. Nonglazing U-factors shall be obtained from measurement, calculation or an approved source.

402.2.1 Ceilings and attic spaces. Add at the end of the subsection: "And in a similar fashion, an uncompressed R-52 over the top plate will satisfy the requirement for R-65."

402.2.3 Mass walls. Delete this subsection. (Mass walls are not a significant energy saver in Alaska; see Seifert, R.D. and George S. Mueller, June 1983, *An Analytical Study of Passive Solar Energy and Mass Storage Observations from a Test Building at Fairbanks, Alaska*, Report #AK-RD-85-21, 50 pages plus appendices, published by the State of Alaska, Department of Transportation and Public Facilities.)

402.2.8 Crawl space walls. Replace the second sentence with "Crawl space wall insulation shall be permanently fastened to the wall and extend downward from the floor to the finished grade level and then either (a) vertically down to the top of the footer, or (b) vertically down and/or horizontally outward for a total of at least 36 inches." At end of subsection add: "*Exception:* This alternative is permitted if the only venting in the crawlspace is mechanical."

402.3.7 Skylights. [New subsection] In very cold climates, a skylight is essentially a low-R-value hot roof that is subject to ice damming and subsequent leakage; their use is strongly discouraged unless they are carefully designed to avoid these problems. The total skylight area shall not exceed 1% of the total ceiling thermal envelope area. A skylight sidewall that is not an integral part of a skylight product shall be insulated to the same R-value as the ceiling.

402.5 Moisture control. Add under Exceptions "4. A vapor retarder may be installed within the thermal insulation so long as the R-value of the thermal insulation on the warm side of the vapor retarder does not exceed one third of the total R-value. (Note that this is a statewide minimum and more restrictive values may be needed in the colder climate zones.)"

403.2.4 Duct material. [New subsection] A duct transporting ventilation air shall be constructed of a smooth-walled material, such as galvanized steel or lined fiberglass (rigid or semi-rigid), as much as possible. When necessary to use flexible ducting, it shall be supported along its full length with no sags and no bends greater than 90 degrees.

403.3 Mechanical system piping insulation. Add "Exception: piping carrying fluids above 105°F (41°C) within the thermal envelope."

403.5 Mechanical ventilation. Add second sentence: "An exterior exhaust vent shall be located to minimize exhaust air rising into an attic vent."

403.6 Equipment sizing and installation. Add at end of subsection: "The AkWarm design heating load methodology is an approved heating calculation methodology. All heating, cooling, and ventilating equipment shall be installed in accordance with the manufacturer's installation instructions and the requirements of this code."

403.7 Ventilation Standard. [New subsection] Ventilation must meet the ANSI/ASHRAE Standard 62.2-2004 as amended below.

The following amendments refer to the *ANSI/ASHRAE Standard 62.2-2004* and are numbered according to that standard.

Section 3 – Definitions. Add the following:

> ***Air change rate at 50 Pascals:*** the ***air change rate*** when a pressure differential of 50 Pascals in maintained between the inside and outside of the envelope; it is commonly abbreviated as ACH_{50}.

4.1 Ventilation Rate. Equations 4.1a and 4.1b shall be replaced by:

$$Q_{fan} = 0.01A_{floor} + 10(N_{br} + 1) \qquad \text{A(4.1a)}$$

and Tables 4.1a and 4.1b shall be replaced by

Table A4.1a, Ventilation Air Requirements, cfm

Floor Area (ft²)	Bedrooms				
	0-1	2-3	4-5	6-7	>7
<1500	35	55	75	95	115
1501-3000	50	70	90	110	125
3001-4500	65	85	105	125	145
4501-6000	80	100	120	140	160
6001-7500	95	115	135	155	175
>7500	110	130	150	170	190

4.1.1 Different Occupant Density. Replace “4.1a and 4.1b” with “A4.1a”, “Equation 4.1” with “Equation A4.1”, and “7.5 cfm (3.5 L/s)” with “10 cfm.”

4.1.3 Infiltration Credit. Delete this subsection. (ASHRAE is likely to delete this section because of the confusion that it causes; in any case, it was not intended to change the amount of mechanical ventilation air required.)

4.2 System Type. Add the following two sentences after the first one: “Supply-only systems are not permitted in Alaska during the heating season. Balanced, heat-recovery ventilation systems as described in Appendix B4.5 that provide well distributed ventilation throughout the entire occupiable space are strongly recommended in Alaska.”

4.5.2 Very Cold Climates. Delete this subsection. (In Alaska supply-only ventilation during heating season is not allowed.)

6.5 Garages. Third sentence, after "located in garages" insert "are not recommended."

6.6 Ventilation Opening Area. After the second sentence, add: "Ventilation air through an exterior door or operable window shall not be considered as part of a mechanical ventilation system design and shall not be included in proving compliance with the required minimum ventilation rate."

6.8 Air Inlets. [New subsection under ***Exceptions to 6.8***] (d) A ventilation system's supply and exhaust vents on the exterior of a building may be separated less than 10 feet as long as they are separated a minimum of 6 feet horizontally. They may be separated less than this if they are part of a system engineered to prevent entrainment of the exhaust air. Care should be taken to locate an intake vent where it can be easily cleaned at regular intervals.

7.1 Selection and Installation. Add at end of subsection: "A ventilation appliance should not be located in a space that is difficult or inconvenient to access such as a crawl space or attic if the appliance requires annual or more frequent maintenance (changing of filters, oiling, cleaning, etc.).

B4.4 Exhaust Ventilation. Add at the end of subsection, "In very cold climates, intakes that do not temper the incoming ventilation air have proven sufficiently problematic, that their use is strongly discouraged."

B4.7 Distribution and Circulation of Supply Air. [New subsection] A ventilation system should be designed and installed to uniformly mix and circulate supply air throughout the occupiable space. Supply air should be introduced into a room in a manner that does not create human discomfort and is not potentially damaging to the building. There should be adequate air circulation into and out of a room at all times. A door or transom louver, undercut door, wall transfer fan, return grille or other means should be used.

This is the end of the *ANSI/ASHRAE Standard 62.2-2004* amendments.

Section 404 - Simulated Performance Alternative (Energy Rating Method).

404.3 Performance-based compliance. Replace this subsection with following: Compliance with this code may be shown through a home energy rating under a program approved by the Alaska Housing Finance Corporation (AHFC) that meets the following requirements:

a) At least a Four Star plus rating to qualify.

b) An air-tightness level of 7 ACH_{50}, or less, utilizing an AHFC-approved blower-door testing protocol.

c) Only a person authorized by AHFC shall submit a rating for compliance. A copy of the energy rating shall be provided to AHFC officials. (A list of authorized home energy raters may be obtained from AHFC, Research Information Center.)

Delete the remainder of this section (404.4 – 404.6.3).

Chapter 5 - Commercial Energy Efficiency.

Delete chapter 5. (Alaska Statute 46.11.040 and AHFC regulations 15 AAC 155.010 - 15 AAC 155.030 only apply to residential buildings.)

Chapter 6 – Referenced Standards.

Add to the ASHRAE section: “62.2-2004 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.”

Appendix 2
Secondary Educational Standards Achieved Through This Manual

The following is a list of secondary educational standard achievements and curricular terms, which can be met using this manual as a text in secondary education. The listing of standards is by chapter. It is included here as an aid to teachers who may wish to use this manual as a text/curriculum for various secondary school courses.

Every attempt was made to conform this manual to the fulfillment of the State of Alaska curriculum requirements for secondary school students. The manual text was reviewed and the following credits for contributions to achieving the various state disciplinary curriculum requirements were researched and suggested by Ms. Ritchie Musick, former physics and science teacher at Lathrop high School in Fairbanks. These may not be comprehensive, but will help instructors choosing to use this text to justify it on many levels as fulfilling various requirements for credits in these curriculum areas.

The objectives of each chapter of the manual have been aligned with the Alaska State Content Standards in Science, Technology, Skills for Healthy Living, and Cultural. Because of the great quantity of technical material in each chapter this has been done for the chapter as a whole rather than by each individual objective.

Objectives	Science	Technology	Skills for Healthy Living	Cultural
Ch 1: A History of Northern Energy Efficient Housing				
To compare designs of pre-contact construction to modern construction	A1 E2, E3, F1 G1, G3			B2
To recognize the relation of climatic environmental characteristics and available materials to both prehistoric and modern dwelling construction				
To recognize the effect of post-contact construction techniques on native construction				
To summarize the evolution of building science technology in the north				
To describe climatic problems unique to northern latitudes				
Ch 2: Building Science Basics				
To understand the physical principles involved in building in the north	B2, B3 C3 D3	A2, A3, A5 C1 E1, E6	D2	
To enumerate the top ten building concepts				

Objectives	Science	Technology	Skills for Healthy Living	Cultural
To describe how energy enters a home and is used	E1			
To describe a building as a system				
To explain how heat moves by radiation,	B2, B3	A2, A3, A5	D2	
conduction, and convection	C3	C1		
To explain how to calculate heat loss	D3	E1, E6		
To explain how to control heat loss	E!			
To describe the principles of air flow				
To describe the measurement and control				
of air leakage				
To describe moisture flow, condensation, dew point				
and relative humidity within a house				
To describe permeance, air leakage, vapor diffusion,				
and capillary action within a house				
To describe ways to control water vapor and condensation				
To plan a vapor retarder design and its placement				
Ch 3: Building Materials				
To explain the key components for heat, air,	B1, B2,		D2	
and moisture control	B3, B4			
To describe the properties of wood				
To describe the properties of synthetic materials				
To describe the effects of building materials on air quality				
To discuss ecofriendly building materials				
To describe materials that can be used to control				
heat flow, air flow, and moisture flow				

Objectives	Science	Technology	Skills for Healthy Living	Cultural
To describe framing materials made of wood, engineered, wood, steel, and concrete	B1, B2, B3, B4		D2	
To relate building materials to health				
To describe green building materials				
To discuss materials incompatibilities				
Ch 4: Foundations, Floors, Basements, and Crawlspaces				
To explain what is meant by permafrost and its effects on building	B1, B2, B3, B4		D2	
To explain the importance of good drainage and level, plumb, and square construction				
To describe site preparation and leveling				
To describe means of preventing frost heave				
To explain the results of capillary break				
To describe the importance of designing foundation drainage				
To describe radon and its source and effects				
To describe the construction of different foundation types:				
Crawl spaces and full basements				
Frost Protected shallow foundation systems				
Post and pad foundations				
To describe seismic design considerations				
To introduce the design of the thermal envelope				

Objectives	Science	Technology	Skills for Healthy Living	Cultural
To describe ways of providing crawlspace ventilation: Passive perimeter venting Exhaust only fan Exhaust and supply fans Furnace supply and return air registers Heat Recovery Ventilators' (HRV) HRV supply and exhausts HRV balanced To describe differences in inside vs outside foundation insulation To discuss ways of building radon out To introduce grading, backfill, and drainage considerations for foundations To discuss the importance of foundation moisture control for energy performance.	B1, B2, B3, B4		D2	
Ch 5: Attics and Roofs				
To describe sources of moisture formation To discuss air and vapor retarder detailing To introduce the role of roofs and truss uplift To describe different kinds of roof truss construction: Raised heel trusses Drop chord trusses Scissor trusses Parallel chord trusses To discuss Attic space framing	B1, B2, B3, B4			

Objectives	Science	Technology	Skills for Healthy Living	Cultural
To describe cathedral ceiling, framing, and conversion to cold roof designs To describe interior partitions and ceilings To discuss possible ceiling penetrations To describe an attic access hatch	B1, B2, B3, B4			
Ch 6: Retrofit				
Explain what we mean when we say retrofit To discuss required assessments prior to planning a potential retrofit: Foundation integrity Factors that affect drying to the exterior Factors that prevent moisture damage from the inside out Factors that effect thermal performance Combustion appliances that are present Kinds of ventilation Types of windows and doors Electrical construction To identify retrofit goals To analyze possible retrofit performance To discuss potential retrofit techniques: interior or exterior choices To describe how to adding insulation to floor sections	B1, B2 B3, B4	C1	D2	

Objectives	Science	Technology	Skills for Healthy Living	Cultural
To describe how to insulate wall systems from the inside	B1, B2	C1	D2	
To describe how to add insulation to the ceiling	B3, B4			
To describe potential kinds of exterior retrofits				

Appendix 3
Glossaries

This Glossary set actually combines two different appendices. The first is a brief glossary of energy efficiency and materials used in modern construction. And the second is the UAF Cooperative Extension glossary of construction terms, which has particular value in defining carpentry terms.

Above-grade Wall is any portion of a thermal envelope wall more than 12 inches above an adjacent finished grade (ground).

Air Infiltration is an uncontrolled flow of air through a hole, opening, crack, or crevice in a thermal envelope caused by pressure effects of wind or the effect of differences in indoor and outdoor air density.

Air Retarder is a material carefully installed as part of the building envelope to minimize the passage of air into and out of the building.

AkWarm is an energy use analysis software developed by the Alaska Housing Finance Corporation.

Approved is approval by an Alaska Housing Finance Corporation or building official of a material or type of construction as the result of an investigation or test by them, or by reason of an accepted principle or test by a recognized authority or technical or scientific organization.

Back Draft is the reverse flow of chimney gases into the building through the barometric damper, draft hood, or burner unit. This can be caused by chimney blockage or by a negative pressure in the building that is too high for the chimney to draw.

Below-grade Wall is any portion of a wall below ground that extends no more than 12 inches above an adjacent finished grade.

British Thermal Unit (Btu) is the approximate amount of heat energy required to raise the temperature of one pound of water by one degree Fahrenheit.

Ceiling is a group of members that define the boundaries of a space and has a slope of 60 degrees or less from the horizontal plane.

Conditioned Space is a room or other enclosed space that is intentionally or unintentionally heated to a temperature of 50 degrees F or higher. A bedroom, living room, or kitchen is an example of a conditioned space.

Design Heat Loss expresses the total predicted heat loss from the building over the heating season for a particular building design in a particular climate.

Dew Point is the temperature at which the air is at 100 percent relative humidity. Consequently, if the air comes in contact with a surface that is colder than this temperature, condensation will form on the surface.

Door Area is an opening (other than a window) in a wall, including the framing and sash, used by people to enter and exit a building.

Dry-bulb Temperature is the temperature of air as indicated by a standard thermometer, as contrasted with wet-bulb temperature, which depends upon atmospheric humidity.

EPDM stands for ethylene propylene diene monomer, a synthetic rubber gasket material.

Frost Heaving is the movement of soils caused by the phenomenon known as ice lensing or ice segregation. Water is drawn from the unfrozen soil to the freezing zone where it attaches to form layers of ice, forcing soil particles apart and causing the soil to heave.

Glazing is a transparent or translucent material in an exterior envelope that lets in natural light, including a window, skylight, sliding glass door, glass brick wall, or the glass portion of a door.

Gross Wall Thermal Envelope Area is the sum of all wall thermal envelope areas, including opaque wall areas, window areas, and door areas. It is measured from the subfloor elevation for an above-grade wall or from the top of the footing for a below-grade wall up to the junction point with a roof or ceiling structural member.

Heat Recovery is the process of extracting heat that would otherwise be wasted. For example, heat recovery in buildings generally refers to the extraction of heat from exhaust air.

Heating Degree Days (HDD) is a cumulative measure of the duration and magnitude of the need for heating in a building. It is used in estimating fuel consumption. For any one day, when the mean temperature is less than 65 degrees Fahrenheit, there are as many heating degree-days as degrees Fahrenheit difference in temperature between the mean temperature for the day and 65 degrees Fahrenheit.

Hot 2000 is a computer-based energy use analysis program developed by Canada for use in the R-2000 building program.

Pascal is a unit of measure of pressure. Building airtightness tests are typically conducted with a pressure difference of 50 Pascals between the inside and the outside. Fifty Pascals is the equivalent of the pressure of .2 inches of water at 55 degrees F, or roughly equal to a 20-mile-per-hour wind.

R-value is a measure of the ability of a given material to resist heat flow. R is the numerical reciprocal of U. Thus, $R = 1/U$. The higher the R, the higher the insulating value. All insulation products having the same R, regardless of material thickness, are equal in insulating value; expressed as ft-hr-°F/Btu. R-values for individual elements can be added to give a total R-value for an assembly.

Semiconditioned Space is a room or other enclosed space that is heated directly or indirectly by the presence of a component of a heating system or by thermal transmission from an adjoining conditioned space. A crawl space, attached garage, mechanical room, or basement is an example of a semiconditioned space.

Skylight Area is an opening in a roof surface that is glazed with a transparent or translucent material, including the frame.

Slab on Grade is horizontally placed concrete in direct or indirect (as when placed over rigid insulation) contact with the ground and used as a thermal envelope floor.

Thermal Envelope is an assembly of a building that is exposed to conditioned or semiconditioned space on one side and the outdoor environment on the other.

Thermal Transmission is the quantity of heat flowing from one space to another through an intermediary element, such as insulation, due to all mechanisms, in unit time, under the conditions prevailing at that time; expressed as Btu per hour.

Unconditioned Space is a room or other enclosed space, which is not intentionally heated and experiences temperatures of 50 degrees F or less.

U-value is the coefficient of heat transmission from an interior air film to an exterior air film. It is the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films, expressed as Btu/ft-hr-°F. U-value applies to the heat flow path through a single or combination of materials that comprise a building section. U-values can **not** be added to give a total U-value for an assembly.

Vapor Retarder is a material that impedes transmission of water vapor from one side to the other under specific conditions. Some vapor retarder materials and the way they are applied also function to impede the flow of air from one side to the other.

Wall is a group of members that define the boundaries of a building or space and that have a slope of 60 degrees or greater from the horizontal plane.

Weather Retarder is the exterior protective material that keeps out wind and rain.

Window Area is an opening (other than a door) in a wall surface that is glazed with a transparent or translucent material, including the framing or sash.

BUILDING IN ALASKA

HCM-04759

Glossary of Home Construction Terms

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absolute humidity. A measure of the actual weight of the water vapor contained in a given volume of air, regardless of the temperature of the air.

acoustical sealants. Do not harden, maintain flexibility, and are very durable under severe climatic changes, including freezing temperatures. They are the most effective type of sealant to use for sealing polyethylene (vapor retarder) to itself or other materials.

adfreeze. Refers to the freezing of backfill materials to a wall or post, forcing movement of the material due to expansion of water within the soil as it freezes.

air changes per hour (ACH). A measurement of air exchanges over a one-hour time period. One air change per hour means that all the air volume in the house is replaced by incoming air in one hour.

air-dried. Refers to seasoning of wood. Dried by exposure to air, usually in a lumber yard, without artificial heat.

air intrusion. Results when air penetrates insulation.

air leakage. The primary mechanism of moisture transport and a significant mechanism for heat loss. Air leakage is unintentional air flow through the building thermal envelope through cracks and holes when a pressure difference exists between inside and outside.

air pressure. The pressure exerted by the atmosphere. This may refer to static (atmospheric) pressure, or dynamic components of pressure arising from air flow, or both acting together.

air retarder. A material highly impermeable to air, which may be applied to the interior or exterior of the envelope and can be combined with other retarders to achieve more than one purpose.

air sealing. The practice of sealing unintentional gaps in the building envelope (from the interior) in order to reduce uncontrolled air leakage.

air tightness. The degree to which unintentional openings have been avoided in a building's structure.

alcove. An expanded portion of a room. It is not a separate room.

annual fuel utilization efficiency (AFUE). The calculated efficiency of a heating system based on average usage over a heating season.

architrave. See "head casing."

argon. A colorless, odorless, inert gaseous element found in air and volcanic gasses. Argon is used as a gas fill between panes of window glass.

automatic flue damper. A damper added to the flue pipe downstream of a furnace or boiler and connected with automatic controls to the burner. Its function is to reduce heat loss up the chimney when the unit is not operating.

backdrafting. Describes the pulling of flue gasses back through chimneys and flues into the building. It is to be avoided in all housing, and this is accomplished by using sealed combustion heating appliances and isolating combustion from the living space of a home.

backer rod. A foam rope gasket material used for sealing joints that exceed ¼-inch where caulks and other sealing materials are not adequate.

balloon framing. A type of framing wherein the first-floor studs continue upward, unbroken, past the second-floor joists, to become the second-floor studs as well. A ledger is used to support the second-floor joists (Fig. 1).

batter boards. A combination of stakes and boards to which string is attached to locate the building lines. The boards are installed level and all boards are at the same level. The batter boards and/or lines then serve as a vertical reference as well as for locating building lines. They must be kept far enough back from the actual building corners (normally 3 to 5 feet) so that the excavation does not interfere with them. Either single or double batter boards may be used (Fig. 2).

beam. A main structural member that supports other members or loads which are applied perpendicular to the grain lines of the beam. Also called a girder (Figs. 1 and 3).

birds mouth. See "crows foot".

blower door. A common device for measuring air leakage. The blower door consists of a fan, adjustable door frame, a calibrated hole, and metering equipment.

boards. Lumber less than two inches thick and one or more inches wide.

bottom cut. See "heel cut".

bow. The distortion in a piece of lumber that deviates from flatness along its length but not across its width.

bracing. Materials or the installation of materials to form rigid geometric figures—usually a triangle—to reduce or eliminate movement of framing components.

bridging. Bracing to stiffen either side wall studs or floor joists (Figs. 1 and 3).

bridging, cross. See "cross-bridging".

bridging, diagonal. See "cross-bridging".

bridging, solid. See "solid bridging".

British thermal units (BTUs). Are a measurement of heat. One BTU is equal to the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

broken gable roof. See "salt box roof".

building orientation. The siting of a building on a lot, generally used to refer to solar orientation which is the siting of a building with respect to solar access.

building science. The study of how building thermal envelopes function under various sets of conditions.

building thermal envelope. Consists of the parts of the building that separate heated space from unheated space. The building thermal envelope generally includes the foundation, floors, walls, attic, and windows and doors.

butts. The type of hinge usually used to hang the doors in homes. A hinge with "identical" pieces on each side of the pin. The length along the pin is usually about double the length measured from the pin to one side.

bypass. An intentional opening cut for electrical, mechanical, or plumbing items that allows air to leak from one area to another.

CGSB. The Canadian General Standards Board is a government agency within the Canadian Federal Department of Supply and Services. CGSB has been accredited by the Standards Council of Canada as a national standards writing organization engaged in the production of voluntary standards in a wide range of subject areas through the media of standards committees and the consensus process.

cap. See "plate".

capillary action. The ability of liquid to rise upward due to the attraction of liquid molecules to a surface. Wicking is an example of capillary action. It is the least obvious mechanism of moisture flow.

capillary breaks. Are created by using materials with larger pores or an impermeable surface to create a break between porous materials and moisture sources.

casing. Pieces of trim board used to finish off the edge of a jamb. Used to close the opening between the edge of the jamb and the face of the wall.

casing, head. See "head casing".

casing, side. See "side casing".

Celsius. A temperature scale at which water freezes at 0° and boils at 100°.

cement. The basic ingredient of concrete. A chemical combination of calcium, silica, aluminum, iron, and small amount of other materials. During grinding, gypsum is added to control the setting time of the concrete. See "concrete".

check. A lengthwise separation of wood that usually extends across the rings of annual growth and commonly results from stresses set up in wood during seasoning.

cheek cut. A bevel cut. Necessary, for example, where a jack rafter joins the hip rafter. Also called a side cut.

cladding. Covering applied to outside of a structure to protect the inner core.

cleat. A block, usually shorter than a ledger but serving the same purpose, used to support another member. For example, in one stair-framing method, cleats are nailed to the stringers to support the treads.

clerestory. An outside wall of a room or building that rises above an adjoining roof and contains windows.

coefficient of performance (COP). The measure of a heat pump's rate or net heat output. COP is the ratio of the net heat out for heating to the total on-site energy input to the heat pump.

collar beam. See "collar tie".

collar tie. A horizontal member used to tie a pair of opposing rafters together. May be high to hold the upper joint together or may be low to serve as a ceiling joist. Also called a collar beam (Fig. 6).

combustion air. The air required to provide adequate oxygen for fuel burning appliances in the building. The term is often used to refer to the total air requirements of a fuel burning appliance, including both air to support the combustion process and air to provide chimney draft (dilution air).

common rafter. A roof member extending from the plate to the ridge, except valley or hip rafter (Fig 6).

concrete. A combination of cement, water, and other inert materials such as sand and gravel which hardens as it dries because of the chemical action between the water and the cement. The water and cement bind the other aggregates together. See "cement".

condensation. The beads, drops of water, or, in extremely cold weather, the frost that accumulates on building elements or surfaces (most often windows) when warm, moisture-laden air from the interior reaches the point at which the temperature no longer permits the air to sustain the moisture it holds.

conduction. The main mechanism of heat flow from energy tight houses. By direct contact, heat is transferred from molecule to molecule from the warm side of a solid material to the cold side.

controlled ventilation. Ventilation brought about by mechanical means through pressure differentials induced by the operation of a fan.

convection. The transfer of heat by the circulation or movement of the heated parts of a liquid or gas.

corner post. Forms the corner of the wall. Usually made from three studs (Fig. 7).

cornice. A group of moldings used to enclose the ends and bottom of the rafter tails. It forms the finish for the eaves. Also, sometimes applied to the finish on the ends of the roof. See "rake".

cricket. The small "gable dormer" built behind a chimney to direct water around or to the sides of the chimney. Also called a saddle.

cripple jack rafter. A rafter that is cut to fit between a hip rafter and a valley rafter and touches neither the plate nor the ridge (Fig. 6).

cripple jack stud. A stud that touches neither the shoe nor the plate. For example, the stud used to form a window opening (Fig. 5).

crook. The distortion in a piece of lumber that deviates from a straight line along its edge, from end to end.

cross-bridging. Bridging that consists of either metal straps or narrow pieces of wood. Two members are used, for example, between each pair of joists so as to form an "X". Also called diagonal bridging (Fig. 4).

crows foot. One type of rafter bottom cut, consisting of a level cut and a plumb cut making a notch to set over the plate. Also called a birds mouth.

cup. The distortion in a piece of lumber that deviates from flatness across its width but not along its length.

dampproofing. The process of coating a floor or the interior or exterior of a foundation wall with bituminous emulsions and plastic cements. The purpose of dampproofing is to prevent or interrupt the capillary draw of moisture into the wall or floor system and to the interior of the foundation. Polyethylene can also be used for exterior dampproofing.

dehumidistat. An electronic sensing and control devise used to regulate mechanical ventilation according to relative humidity in the building. When the relative humidity surpasses the preset limit, the dehumidistat activates the ventilation system to exhaust house air and bring in drier outdoor air.

delamination. Separation of plies through failure of the adhesive holding the plies together, as in plywood. The term is often used in reference to the durability of the glue line.

Delta T. The difference between inside temperature and outside temperature. Delta T is used in heat loss calculations and comes from engineering jargon, where the Green letter delta, Δ, is used to mean "difference".

design heating load. The design heating load of a house is calculated from the 97.5 percentile low temperature. Only 2½ percent of the days at any site are colder than this, so it is used as the economic choice for heating system capacity.

dew point. The temperature at which air can no longer hold additional moisture. The dew point is the temperature at which condensation will occur and relative humidity reaches 100 percent.

diagonals. The interior or web members of a truss which form triangles — rigid geometric figures — between or in conjunction with the top and bottom chords. See "truss."

dilution air. The air required by some combustion heating systems in order to isolate the furnace from outside pressure fluctuations and to maintain an effectively constant chimney draft.

dimension lumber. Lumber from two inches to, but not including, five inches thick and two or more inches wide.

direct gain. A term referring to a type of solar heating in which the solar collection area is an integral part of the building's usable space; for example, windows. Direct gain is the solar energy received through these windows.

direct vent. Equipment which uses combustion air supplied from outside the building envelope rather than air that is inside the building envelope. Exhaust gasses are vented directly outside. The system is closed (See "sealed combustion").

dormer. An addition to a roof and attic to provide extra space and to allow windows in the attic space.

dormer, gambrel. See "gambrel dormer".

dormer, gable. See "gable dormer".

dormer shed. See "shed dormer".

dressed lumber or size. The finished size of a piece of lumber after drying and surfacing by a planing machine. For example, a 2- by 4-inch stud actually measures 1½ by 3½ inches after drying and being planed. See "normal size".

eaves. The lower end or bottom of the rafters. With no rafter tail, the junction of the wall and rafters form the eaves.

edge effect. Thermal conduction which occurs around the edges of window frames. Condensation, often seen around the edge of windows, is a result of edge effect.

emissivity. A measure of the amount of radiation intensity emitted from a surface compared to the radiation intensity at the same wavelength emitted from a black body at the same temperature. Reflective coatings, known as low emissivity or low-E coatings, reduce radiant heat loss from windows because they are good reflectors of thermal radiation (heat).

energy. The capacity to do work and overcome resistance or potential forces, and such forces or power in action.

energy factor (EF). An overall efficiency rating which includes standby losses used for rating water heaters. EF is based on the use of 64 gallons of hot water per day.

energy target. An approach for establishing energy efficiency goals. Energy targets are established in terms of BTUs per year per square foot of floor space for a given climate and are calculated by ACHP homes by utilizing the HOT2000 computer simulation.

EPDM. Ethylene propylene diene monomer, a synthetic rubber gasket material.

equivalent leakage area (ELA). The total area of all cracks and holes in the building envelope added together to measure the size of an equivalent single hole in the building envelope.

exfiltration. Air leakage that flows out of the house.

exhaust air. Air removed from a location such as the bathroom, kitchen, or laundry room. Exhaust air is not reused but mechanically expelled to the outdoors.

external static pressure. The pressure developed external to the unit (filters, core, housing, and fans) to deliver a specific air flow, expressed as Pascals or inches of water column.

Fahrenheit. A temperature scale at which water freezes at 32° and boils at 212°.

fascia. The part of the cornice that encloses or covers the ends of the rafter tails; or, the part of the rake trim that covers the outer side of the fly rafter.

fire stop. A horizontal wood member cut to fit between the studs. Usually placed at each floor level to help keep fire from spreading from floor to floor. Primarily necessary with balloon framing. Helps to prevent the space between studs from functioning as a chimney. May also be used between joists (Fig. 1).

flashings. The process or materials used in making a joint watertight by fitting tin, lead, zinc, or other material in such a way as to prevent the water from penetrating the joint.

flight of stairs. The series of steps leading from one landing to another.

flow-through principle. Describes the construction of building assemblies so that each material used has a higher permeability as vapor travels through a cross section of the building envelope from inside to outside. Using the flow-through principle for construction of building assemblies prevents vapor from being trapped at any point inside the assembly.

flue and vent effect. A pressure difference across the building envelope caused by mechanical equipment exhausting air from inside the building envelope.

fly rafter. A rafter located beyond the end wall of the house. It forms the extreme outer edge of the structural part of the roof.

footing. The lower and expanded portion of a foundation which rests on the excavated surface. The purpose of the footing is to provide a larger bearing surface over which the weight of the building is spread so that the bearing pressure created by the weight of the building does not exceed the allowable bearing pressure of the soil.

forced draft. Appliances place a fan in front of the flame, forcing air into the combustion chamber, resulting in forced draft.

framing. The lumber used as structural members in a building, such as studs and joists. Also refers to the process of erecting the structural members of a building.

frieze board. The board that forms the junction between the finish siding and the plancher.

foundation. Walls, piers, or other supports placed below grade or curb levels to support the building. Usually made of materials that are not susceptible to damage from soil, moisture, or soil organisms. Concrete and preservative-treated wood are examples.

foundation coating. A material, usually of a bituminous composition, applied to the outside surface of a foundation to retard or prevent moisture migration through the foundation.

freezing degree days. (or Air Freezing Index) A measure of the total number of degrees that outside temperature is below freezing during the year. Freezing degree days (measured below 32°F) provide a basis for calculating the depth of annual ground freezing or ice thickness.

frost heaving. The movement of soils caused by the phenomenon known as ice lensing or ice segregation. Water is drawn from the unfrozen soil to the freezing zone where it to forms layers of ice, forcing soil particles apart and causing the soil surface to heave.

furring. Additional framing placed inside or outside that protects the air-vapor retarder and allows more space for insulation.

furring strip. Any piece of material (though usually a 1 by 2 or 1 by 3) used to form an air space, as between a basement wall and paneling; or to form a mounting materials for a new siding or ceiling, such as used when applying ceiling tiles over a plaster ceiling.

gable. Refers to the end wall area of a building, located between the end wall plate (bottom of rafters or trusses) and the roof.

gable dormer. A dormer with a gable-type roof and its own ridge board perpendicular to the ridge board of the main roof.

gable roof. A roof with two equal slopes meeting at the ridge. The end of the roof is vertical and appears to be an inverted cone (Fig. 8b).

gambrel dormer. A dormer with a gambrel-type roof and its own ridge board perpendicular to the ridge board of the main roof.

gambrel roof. A modified gable roof in which each side of the roof has two distinctly different slopes — a steeper slope at the bottom and a smaller or lower slope near the ridge. The slopes on each side of the roof are equal. A "true" gambrel roof has a slope inclined 60° above the horizontal at the bottom and a slope inclined 30° above the horizontal at the top. This roof style is typical of "Dutch Colonial" homes (Fig. 8c).

girder. A main horizontal member, on edge, intended to support secondary structural members, such as joists (Figs. 1 and 3).

girt. See "plate".

gusset. The parts of a truss that hold the joints together. May be plywood, metal, sawn boards, or any other material of adequate strength.

head casing. The horizontal casing used along the top of an opening such as a door or window opening. Also called the architrave.

header. A horizontal member, on edge, that closes off space between joists. Also used to form an opening through joists, such as when making an opening through which stairs will pass (Figs. 3 and 9).

head jamb. A horizontal member used to form the finished top of an opening, such as for a door.

heat. A form of energy resulting from the average kinetic energy (velocity) of molecules.

heat mirror. A trademark for a low emissivity coating applied to glass directly or to a plastic film that is adhered to glass or suspended between the glazing in windows.

heat recovery ventilators (HRV). Includes air-to-air heat exchangers and air-to-water heat exchangers. HRVs extract heat from ventilation air that would otherwise by wasted.

heat capacity of air (HC). A physical characteristic of air used in air leakage and heat loss calculations. HC is the amount of heat required to raise the temperature of one cubic foot of air one degree Fahrenheit. This amount of heat depends on the density of the air and varies from area to area. It will generally be within the range of 0.018 to 0.022 BTU/per cubic foot degree Fahrenheit.

heating degree days. A measure of the difference between average daily outdoor temperature and an index temperature, usually 65° F. Heating degree days measured below 65°F provide information for calculating the annual fuel requirement for a heated building.

heating season performance factor (HSPF). A factor used to rate heat pump or central air conditioner performance. HSPF is the total heating output in BTUs of a heat pump during its normal annual use divided by the total electric power input during the same period.

heel cut. A cut on a rafter where it meets the plate; it is horizontal when the rafter is properly located.

hip. An outside corner in the roof (Fig. 6).

hip rafter. The main rafter of the hip which forms the roof break line (Fig. 6).

hip roof. A roof in which both sides and both ends lean towards the center of the building, with the same slope.

HOT2000. A computer heat loss calculation program used for estimating the space heating requirements of residences. It was primarily developed by the National Research Council of Canada. It includes calculations for home design optimization, below-grade heat loss, and solar gains through windows. It is also a required element in design and certification of an Alaska Craftsman Home.

hot roof. Unvented roof.

house depressurization. The condition that exists when pressure within the envelope is lower than the pressure outside.

ice damming. An ice buildup that occurs from heat loss through a roof where there is insufficient insulation and ventilation. In addition, air leakage from exterior walls coupled with inadequate soffit ventilation contributes to ice damming. Typically ice damming is associated with dysfunctional hot roofs.

impermeable. Not permitting water vapor or other fluid to pass through.

induced draft. An appliance in which a fan is placed after the flame, pulling air into the combustion chamber, resulting in induced draft.

infiltration. Air leakage that flows into the house.

insulation (thermal). Materials that retard the transfer of heat.

intrinsic heat. Heat from human bodies, electric light bulbs, cooking stoves, and other objects not intended specifically for space heating.

jack rafter. Any rafter that is shorter than a common rafter and touches either ridge board or plate but not both. Hip jack rafters and valley jack rafters are examples (Fig. 6).

jack rafter, cripple. See "cripple jack rafter".

jack stud. A stud that touches either the plate or the shoe but not both, such as the studs above or below a window (Fig. 4).

jack stud, cripple. See "cripple jack stud".

jamb. A member used to form the finished sides of an opening, such as door jambs.

jamb, head. See "head jamb".

jamb, side. See "side jamb".

joist. A horizontal member, usually placed on edge to support floor or ceiling; one of a series of parallel beams (Figs. 1 and 3).

joist hanger. A metal "U-shaped" bracket for supporting the ends of joists. The use of joist hangers permits joists to be supported along the side of the support beam or girder, thereby increasing headroom.

KD. Abbreviation for kiln-dried.

kiln. A heated chamber used for drying lumber, veneer, and other wood products.

kiln-dried. Dried in a kiln with the use of artificial heat.

laminate. A product made by bonding together two or more layers (laminations) of material or materials. Plywood is an example.

landing. A horizontal resting place in a flight of stairs. Used in long flights or at turns.

latent heat. Heat added or removed during a change of state (for example, from water vapor to liquid water), while the temperature remains constant.

lath. Thin strips of wood or metal that are nailed to studs to form supports for a plaster wall. The plaster is applied over the lath.

lean-to. See "shed roof".

ledger. See "ribband".

let-in. To notch one member so as to form a socket to receive a second member. A ribband is sometimes "let-in" to the studs which support it. Likewise, corner bracing may be "let-in" to the studs it is bracing.

level cut. Any cut which, when the member is properly located, is horizontal or level.

lintel. A horizontal member over an opening, such as a door or window, which carries the weight of the studs, joists, or rafters above it (Fig. 5).

log. A section of the trunk of a tree of suitable length for sawing into commercial lumber.

lookout rafter. Roof-framing members that tie together the fly rafter and the first common rafter in from the end wall. They lie on the end wall and support the fly rafter.

low-E. Or low emissivity, from emissivity, which represents a measure of the tendency of a surface to emit or absorb radiant heat. Typical references to "low-E" occur in modern window systems.

lumber. Any product of the saw and planing mill produced by sawing, resawing, passing lengthwise through a standard planing machine, and crosscutting to length with no further manufacturing.

lumens. A measure of visible light output. A standard 60-watt incandescent bulb produces 870 lumens.

make-up air. Outdoor air supplied to replace exhaust air. Make-up air may enter the house by infiltration, through a make-up air duct, through a supply fan, etc. It does not include air entering the house as combustion air or to replace exfiltration air.

mechanical systems. Provide and maintain the internal environment of the house. They include heating, domestic hot water, ventilation, plumbing, and electrical systems.

mechanical ventilation. One or more fans used to move air to achieve desired air exchange and ventilation.

mechanisms of air flow. The processes by which air leakage occurs. Air flows in or out of a home unintentionally through three mechanisms: wind effect, stack effect, and flue and vent effect.

mechanisms of energy flow. The processes by which energy flows from the house. Energy leaves a home through three major mechanisms: conduction, convection, and radiation.

mechanisms of moisture flow. The processes by which moisture flows into or out of a home. There are four primary mechanisms of moisture flow: air leakage, vapor diffusion, capillary action, and gravity.

millwork. Generally, all building materials made of finished wood and manufactured into such items as doors, windows, moldings, etc. It does not include flooring, ceiling, or siding materials. See "planing-mill products".

mitre. The angular joint formed by two pieces of material each sawed at an angle to match when joined. Casings (head and side) are usually mitred where they meet.

muntins. The part of a window sash that supports the edges of adjoining pieces of glass.

NFS. An abbreviation of non-frost-susceptible materials, which are not subject to frost heave or other frost action when freezing.

natural draft. Combustion appliances that use the buoyancy of hot air for venting gasses are referred to as natural draft appliances.

natural ventilation. Air leakage through holes and cracks or by opening windows and doors for a supply of outdoor air. It is unreliable and random, since it is uncontrolled and varies widely by season.

negative pressure. A lower pressure than the surrounding area. The surrounding area is usually the outside.

neutral pressure plane. An area that separates the regions of the house where air pressure is either positive or negative in relation to the outside at any given time. At a neutral plane, the pressure is equal both inside and out, and no leakage would occur through holes at this point.

nominal size. As applied to timber or lumber, the rough-sawed commercial size by which it is known and sold in the market. See "dressed lumber or size".

normalized leakage area (NLA). The NLA is calculated by dividing the equivalent leakage area (ELA) from the fan test by the area of the exterior envelope of the house.

nosing. The outer or front edge of the step that projects beyond the riser.

orientation. The direction with respect to point of the compass in which the building axis lies or external walls face.

outgassing. The emission of gasses from various building products after the manufacturing process is complete.

Pascal. A metric measurement of pressure difference. One Pascal is equivalent to the amount of pressure that .004 column inches of water exerts at 55° F. House air leakage tests are typically conducted by maintaining a constant pressure difference of 50 Pascals.

passive ventilation. Takes advantage of the stack effect or wind pressure differences to provide air movement. It is unreliable and random.

permafrost. Perennially frozen subsoil in arctic or subarctic regions. Technically, permafrost is any material of the earth's crust which remains below 32°F (0°C) for two consecutive years or more.

permeance. Water vapor permeance is the rate of water vapor diffusion through a sheet of any thickness of material (or assembly between parallel surfaces). It is the ratio of water vapor flow to the differences of the vapor pressures on the opposite surfaces. Permeance is measured in perms (grams/ft^2/hr/in. mercury).

piazza. See "porch".

pitch. The slant of a roof; the total roof rise divided by the total roof span. For example, for a 24-foot span and a 6-foot rise, pitch would equal 6/24 or 1/4. See "slope".

plancher. The part of a cornice that covers or encloses the bottom portion of the rafter tail. Sometimes called the soffit.

planing-mill products. Products worked to pattern, such as flooring, ceiling, and siding materials.

plank. A broad board, usually more than one inch thick, laid with its wide dimension horizontal.

plate. A horizontal member that rests on the upper end of the studs and upon which upper floor joists or roof rafters rest. May be a single or double member. Also called a girt or cap (Figs. 1, 3, and 5).

platform framing. A type of framing wherein the first- and second-floor studs are separate pieces of wood. The first-floor studs have a plate on top of them upon which the second-floor joists rest. The second-floor studs continue upward from a shoe placed on the second-floor joists (Fig. 3).

plenum. The space in which a gas, usually air, is contained at a pressure greater than atmospheric pressure. It is usually found as an element of a forced-air heating system.

plumb cut. A cut that is vertical when the member is properly located. For example, the cut on a rafter where it meets the ridge board. Also called a top cut when referring to rafters.

plywood. A cross-banded assembly made of layers of veneer or of veneer in combination with a lumber core or plies joined with an adhesive. The grain of adjoining plies is usually at right angles, and almost always an odd number of plies is used to obtain balanced construction.

porch. A covered platform at the door of a house, usually having steps with baluster guards and sometimes seats at the sides. (Note distinction between porch and stoop.) Also commonly called a piazza or verandah.

positive pressure. Greater than atmospheric pressure. In residential construction this refers to pressure inside the house envelope that is greater than the outside pressure; a positive pressure difference will encourage exfiltration.

preservative. Any substance that, for a reasonable length of time, is effective in preventing the development and action of wood-rotting fungi, borers of various kinds, and harmful insects that deteriorate wood.

pressure difference. The difference in pressure of the volume of air enclosed by the house envelope and the air surrounding the envelope.

psychrometric charts. Psychrometric charts are used to determine dew point (the temperature at which condensation will occur) and the relative humidity of air at various temperatures.

R-value. (Resistance value) is a measurement of the ability of a material to resist heat transfer. The higher the resistance to heat transfer (R-value), the less heat transfer through the material.

radiant heat. (transfer) The transfer of heat from a location of higher temperature to a location of lower temperature by means of electromagnetic radiation.

radiation. A mechanism of heat flow. Radiant energy is exemplified by sunlight, which flows omnidirectionally from the source of radiation, the sun. A wood stove is a good example of a radiant heater.

radon. A radioactive gaseous chemical element formed, together with alpha rays, as the first product in the atomic disintegration of radium.

rafter. Usually an inclined member which supports the roof. Can also be flat or horizontal (Figs. 1, 3, and 6).

rafter, common. See "common rafter".

rafter, cripple jack. See "cripple jack rafter".

rafter, fly. See "fly rafter".

rafter, hip. See "hip rafter".

rafter, jack. See "jack rafter".

rafter, lookout. See "lookout rafter".

rafter, valley. See "valley rafter".

raised grain. A roughened condition on the surface of dressed lumber in which the hard summerwood is raised above the softer springwood but not torn loose from it.

rake. The portion of the roof projecting beyond or overhanging the end wall. Sometimes called a cornice.

reflective coatings. Layers of metal atoms applied to glass to change the emissivity and limit radiant heat transfer.

relative humidity. A measure of the amount of water vapor that is held by air at a given temperature, relative to the maximum amount of water vapor it can hold at that temperature. Relative humidity is expressed as a percentage.

reveal. The portion of the edge of a jamb or stile that is exposed by keeping the casing back a small amount — usually 3⁄16 to 1⁄4 inch.

ribband. A horizontal member attached to other members either vertical or horizontal, by spiking or letting-in to form a ledge or "shelf" for a third member to rest upon. Also called a ledger or spiking strip.

ridge board. A member made of 1- or 2-inch board, against which the upper part of the rafters rest. The rafters of one side of the roof meet the rafters from the other side of the roof at the ridge board (Fig. 6).

rise. The difference in height between one end of a rafter and the other; or the vertical distance between the treads of a set of stairs; or the difference in height of the top and bottom of a set of stairs.

riser. The board forming the vertical portion of the front of a step.

rough lumber. Lumber as it comes from the saw.

run. The horizontal distance over which a rafter stretches. For example, as measured from a plumb line dropped at the ridge to the outside of the plate.

saddle. See "cricket".

salt box roof. A modified gable roof with a different slope and rafter run on each side of the ridge. The portion of the roof behind the ridge is usually longer and has a smaller slope than the portion of the roof in front of the ridge. Also called a broken-gable roof (Fig. 8e).

sandwich, structural. See "structural sandwich construction".

sash. The portion of a window into which the glass is set or mounted. Roughly, the movable part of a window.

scaffold. A platform built against the side of a building for the support of workmen. A one-story structure suitable for work on low buildings. See "staging".

sealants. Flexible materials used on the inside of a building to seal gaps in the building envelope thereby preventing uncontrolled air infiltration and exfiltration.

sealed combustion. A type of appliance which uses an air supply that is connected to the outside. A sealed pipe brings combustion air to the flame and a sealed flue takes the gasses away. The flame and its gasses are located outside the envelope, contained within the appliance's separate system.

seasoning. Removing moisture from green wood in order to improve its serviceability.

seat cut. See "heel cut".

shading coefficient (SC). A measure of a window's ability to transmit solar energy. SC is expressed as a number between 0 and 1. The lower a window's shading coefficient, the less solar heat it will transmit and the greater its shading ability.

shake. A separation along the grain, the greater part of which occurs between the rings of annual growth.

sheathing. A floor, wall, or roof covering which forms a solid surface for attachment of the finishing flooring, siding, or roofing.

shed dormer. A dormer with a one-slope roof. Usually used when a dormer is desired over the full length of the main roof.

shed roof. A roof with only one slope. Also called a lean-to (Fig. 8a).

shoe. A horizontal member upon which the lower end of studs rest. May also be called a sole (Figs. 3 and 5).

side casing. A vertical casing used along the sides of an opening such as a door or window opening.

side cut. See "cheek cut".

side jamb. A vertical member used to form the finished sides of an opening, as for a door.

sill. A horizontal framing member placed across the bottom of door or window openings (not always used on interior openings). Also, a horizontal member which lies on top of a stone or masonry wall, usually bolted down to tie the wood construction to the masonry or stone construction (Figs. 1 and 3).

skylight. A window placed in the roof of a building, or ceiling of a room, for the admission of light and usually also for ventilation.

slope. The angle of a roof; the total roof rise divided by the total roof run. For example, with a 24-foot span and a 6-foot rise, each side of a gable roof would have a run of 12 feet and slope would equal 6/12 or 1/2. See "pitch".

soffit. The portion of the rake trim that encloses the bottom of the lookout rafters.

solar heat gain. In passive solar heating a term referring to the amount of heat gained through windows over the heating season. Net solar gain refers to the solar heat gain less the heat losses through the windows.

sole. See "shoe".

solid bridging. Bridging consisting of pieces of wood of the same size as the member being braced (joist or stud) and cut to fit between each two members (Fig. 4).

span. The horizontal distance from the outside of one plate to the outside of the other.

spiking strip. See "ribband".

stack effect. A pressure difference across the building envelope caused by inside and outside temperature differences.

staging. An elevated platform built against the side of a building to support workmen. More substantially built than scaffolding and suitable for greater heights. See "scaffold".

stand-by loss. Heat loss from domestic water heaters while the heater is standing by waiting for hot water to be used. Also similar for hot water hydronic heating systems.

strapping. In framing, additional horizontal wood members used to add strength to the wall.

stile. The vertical, or side, pieces of a window frame which form the finished sides — similar to the side jambs of a door opening.

stoop. An uncovered platform at the door of a house, usually having steps with baluster guards and sometimes seats at the sides. (Note distinction between stoop and porch.) Essentially a "primitive porch" without a roof.

stringer. The inclined member used to form the main supports for a set of stairs (Fig. 10).

structural lumber. Lumber that is two or more inches thick and four or more inches wide. It is intended for use where working stresses are required.

structural sandwich construction. A layered construction comprising a combination of relatively high-strength facing materials intimately bonded to, and acting integrally with, a low-density core material.

stud. A vertical framing member that is used to form partitions or outside walls and carries the floor or roof above it (Figs. 1, 3, and 5).

stud, cripple jack. See "cripple jack stud".

stud, jack. See "jack stud".

supply air. Is recirculated and ventilation air supplied into a space after conditioning by heating, filtering, cooling, or mixing with outside air.

surfaced lumber. Lumber that is dressed by running it through a planer.

tail. That portion of a rafter or truss that extends beyond the outside edge of the place (Fig. 6).

tail beam. A joist which has been cut off in order to provide an opening for a set of stairs, chimney, etc. (Fig. 9).

thermal break. A material of low conductivity used in an assembly to prevent flow of heat by conduction from one side of the assembly to the other; materials used for this purpose in the frame of metal windows.

thermal bridge. A low thermal-resistance path connecting two surfaces; for example, framing members in insulated frame walls or metal ties in cavity wall and panel construction. The opposite concept of a thermal break.

timbers. Lumber five or more inches in its least dimension.

threshold. The finished bottom of a door opening. The purpose is to raise the bottom of the opening, which in turn permits the door to be shorter so that it has clearance at the bottom when opened but still closes tightly.

top cut. See "plumb cut".

tread. The horizontal or step part of a set of stairs.

truss. A structural member used in place of common rafters on longer spans. Consists of an upper chord in place of the rafter and a lower chord which replaces the top-floor ceiling joists. Diagonals or web members are placed between the chords. See "diagonals".

truss uplift. An upward truss movement due to the bottom and top chords being exposed to different temperatures and relative humidities.

twist. A distortion caused by the turning or winding of the edges of a piece of lumber so that the four corners of any face are no longer in the same plane.

U factor. A measurement of the ability of a material to conduct heat. The lower the conductance (U Factor) the less heat loss through the material. The units for total conductance (U) are BTUs per hour per square foot of material per degree Fahrenheit temperature difference across the material.

valley. An inside corner in the roof (Fig. 6).

valley rafter. The main rafter of the valley which forms the roof break line (Fig. 6).

vapor barrier. A membrane resistant to moisture penetration, used to prevent warm, moist air from traveling through the wall, ceiling, etc.

vapor diffusion. The movement of water vapor between two areas caused by a difference in vapor pressure, independent of air movement. The rate of diffusion is determined by 1) the difference in vapor pressure, 2) the distance the vapor must travel, and 3) the permeability of the material to water vapor. Hence, the selection of materials of low permeability for use as vapor retarders in buildings.

vapor pressure. The pressure exerted by a vapor either by itself or in a mixture of gases. For example, when referring to water vapor, the vapor pressure is determined by the concentration of water vapor in the air.

vapor retarder. A material with a low perm rating. Vapor retarding materials are used to reduce water vapor transport.

veneer. A thin layer or sheet of wood.

ventilation. Intentional air flow with a specific purpose, typically to provide ample healthy fresh air.

verandah. See "porch".

voids. Areas without insulation, resulting from improper or careless installation of the insulation.

warp. Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

weather barrier. In building, the weather barrier is the exterior wind and water shedding material.

web members. See "diagonals" and "truss".

western framing. See "platform framing".

wind effect. A pressure difference across the building envelope caused by wind.

winders. Steps which are not parallel to each other — as in stairs that go around a turn without a landing (Fig. 10).

yard lumber. Lumber of all sizes and patterns that is intended for general building purposes.

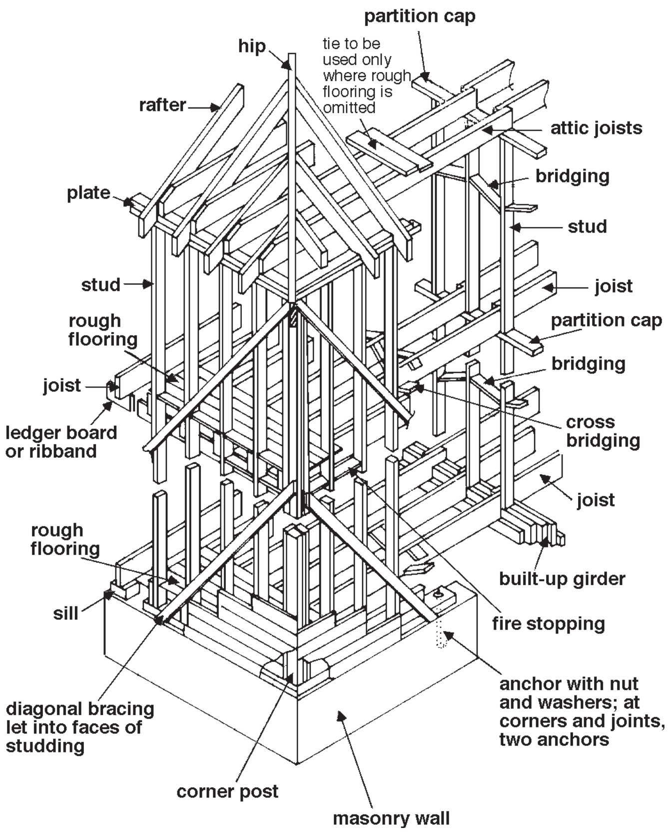

Figure 1. Balloon Framing

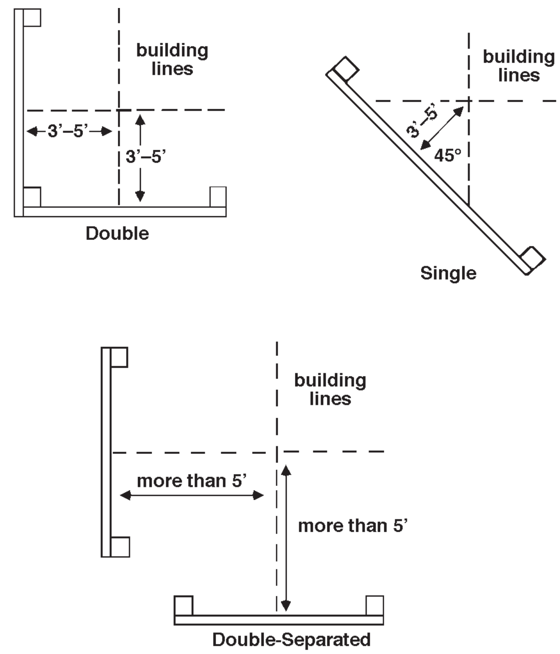

Figure 2. Batter Boards – Alternate Layouts

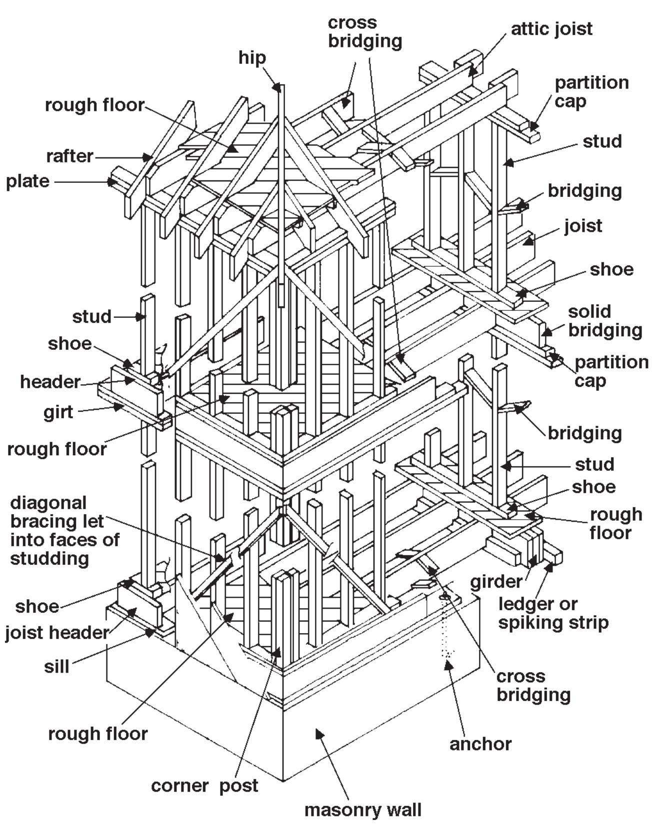

Figure 3. Platform or Western Framing

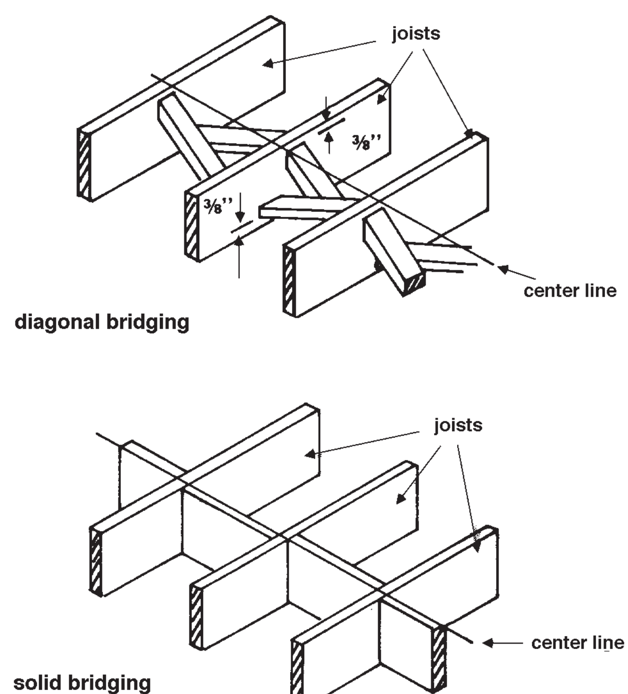

Figure 4. Methods of Installing Bridging

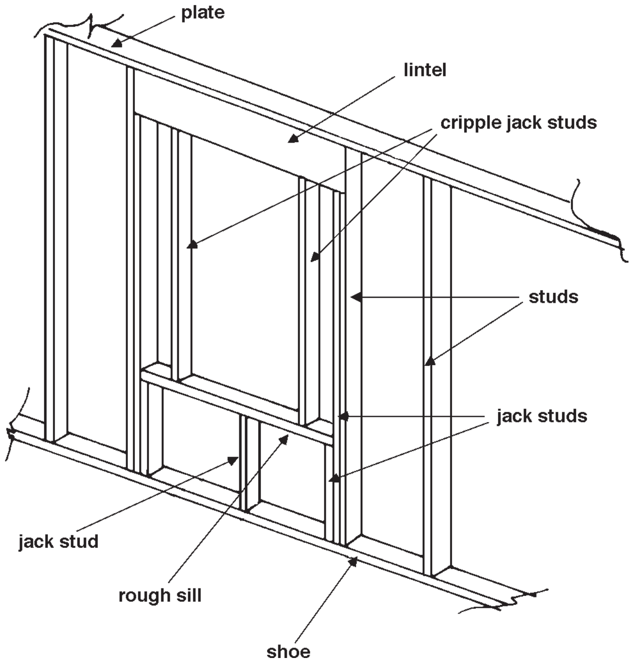

Figure 5. Window Framing

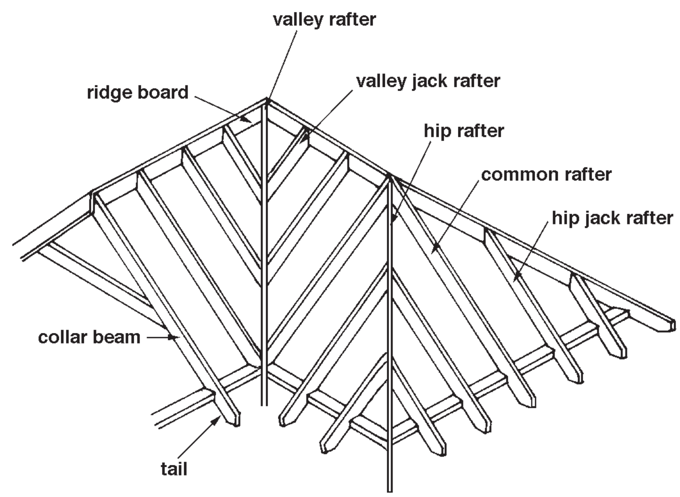

Figure 6. Hip and Valley Framing

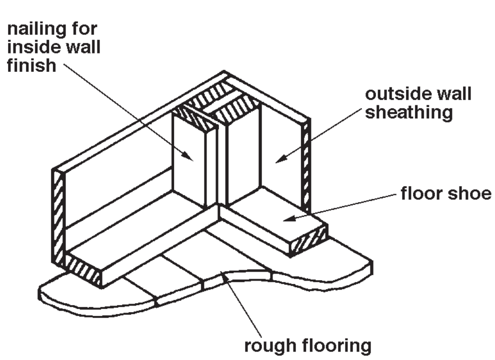

Figure 7. Three-Piece Corner Post

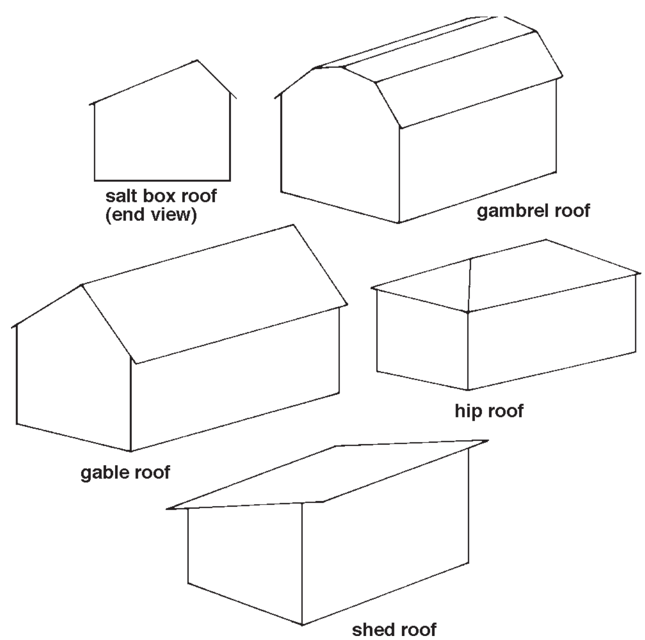

Figure 8. Roof Styles

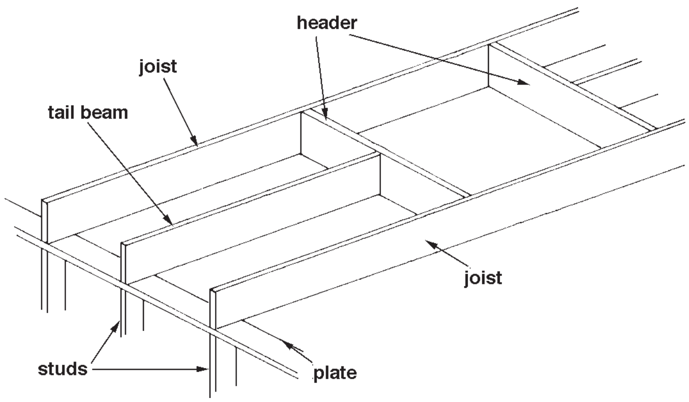

Figure 9. Open Framing

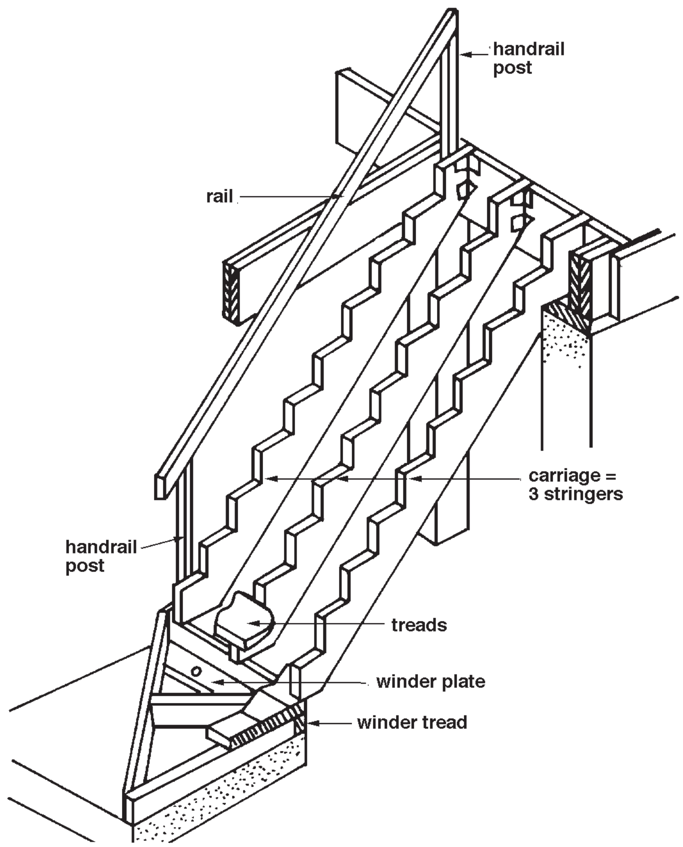

Figure 10. Stair Framing

Appendix 4
Additional Material

1. Suggestions for Installing Domestic Water Storage Tanks. HCM-04950.

2. New Insight from Radon Research in Interior Alaska. A research paper on radon issues in Alaska.

3. Radon In Homes — The Alaska Experience. RAD-01250.

4. Heating Values of Fuels. EEM-04253.

5. Water Cistern Construction for Small Houses, Alaska Building Research Series. HCM-01557.

BUILDING IN ALASKA

HCM-04950

Suggestions for Installing Domestic Water Storage Tanks

by Richard D. Seifert
Energy and Building Specialist

Introduction
For many Alaskans whether it be home or commercial establishments, sufficient quantities of water may be difficult to obtain from a well or the home may be out of range of a local utility service. The most common way of dealing with this problem is to install a holding tank and have water commercially delivered. Some state regulations apply to the installation of holding tanks, and experience allows us to present these general guidelines for installations, which will be helpful to the contractor or to the owner-builder. It should be noted that the delivery services, especially truck services, are now required to report on the quality of their water and to maintain sanitary delivery methods. This is controlled by the Alaska Department of Environmental Conservation. Each delivery service should have a recent report describing the quality of their water and the results of the most recent test. These tests are regularly repeated to ensure continuing quality of the water delivered.

General Guidelines
Most people have no idea how much water they actually use. A standard American family of four commonly uses 150 to 200 gallons of water per day. In Fairbanks, the average city user consumes 3,000 to 6,000 gallons per month. Since most of us become quite accustomed to this rate of use, this obviously has clear implications for installing a large holding tank. If you are presuming to get water from a holding tank where you are paying 5 to 6¢ a gallon for the delivered water, you need to first understand that water conservation will be a prime motivator and a very good policy for operating your home holding tank. In the past, homeowners with little experience in water use rates installed 500-or 1,000-gallon holding tanks. At first, this sounded like an adequate amount of water, but most people find it is absolutely

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inadequate. A family with this size tank will frequently run out of water and will require deliveries every one or two weeks.

Guideline 1
Because of standard water use rates and the economies of delivering larger amounts of water, the minimum recommended tank size is 2,000 gallons.

Tank Specifications
Welded steel tanks used to be commonly used for most underground water storage in Alaska. But there are unique specifications for water tanks, and the prospective buyer should talk to the tank fabricator if you are intending to buy steel. Steel tanks are still available and made in a wide range of sizes. They are competitively priced with other alternatives. However they are declining in use and their advantages do not outweigh their disadvantages. Commonly they are coated with a epoxy lining to keep them from rusting but ultimately that doesn't always keep them from deteriorating. As of 2004, during which this publication was revised, the alternative of choice is to use high density polyethylene (HDPE) tanks. These are becoming the standard and are very competitively priced. They have all the advantages of steel and none of the disadvantages. Polyethylene is easy to repair, it is a lifetime investment because it doesn't rust or corrode, and it has no vulnerability to the normal chemistries that are put into water tanks. For this reason one can expect the tanks to last 100 years. The only things that degrade polyethylene once it's buried, are chemical or physical destruction. The only vulnerability to degradation most plastics have is ultraviolet light. Once the tank is buried, it is not exposed to any ultraviolet light. Plumbing failures might also cause it to leak, but generally speaking polyethylene tanks are the tanks of choice.

A schematic is shown in Figure 1 describing another useful feature which serves as a low-level water alarm[1].

The standard pipe delivery port for a double-tap fitting is shown. And then, a second double-tap port is included to provide for a second intake line into the home water system. The down pipe for the standard intake goes to within 10 inches of the bottom of the tank. When the water in the tank drops below this level, the normal supply runs out. The second line provides a reserve tank similar in function to a motorcycle fuel tank. When the water level drops below the intake of the standard line, a valve is closed in that line and another is opened in the reserve line. This allows another 50 to 100 gallons of water to be withdrawn before the water tank is empty.

This serves two useful purposes for those homeowners who may be on water tank supplies:

1. It serves notice that the water level is low and motivates the homeowner or operator to call for a delivery (presuming they are not on automatic delivery service).
2. It allows for a margin of water supply before completely running out.

The second intake fitting must be specified when ordering the tank. It is highly recommended and the additional costs are minimal.

As stated previously, recent experience with polyethylene plastic water tanks

[1]*This feature was suggested by Don Cameron of Water Wagon delivery service.*

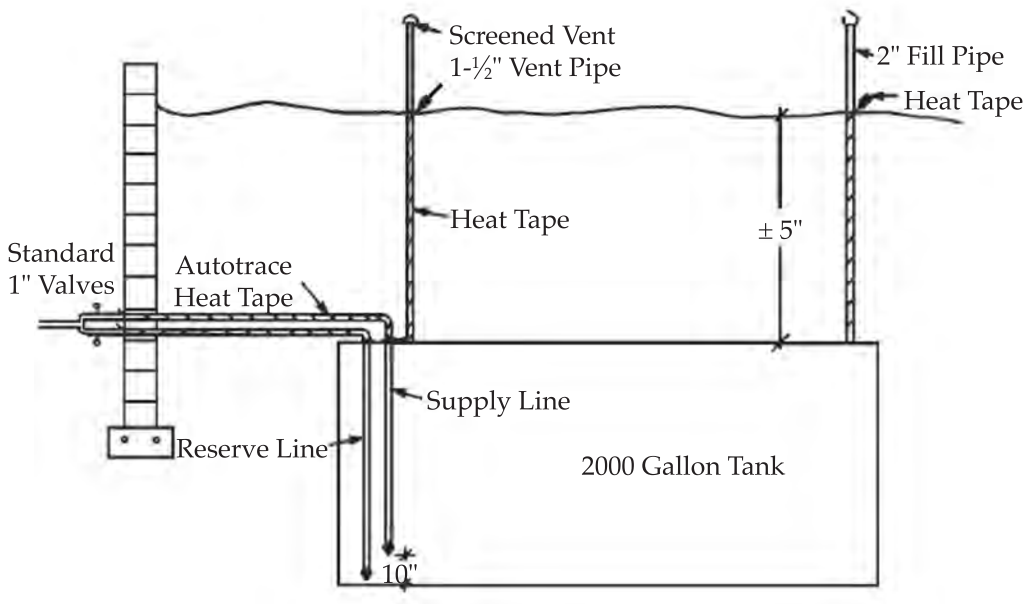


Figure 1
Typical Underground Tank Installation

has shown them to be a desirable and superior choice for domestic water storage. A major advantage is the virtual elimination of corrosion. This makes a buried polyethylene tank a lifetime tank. Previously these tanks were not manufactured in Alaska but this is changing, and will probably lower the cost. At present a quote from one supplier (M&M Constructors) on both a 1,200 gallon and a 1,700 gallon cistern HDPE water tanks, is as follows: the 1,200 gallon lists for $1,450 and the 1,700 gallon lists for $1,700. As a comparison, a 1,500 gallon steel tank (quote from Greer Tank and Welding in Fairbanks), is $1,590 and a 2,000 gallon tank is $1,781. So these are quite competitive prices for either option. A photograph of the Norwesco water tanks, courtesy of M&M Constructors, is shown in Figure 2.

Tank Size

- The average family (of four) can expect to use 1,500 to 2,000 gallons of water per month. Even that rate requires some considerable water conservation.
- 1,000 gallon tanks are simply too small to serve this usage. Owners will find themselves running out of water too often and delivery companies are hesitant to put small tanks on automatic delivery, as the cost escalates with the number of deliveries required.
- Consider a 2,000 gallon tank as a minimum size.
- Bear in mind that the larger the tank, the more efficient the delivery, and thus, the cheaper the price per gallon. A large tank can also provide a large reservoir of water for use in case of a fire. Plumbing should be roughed in for this option at the time of installation if you so choose.
- The fill and vent lines should extend at least 2 feet above grade, and preferably 4 feet.

Guideline 2

When using tanks for holding water, several measures must be considered for

Figure 2
M & M Tanks —High density polyethylene tanks. Tanks shown are ~1,500 gallons.

ease of filling and protection from freezing and pollution. You should place the tank in a location where truck access for fill-ups is as simple and direct as possible. The folks at Water Wagon have also noted that auto-fill customers and any customers who expect winter service, should keep their driveway and fill pipe area well maintained in winter. Driveways that aren't plowed are difficult and often create obvious problems. The trucks are wide, long, and heavy and they do not have 4-wheel drive in most cases. These trucks require a 10-foot-wide clear driving surface and extra room to maneuver around curves, trees, and obstacles. The situation could become so difficult that they won't attempt to deliver your water in marginal conditions. The run to the tank from the truck should be 30 feet or less. You should locate the tank as close as possible to a utility room and be able to see the tank location from the truck pumping area so that the driver can see the tank and vent. Putting the tank in a crawl space is feasible, but the filler and the vent should slope downward and away from the tank to prevent water being trapped in them after filling (see Figure 3). *The vent and the filler should be in plain view and clearly marked with a sign. Filler caps should be blue to indicate that they are water (a red cap indicates an oil filler tank). Keep the water tank as far from fuel tanks as possible.* More than once water tanks have been accidentally filled with fuel oil.

Guidelines for Buried Tanks

First, every tank should be flushed with water very thoroughly. Most water storage tanks are buried outside a building. The tank should be a minimum of 4 feet below the surface. However this can be lessened by insulating the tank from above with 2 inches of styrofoam rigid board insulation or some other foam insulation. Every inch of this insulation is equivalent to 3.7 feet of soil in insulating value, so it doesn't take much extra foam to protect the tank

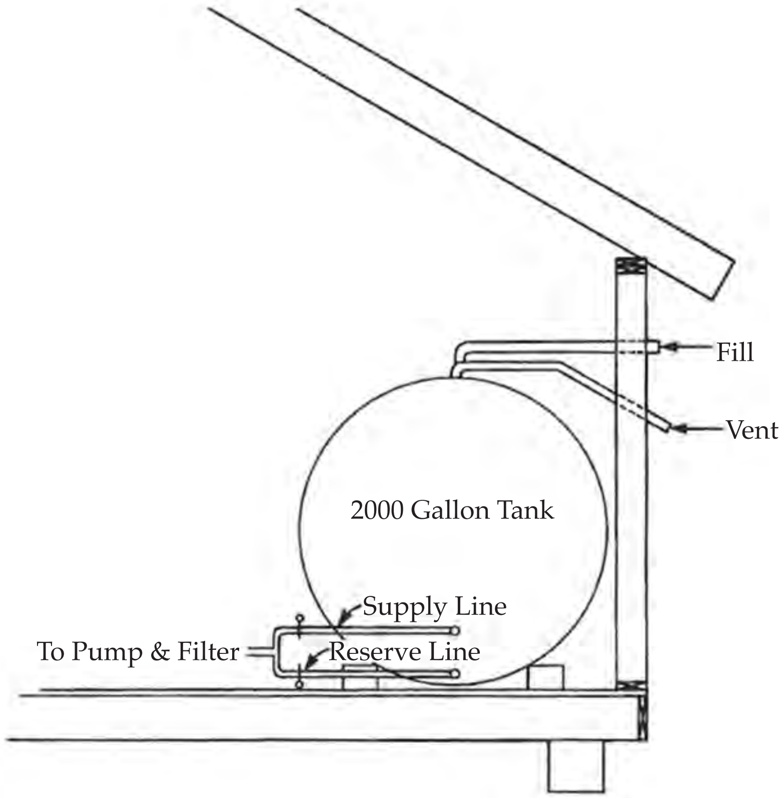


Figure 3
Typical Shed Installation
(In Heated Space)

from freezing. Even so, in extremely low snow years, some ice can form in a tank. Usually this is not a problem. The intent is to protect the tank from freezing in the winter, and from mud and possible floating of the tank during breakup or in a heavy precipitation event. The soil should be mounded or graded above the tank to divert surface water. And for extra safety, insulating the tank with at least 2 inches of foam insulation, as previously noted, is an excellent precaution.

If an extra option for thawing frozen fuel lines is desired, electrical, autotrace heat tape can be installed on the supply line to the structure. The heat tape should not be used continuously, but only in the case of an emergency when it is certain that the supply lines are frozen. Note the inclusion in this publication of the Consumer Products Safety Alert on electrical heat tapes and their possible dangers. If the water line is uninsulated, it should be at least 5 feet below grade, if possible. Uninsulated lines are not recommended.

The burial of the tank has several advantages. First, burying the tank avoids using valuable indoor space, which costs $100 or more per square foot, for water storage, perhaps less in a basement. Second, there is no chance of flooding the living space with the water if a leak should occur. And third, if water is stored indoors, 20 to 30 gallons of fuel oil a year can be expended to heat it. Some people feel this is worth the price but it is not really necessary. Indoor tanks result in cold water not really being cold, but being closer to room temperature due to the inadvertent heating by room air contact.

If the soil conditions, such as the presence of rocks or permafrost, do not permit burial of the tank, an insulated shed, preferably attached to the house, should be provided. A full 2,000-gallon water tank however, weighs in excess of 17,000 pounds (8½ tons). Therefore, a reinforced floor is a must. Sealing the system to avoid interior spillage is also very important. This type of installation is detailed in Figure 3.

Avoid burying tanks or water lines under driveways and other cleared areas. Heavy traffic may collapse a tank and the lines. Also, the soil under cleared areas is colder, increasing the likelihood for freezing problems. Before burial, pad the bottom of the tank with sand to protect it from sharp rocks.

Pump Protection

It is advisable to consider protection of the pump in your water system in the event of a water leak or for when you run out of water. When you run out of water the pump will attempt to pump water on demand when none is available and it could destroy itself. To prevent this, there are water level switches and low-pressure pump cutoffs, which can shut the power to the pump off when there is no water in the tank. Many product types are available, and new products are becoming available regularly such as:

1. Mercury float switch, which simply floats when water is present but when contact is made with tank bottom, this switch shuts off the pump. It is available for $30 to $40 in most cities in Alaska.

2. Conductive water level sensing device, which relies on conductivity of water to maintain pump operation. When water is absent, the pump shuts off.

Other Tanks Are Available Also

As previously noted, most common tanks are rolled steel tanks or polyethylene plastic tanks. Inevitably steel tanks are going to be replaced by polyethylene tanks, as they are becoming more durable and stronger, so that they can be buried empty. They have none of the disadvantages or shortened lifespan of steel tank.

Aluminum tanks are available in all sizes and applications. They do not rust, are lighter than steel, and will last a lifetime (barring damage). However, they cost about twice as much as an equivalent steel tank and have no real advantages over polyethylene. Stainless steel tanks are also available but are about 4 times as expensive as steel.

A collapsible steel tank with liner is available in a 1,500 gallons size for $2,850. This is especially good for transport to bush locations and other difficult logistical situations. It can be assembled by one man on-site and is transportable by small plane or boat.

Further Information

There are many options for on-site water storage not covered in this publication. For further information, call the Cooperative Extension Service in Fairbanks at 474-7201.

A useful reference for on-site water systems as well as other private water supplies is *Private Water Systems Handbook*, MWPS-14, $7.00. A new publication from Cooperative Extension has been developed for Interior residences to help residents with water protection and quality, indoor air quality and waste disposal. It is titled: *Living in the Interior*, CDR-00011, $5.00. Both are available from: Distribution Center, Cooperative

cont'd on page 8

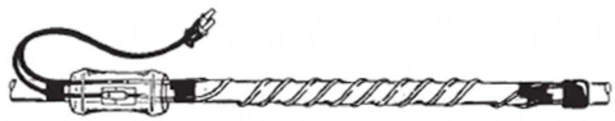
This publication contains advice on the use of electric heat tapes. These can cause fires if installed improperly. Please read the following consumer product safety commission alert, if you are planning to use heat tapes on your water lines.

Consumer Product SAFETY ALERT

From The U.S. Consumer Product Safety Commission, Washington, D.C. 20207

Electric Heat Tapes May Cause Fires

- **Install only as instructed.**
- **Some heat tapes must not overlap or touch themselves, unless specifically permitted in the manufacturer's instructions.**
- **Replace if electrical insulation is damaged or deteriorated.**



Electric heat tapes are used by thousands of home-owners (especially mobile homeowners) to protect their water pipes from freezing. Yet, if improperly installed or maintained, heat tapes could go beyond keeping your pipes warm; they could burn your house down.

A heat tape (also known as a pipe heating cable) consists of two wires enclosed in plastic insulation. When plugged into an outlet, it emits heat from electrical current passing through the cable. Heat tapes are usually installed in crawl spaces and in the sub-structure of mobile homes and other dwellings where exposed water and drain pipes could freeze during the winter. The products are often plugged in year-round and are activated by a thermostat when the outdoor temperature approaches freezing.

The U.S. Consumer Product Safety Commission (CPSC) estimates there are 2,600 fires each year involving heat tapes. These fires result in an estimated 20 deaths, 110 injuries and $24.8 million in property loss. Fires often occur because of improper installation by consumers. For example, a heat tape that is wrapped over itself or used near flammable material can lead to fire.

CPSC urges consumers to inspect their heat tape annually. If there is any damaged or cracked insulation or bare wires the old heat tape should be replaced immediately.

If you are purchasing heat tapes CPSC offers the following safety tips.

- Buy the proper tape for the proper pipe. Know the diameter and length of the pipe to be protected, then buy the heat tape recommended for that size by the manufacturer. (Some heat tape can be cut to fit the length of the pipe.)
- Buy heat tape that meets voluntary standards and is listed by a nationally-recognized laboratory such as UL.
- Follow the manufacturer's instructions for installing heat tape. Heat tape should not be lapped over itself around the pipe unless specifically permitted in the manufacturer s instructions.
- Wrap the heat tape directly over the pipe to be protected, never on top ot the thermal insulation covering a pipe.
- Don't cover the heat tape with insulating materials unless so advised by the manufacturer. If you insulate the tape, it must be a nonflammable insulating material such as fibrous glass.
- Never use more insulation than recommended by the manufacturer. Over-insulation can cause a fire.

009201

TYPICAL MATERIALS LIST FOR A BURIED HOLDING TANK
2,000 GALLON CAPACITY WITH RESERVE FEATURE

1	–	1½" X 7' galvanized pipe - thread both ends
1	–	2" x 7' galvanized pipe - thread both ends
1	–	1½" vent cap with screen
1	–	2" fill cap
1	–	10' heat tape
2	–	2" x 1" double-tap tanks adapters
2	–	1" foot valves
1	–	1" x 58" galvanized pipe - thread both ends
1	–	1" x 48" galvanized pipe - thread both ends
2	–	1" swedge 90° fittings
	–	1" copper pipe (soft) sufficient for need
2	–	1" copper gate valves (sweat)
1	–	1" copper tee
	–	Auto-trace heat tape with ends—sufficient for need
	–	Insulation and visqueen

Extension Service, P.O. Box 756180, University of Alaska Fairbanks, Alaska 99775-6180, Phone: 474-7268.

Acknowledgements
The author wishes to thank Mr. Don Cameron of Water Wagon for suggesting this publication and helping in its preparation. The staffs of Greer Tank and Welding, M & M Constructors, and Tanks Unlimited LLC were consulted about local product experience and availability.

Electric Heat Tapes May Cause Fires, Consumer Product Safety Alert is from the U.S. Consumer Product Safety Commission.

The use of trade names in this publication does not imply endorsement by the Cooperative Extension Service.

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Further publications relating to water develpment and quality can be found at
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5-83/RDS Revised July 2004

NEW INSIGHTS FROM RADON RESEARCH IN INTERIOR ALASKA

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Fairbanks, Alaska, 99775

INTRODUCTION

Residents in the interior of Alaska spend a significant amount of time indoors during the colder winter months of the year. Achieving suitable indoor air quality in an economic manner, is important to maintain a healthy indoor environment. Indoor radon gas concentrations are a problem for some areas in the Fairbanks basin. Consequently a good radon public awareness program is necessary to help owners make informed choices about radon reduction and reduction strategies. Information about indoor radon concentrations was gathered from 57 Fairbanks area homes in this study. This paper is a review of highlights of a thesis by the first author, Mr. Jack Schmid and was presented to the University of Alaska Fairbanks in the partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering, in May 1999.

Tracer gas tests were used to estimate ventilation rates. The gases used included carbon dioxide. Differential pressures across the building envelope were correlated with indoor temperature differentials. It was demonstrated that there are homes in the hills surrounding Fairbanks with elevated levels of indoor radon and results show that subslab depressurization radon mitigation systems were effective. It is also clear that radon control is most economic when done during initial construction. Map 1 shows the Fairbanks area, a river bottom surrounded by an amphitheater of hills, known as the Tanana/Yukon uplands. Latitude is 64° 47' N, and Fairbanks is only 150 miles from the Arctic Circle. Winters are long and cold and are in the climate zone known as subarctic continental, typified by those long cold winters and short warm summers.

Several previous studies of the radon conditions and occurrence in Interior Alaska set the backdrop for this research study. A survey conducted by the Department of Transportation and Public Facilities of the State of Alaska, focused specifically on buildings in the hills surrounding Fairbanks. It was conducted in 1987 and 38 houses from the data sample were at or above the 229 meter contour interval (700 feet). Detection devices used in this particular survey were activated charcoal detectors (Air-Chek) and were exposed for durations between 24 and 96 hours. They were also deployed in the month of July (Hawkins et al., 1987). In 1989, an EPA ten state survey was conducted which included Alaska. The Alaska portion was performed jointly with the Alaska Department of Geology and Geophysical Surveys and is referred to as the ADGGS survey. There were 204 houses from the Fairbanks area included in this sample and all measurements were made with charcoal detectors, exposed for 48 hours. These detectors were placed in the winter in the lowest livable level of a home (Nye and Kline, 1990).

The ADGGS survey was a telephone random survey and the subjects of the survey were responsible for deployment of the detectors as directed. They also reported the type of terrain around their house. Terrain categories were: hill tops or ridge crests as the highest, steepest, shallow soil category; steep slopes; then gradual slopes, less than 10°; and then flat areas and riparian bottom lands. There were actually no specific criteria defining each category and the determination of the site was left up to the subjects. This survey showed that the highest incidence rate and the highest levels of radon in Interior Alaska, occurred in the Fairbanks uplands and that the steepness and location of the site was an important characterization for the likelihood of radon occurrence.

THIS STUDY AND SOME FURTHER BACKGROUND

The intent of the study was to learn in more rigorous detail, the driving forces operating on a building, which helped to induce radon flow into it. Of course the basic physics follows the law known as Darcy's Law, a law which describes flow through porous media, describing that flow as proportional to the permeability of the media and the magnitude of the pressure gradient. Because of the atmospheric effects, the pressure gradients and determination of the effects of the pressure differences across the shell of the buildings in Interior Alaska are an important investigatory element of this research. Radon transport is suspected to be directly related to ventilation rates and air leakage rates, so stack effect and its determination of soil gas transport is an important process to understand in our climate. Therefore, it was a focus of this research work.

For the Darcy flow of soil gas, the amount of flow can be described in terms of, flow of air, soil gas resistance to that flow, and the differential pressure across the building shell inducing that flow. Atmospheric pressure variations have also been demonstrated to be a factor in driving soil gas into a house under some conditions, and this flow generally follows the time rate of change of atmospheric pressure. Although some of that type of investigation was undertaken in this study, it was not the major focus. It is generally understood from calculations done by the researchers, that temperature driven flow is by far a dominant factor in the movement of soil gas and consequently radon, into a house from the subsoil beneath it.

In order to determine the permeability and the air leakage of the house, a blower door was employed. This blower door uses a fan to induce a large and roughly uniform pressure difference across the building envelope. This enables the measurement of airflow required to maintain that pressure difference. Although there is no simple relationship between the ventilation rate of the building and its air leakage, the Lawrence Berkeley Laboratory infiltration model provides a means of generating specific infiltration and flow rate (Sherman, 1998). Using this model requires the use of the leakage distribution, house height for determining stack factors, wind shielding parameters, and both indoor and outdoor temperatures. Blower door data for this work, were analyzed with software provided by the blower door equipment manufacturer. The software uses the Lawrence Berkeley Laboratory (LBL) model, developed by Max Sherman (Energy Conservatory, 1992). This model estimates an average natural infiltration on an annual basis. House parameters put into the model are the number of stories, the volume of the house, the above grade exposed surface area, and a wind shield factor. Parameters for climatic factors and leakage distribution are entered into the initial program setup and are not among the operator entered parameters at the test site. All of this data acquisition was aimed at finding effective air quality management strategies and mitigation factors that worked in the Fairbanks area.

A QUICK REVIEW OF METHODOLOGIES

Initial background data were collected using two methods. The first was phone contact of home owners who had previously tested their homes with alpha track detectors obtained through the Alaska Cooperative Extension. Records available comprised information of a fraction of purchases of radon test kits from Alaska Cooperative Extension and some information was no longer current. The second method was to solicit home owners in radon prone areas who would allow their homes to be tested for elevated indoor radon levels. Criteria used for house selection was a location in the hills surrounding Fairbanks that had direct communication with underlying soil via a basement, crawlspace, or a concrete slab on grade construction. Other types of houses were excluded from the study.

Two alpha track detectors were provided to each home owner to place in their homes and they were placed during the 1995/96 and l996/97 heating seasons. Generally the EPA suggested protocol for where to place the tests were utilized. The detectors were typically deployed for ten to twelve weeks during the heating season from October through March. During some of these periods, additional data was available by strategic timing of air leakage tests, blower door tests, and tests of infiltration utilizing tracer gases. In order to fully understand the relationship of temperature and temperature differential induced leakage, outdoor and indoor temperatures were measured simultaneous with the radon and other indoor air quality measurements as well.

In three cases the differential pressure across the foundation slab was measured. This required a very cooperative home owner since penetrations were required in the foundation slab, i.e., drilling through the slab. One particular house which was very intensively monitored, referred to as house R-P, was also unoccupied for about eight weeks during the heating season. This offered the opportunity to take measurements and operate the radon subslab depressurization system which this house had, for investigative purposes without disturbing resident householders. This house provided a very interesting case study and served all the reasonable functions that a research test house would.

RESULTS

Information collected during the winter seasons of 1996 through 1998 from alpha track detectors recording indoor radon concentrations are reported on Table 1. The reporting is done in ranges from less than 4 picocuries per liter, 4 to 20, 20 to 80, and greater than 80 picocuries per liter. Three of the 19 homes which had less than 4 picocuries per liter, incorporated vapor barriers (polyethylene) under the slab, which minimize infiltration routes from the subslab during construction to reduce the radon influx. Three homes with concentrations of 4 picocuries were mitigated for concentrations greater than 30 picocuries per liter.

Table 1
Summary of ATD Survey Results 1996-1998

Number of homes	<4 pCi/L	4-20 pCi/L	20-80 pCi/L	>80 pCi/L
34	19	9	4	2

One result is an indication of how effective the subslab depressurization system is for lowering the radon concentration in a house. Figure 1 from Schmid's thesis shows house R-F with the subslab depressurization system off and on. The large vertical bars indicate the duration during which the fan was off. It's extremely clear that the radon level in the house ascends over about a day, from around 3-5 picocuries per liter to nearly 80 and then levels off. Late in the evening of the second day during which the subslab depressurization was off, the heat recovery ventilator was turned on and it slowly, with some strange cycling, lowered the rate from the approximate starting point of 40 picocuries to about 25-30, after which, on the 12th February, the subslab depressurization system was turned on again and radon levels in the house rapidly fell back down to their previous mitigation levels.

A similar pattern was noticed in other houses that were tested with the fans off and on. In no case when the fan was off, did the concentration of radon not exceed the mitigation level in the house by a factor of more than 10. A subslab depressurization system is clearly an effective mitigation strategy.

Earlier mention was made of the importance of the subarctic continental climate as the driving force of the temperature difference between the indoors and outdoors, and as a factor in increasing radon concentration and radon induction indoors. Figure 2 from house R-P, is a plot of several days when radon concentrations were measured, plotted versus the indoor/outdoor temperature differential. During the period indicated, the indoor/outdoor temperature differential varied from about 34°C to about 43°C and the radon concentration varied in a tightly linear manner with an R^2 variance of 0.54 between 400 and about 700 picocuries per liter.

Radon concentrations were also measured during the summer to indicate how the magnitude of radon induction changes from winter to summer. Table 2 shows three different instances during the summer (or at least the warm period of the year) for two different houses. House R-P for the period 17th May through 14th September 1998 and the house R-L between 14th May and 13th June and again from 19th September through 12th October. Indications are that the average is well below the EPA remedial action level, a maximum of 1.3 picocuries per liter in house R-L during the early summer and the minimum of 0.2 picocuries per liter in house R-L during the autumn test period. Even house R-P which is one of the houses with the highest winter radon concentrations measured, had an average of only 1.2 during the summer months of 1998.

Table 2
Warm Weather Indoor Radon Concentrations

House	Date	Average	Standard deviation
R-P	5/17/98-9/14/98	1.2 pCi/L	1.0 pCi/L
R-L	5/14/98-6/13/98	1.3 pCi/L	1.1 pCi/L
R-L	9/19/98-10/12/98	0.7 pCi/L	0.2 pCi/L

Perhaps one of the most interesting results of this study, occurred in the intensive evaluation of house R-P and is demonstrated in Figure 3, a complex plot of the indoor/outdoor temperature differential. This figure shows that when the temperature differential exceeds 33°C, the basement actually goes negative in pressure with respect to the subslab area. This means that the subslab depressurization system is being overpowered by the outdoor/indoor temperature differential and the mitigation system is virtually ineffective. There are several reasons for this, which will be discussed in the results, but primarily it's due to the fact that the house is extremely leaky above grade, and the pressure differential gets to be so enormous that even the subslab depressurization can't keep the difference greater than a negative pressure. So this house, because of the climate it is in, has double jeopardy and sometimes even the subslab depressurization isn't enough to keep radon out.

Table 1 cited earlier, clearly illustrates that of the homes sampled in the hills around Fairbanks, a substantial fraction have radon concentrations above the EPA remedial action level of 4 picocuries per liter. The proportion of the homes in this category in this most recent study was 52 percent. (Three homes were mitigated in this study to below 4 pCi/L). Nationwide only 6.1 percent of the homes exceed 4 picocuries per liter (BEIR VI, 1999). About 30 percent of the risk attributed to radon exposure, is associated with homes having a concentration greater than 4 picocuries per liter. Many homes in the Fairbanks area have concentrations above 20 picocuries per liter. This recent survey adds confirmation that homes in the hills around Fairbanks have a much higher probability of having elevated indoor radon concentrations than homes in the lower alluvial areas down near the flood plain of the Tanana and Chena rivers.

A result crucial to considerations regarding expenditures for public education, has been included in Schmid's thesis (1999). He makes the statement that "when considering the public education effort to help residents become more aware about radon, it is necessary to look at the investment required. The funds spent on public education are modest compared to the impact it has on the public. Investment in the State of Alaska for radon education is approximately $30,000 per year". In Appendix 1 of the Benefits and Costs of the Clean Air Act of 1970 to 1990, estimates of the public's value of a statistical premature death avoided ranged from $0.6 to $13.5 million in 1990 US dollars (US EPA, 1997). Efforts to educate the public might avoid about nine cases of cancer over ten years. The cost per life saved for this group educated over a ten year period, is 10 years times $30,000 per year expense, times one-ninth (for one out of the nine lives saved), yielding $33,333 per life saved. This is clearly much less than the public's perceived value of saving a life. These risk calculations are further elaborated in the Schmid thesis. They were based on the radon concentration distribution in the Fairbanks homes, the number of people mitigating, and a linear dose response for the effects of radon. The estimate considers only those homes with greater than 40 picocuries per liter to be very conservative in this assessment. This estimate therefore ignores the fraction of houses that have concentrations between 4 and 40 picocuries per liter and those houses which have been built using passive reduction methods, such as the radon resistant new construction system advocated by EPA.

Equally interesting as a summary, are the conclusions that can be drawn (at least strong inferences which can be drawn) by looking at the substantial variations in soil gas radon concentrations that were observed between summer and winter. Particularly of interest is a period, 3rd through 9th May 1998. During one measurement period, concentrations went from 7,946 picocuries to 6 picocuries per liter in only six days. These concentrations were determined using grab sample technique with a scintillation counter. Although more information needs to be gathered on what actually happens to radon concentrations and radon soil gas concentrations in the summer time, clearly a large change seems to be occurring between winter and summer in inducted radon, in differential pressures driving the radon into residences, and the resulting radon concentration in homes in summer.

Some Important Conclusions

These surveys confirm the previous work indicating that homes in the hills around Fairbanks have a much higher probability of having elevated indoor radon concentration than homes in the lower alluvial areas. The fraction of houses in the hills exceeding the 4 picocuries per liter action level in the three Alaska surveys cited, was much greater than the national average. Thirty percent of the homes in this latest UAF survey had indoor radon concentrations greater than 20 picocuries per liter. The probability of having many homes in the area where the risk of exposure to radon is high, make the public education function of the State of Alaska and the US EPA important. In terms of public health, the goal of the public education program is to decrease radon risk. Those affected by radon in their homes deserve a response to their questions tailored to the specific conditions. The radon education program has credibility in the community. Maintaining this credibility and effectiveness requires accurate and helpful information.

Subslab depressurization systems were effective in significantly reducing indoor radon concentrations in this study. Reductions of indoor concentrations were from one to two orders of magnitude. Annual concentrations in mitigated circumstances were well below the 4 picocuries per liter action level.

Regarding seasonal variations in radon concentration, initial results from this work indicate that the summer season may not reflect the annual average indoor radon concentration in any credible way. In the two houses monitored during the summer, indoor radon concentrations were below two picocuries per liter, and were one to two orders of magnitude lower than during the cold months. A person wishing to assess his risk from exposure to radon wants to know his average exposure. All testing infers an average exposure, but a longer test is more likely to approach the actual exposure. The best way to know the average annual exposure, is to test for a year.

Leaky houses were found to be problematic in this study and altering the leakage distribution to lower the neutral pressure level, could reduce the differential pressure across the foundation. Drawing from experience with building science and energy conservation strategies, this simply means that it is extremely useful for both energy efficiency and for radon mitigation, to seal the top of the house against air leakage. This is the area of the house where leakage is maximum if there is a large stack effect, and where a large differential temperature in the house drives vertical convection of air.

Strategies on where to place intentional openings and how to minimize the pressure difference across the envelope, particularly leakage area at the top of the house, are worthy of further study, but indications are that this strategic element of design ought to be given more attention because all of its effects are positive in a building science context. The phrase “seal the lid”, from weatherization experience, is effective in radon mitigation as well.

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RADON IN HOMES— THE ALASKA EXPERIENCE

RAD-01250

by
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INTRODUCTION

Since radon was first found to be a concern in Alaska in 1986, the interest and awareness of radon as a special housing and health problem has continued to grow. There are certain features of a house that characterize it "at risk" for radon. Efforts at mitigation are being made that have been most effective in reducing radon under Alaska conditions.

Clearly, radon must be able to enter a home in order to be a problem. Riefenstuhl and Kline have analyzed the conditions for radon transport from soils to home interiors (Personal communication, 1988).

Four factors must exist in a house's location for it to be a radon "at risk" house. Two of the factors are geological in nature; the other two factors are determined by the structure of the house itself and the way it is operated.

1. There must be adequate uranium to provide a source for radon transport.

2. There must be enough permeability in the soil to allow rapid soil gas movement to carry radon from its origin to the interior of the home.

3. The house must have soil contact that has imperfections, holes, cracks, or intentional perforations which allow the movement of radon through the basement or crawl space.

4. There must be lower pressure inside the house than in the soil so that radon flows into the house.

All four of these characteristics are necessary for radon be a problem. The absence of any single characteristic eliminates the possibility of radon (in general).

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Through two years of selective testing, it became clear that Interior Alaska —especially the uplands near Fairbanks—is a radon risk area. In the first year of radon screening tests, done non-randomly with Air-Check brand charcoal screening kits, 52 % of the 353 tests were at or above the remedial action level as set by the Environmental Protection Agency (EPA). More than 20% of the tests—or one in five—were above 20 pCi/l (pico Curies/liter), which is five times the EPA recommended remedial action level. Obviously, Fairbanks needed further research to determine how bad the problem is, and see what might be a means of mitigation.

Not only is the long heating season in Fairbanks a factor in radon transport, but throughout the heating season the oil-fired combustion system actually provides the negative pressure to move radon into the house and cause radon concentration. The heating system in a house tends to act as a pump that sucks radon laden air into the bottom of the house, and drives the exhaust out the top.

All of these factors relate to an understanding of the problem in a specific geological setting. This does not mean that radon cannot be present in areas which are less suspect, such as flood plains, highly porous gravel in valleys or deep silts. We have found less of a problem at these sites, but there are always spurious and inexplicably high levels in various places where it is not expected. One such area is the Aurora Subdivision in Fairbanks; another is Lakloey Hill on Badger Road in the North Pole. The Lakloey Hill situation is a model of the larger hills to the north of Fairbanks, so it is more explicable than the Aurora Subdivision case.

The somewhat alarming experience early in Fairbanks led ultimately to Alaska's inclusion in the third round of EPA's Ten State Surveys. The Alaska EPA/DGGS (U.S. Environmental Protection Agency/Alaska Division of Geological and Geophysical Surveys) survey was completed in the spring of 1989 and the results explain, among other revelations, the conditions in Fairbanks uplands which constitute an "at risk" home.

- Built high on a hill slope with bedrock consisting of Birch Creek Schist
- Top soil depth less than the basement excavation (eight feet or less)
- Standard basement construction for daylight basement notched into hill
- Oil-fired combustion heating system
- Basement material either concrete or All-Weather Wood (AWW)

The above conditions constitute an "at risk" radon home. Any house on a similar site with these conditions and construction styles should be tested for radon.

Along with the confirmation of these radon risk characteristics, the Alaska EPA survey found that:

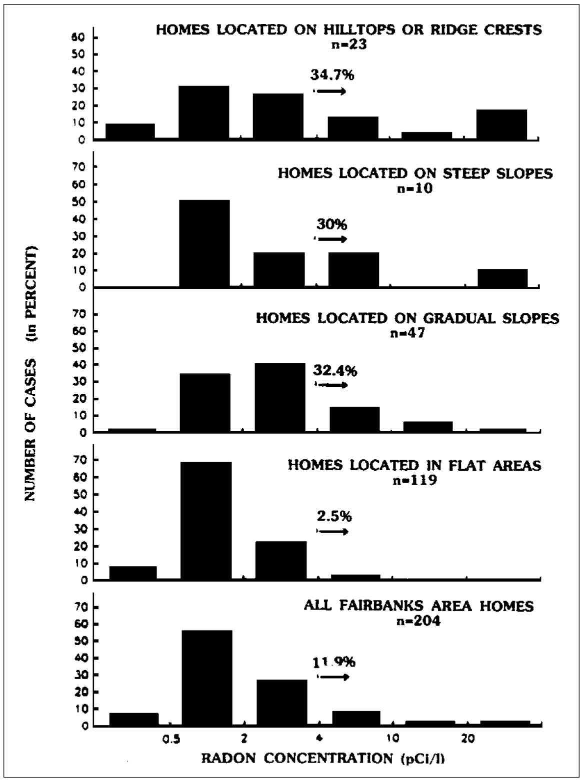

Figure 1. Histograms summarizing radon screening measurements and local geography of Fairbanks area homes.

"Interior Alaska has the highest proportion of homes with elevated radon concentrations as well as the individual homes with highest concentrations. In the Interior, 3% of homes within the sample population had screening levels higher than 20 pCi/l and 17.6% of homes had radon screening levels that were higher than 4 pCi/l. Figure 1 summarizes the responses to a request for home site geographic information which was included with the report of test results that was sent to participants in the survey. This figure shows that 30 to 35% of homes built in the hills around Fairbanks have elevated radon concentrations.

In the Fairbanks area, homes built in the hills surrounding town with concrete slabs or basements in contact with bedrock yielded the highest radon screening levels. These areas also had the highest proportion of home with basements in contact the bedrock that did not have elevated radon concentrations. The data shown in Figure 1 for homes located on hillside sites, includes homes which are built on thick accumulation of windblown glacial silt (loess). Thick accumulations of loess appear to be an effective barrier to radon movement. Homes built on alluvium from the Tanana and Chena Rivers are also much less at risk. High radon concentrations in homes in contact with bedrock are likely to result from high fracture permeability of the bedrock as well as relatively high uranium concentrations in the schist which comprises local bedrock. Low radon concentrations in homes built on loess and alluvium may reflect low soil gas permeability, low uranium concentrations of soils, or both." (Nye and Kline, 1990).

MITIGATION STRATEGIES IN ALASKA

With the information on at-risk sites, it is possible to pursue a strategy for mitigation.

The conditions cited on the previous pages provide a series of options for radon mitigation, since elimination of any of the four characteristics will achieve mitigation. The two geological conditions—uranium presence and permeability—are "givens" on a site. Removing either condition would be expensive and unaesthetic as well as impractical. Therefore, the other two conditions, which are structural, leakiness and pressure difference, are the practical candidates for mitigation.

The solutions are to seal the basement or crawl space, and/or change the pressure differential. A review of EPA mitigation literature shows combinations of these two methods as the most common approach. Alaska experience concurs, with more reliable results from sub-slab ventilation than from just sealing leaks.

Recent surveys show that—in all but one case—sub-slab depressurization accompanied by sealing leaks in the basement or crawl space, was the most successful mitigation technique. (See publication *RAD-00755, Radon Mitigation: Alaska Experiences, Costs, Results,* for results of this survey).

There are climatic as well as geologic reasons why sub-slab depressurization works as opposed to overpressurizing the slab or house interior. While it may be physically logical to overpressurize the interior of a home to exclude radon, this strategy also drives warm, moist, interior air out all the nooks, crannies, keyholes and doorsills. At very cold temperatures, an overpressurized system would freeze doors, windows and fire exits shut. This is obviously an unacceptable alternative. Sub-slab depressurization is presently the only option with a consistently high success rate.

New construction on radon-suspect sites has been tried with mixed success. Often, immaculate air seal detailing, vapor barrier detailing, and interior concrete sealing finish work still does not result in a new home that has acceptable levels of radon. One such new construction resulted in a level of 16 pCi/l radon in the first screening test (Musick, personal communication, 1989); therefore a pre-installed sub-slab ventilation system had to be utilized following the recommendations in the EPA publication, *Radon Reduction Techniques for Existing Detached Houses—Technical Guidance, 3rd Edition for Active Soil Depressurization Systems, dated October 1993, which is available from the Energy Specialist's office* in Fairbanks, phone (907) 474-7201 or 1-800-478-8324.

While much remains to be learned about optimizing radon mitigation under Alaska conditions, the fundamental physical parameters of the problem are understood. Radon-proof construction techniques are being tried and tested now, and will be reported further as we see the results of these tests.

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BUILDING IN ALASKA

EEM-04253

Heating Values of Fuels

by
Richard Seifert
Energy and Housing Specialist

The gross heat outputs of various fuels are listed in Table 1. For all fuels except electricity, the gross heat output is a theoretical quantity: you never get that much heat out by burning the fuel in a stove or furnace as part of the heat is wasted up the chimney.

Heat output of wood varies with species and moisture content at burning. A cord of wood is 4' × 4' × 8' (128 cu. ft.) but the actual volume of wood is around 80 to 90 cu. ft. The drier the wood is, the higher the heat output.

The average efficiencies of selected types of heating systems are listed in Table 2. Heating system efficiency depends upon a number of factors, such as: method of firing the fuel, firing rate, air supply, amount of heat surface, volume of the combustion chamber, and cleanliness of the combustion chamber and radiating surfaces of the heating system.

Although electrical resistance heating is rated 100 percent efficient at the heating point, the energy efficiency at the power generation plant in converting fossil-fired fuel to electricity is variable and in the range of 28 to 38 percent. If waste heat for cooling turbines was used for the central heating of a city, the energy end-use efficiency could be increased to 60 to 70 percent.

The net heat outputs of various fuels and heating systems are listed in Table 3. These figures tell how much heat will actually be delivered to the house by burning a certain type of fuel in a certain type of heating system at the assumed efficiencies of Table 2. The numbers given in Table 3 are obtained by multiplying gross heat output of fuel times efficiency of heating system. Thus, a gallon of fuel oil contains 134,000 BTU's, but burned at 65 percent efficiency, it will deliver to the house 89,700 BTU's.

Abbreviations in Text

BTU stands for British Thermal Unit, and is defined as the amount of heat required to raise 1 lb. of water 1 degree Fahrenheit at 60°F;

cu. ft. = cubic foot (feet);
lb. = pound(s);
gal. = gallon(s);
kWh = Kilowatt-hour(s)

Specific gravity of wood is the ratio of weight of wood to equal volume of water, such that one cubic foot of wood at specific gravity of .55 weighs 34.3 lbs (.55 × 62.4).

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TABLE 1: GROSS HEATING VALUES OF FUELS

Type Fuel		BTU/lb.	BTU/Unit
Propane		21,550	91,800 /gal.
Natural Gas		73,890	1,000 /cu. ft.
Lignite Coal		8,700	17,400,000 /ton
Fuel Oil		19,230	134,000 /gal.
Wood:	Paper Birch[1]	8,600	23,600,000 /cord[3]
	Paper Birch	8,600	18,200,000 /cord[4]
	White Spruce[2]	8,600	18,500,000 /cord[3]
	White Spruce	8,600	15,000,000 /cord[4]
Electricity		—	3,413 /kWh

[1] Specific gravity = .55
[2] Specific gravity = .43
[3] Oven dry, moisture content = 0%
[4] Air dry, average moisture content = 20%

Wood values from the U.S. Forest Service/Alaska State Forester pamphlet entitled "Wood As a Fuel," 1979

TABLE 2: EFFICIENCY OF HEATING SYSTEMS

Type of Fuel	Firing Method	Efficiency (Percent)
Coal, lignite	Hand-fired w/controls	50-65
Coal, lignite	Stoker-fired	50-60
Electric	Resistance	100
Gas	All types	70-85
Oil	Designed unit	65-85
Oil	Conversion	60-80
Wood	Space heater, hand fired w/controls	50-60
Wood	Open fireplace	15-20*

*Fireplace efficiency is highly variable, but is especially diminished as outdoor temperatures decrease.

TABLE 3: NET HEATING VALUE OF FUEL

Type Fuel	Heating Plant Efficiency (percent)	Net Heat Output (BTU/Unit)	Quantity of fuel needed 100,000 BTU's
Gas, natural	70	700 /cu. ft.	140.00 cu. ft.
Coal, lignite	55	9,570,000 /ton	20.80 lb.
Electricity	100	3,413 /kWh	29.30 kWh
Fuel oil	80	107,000 /gal.	1.10 gal.
Wood: birch 20% mc	50	9,100,000 /cord	0.99 cu. ft.*
Wood: spruce 20% mc	50	7,500,000 /cord	1.20 cu. ft.*
Propane	80	73,600 /gal.	1.6 gal.
Steam	100	970,000 /1,000 lb.	103.0 lb.

*Cord equals 90 cu. ft.

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WATER CISTERN CONSTRUCTION for SMALL HOUSES

ALASKA BUILDING RESEARCH SERIES
HCM-01557

Introduction

This publication is one of nine that has been translated from Norwegian. They are taken from a series of publications produced by the Norwegian Building Research Institute (NBI) series, "Byggdetaljer," which literally translated means "building details." It is hoped that Alaskan builders will be able to glean useful ideas from these publications. The translations were done by Dr. Nils Johanson and Richard D. Seifert of the University of Alaska Fairbanks with the cooperation and permission of NBI, Oslo, Norway. The financial support for the translations and printing came through the Alaska Department of Community and Regional Affairs, from USDOE Grant DE-FG06-80CS6908. The publications use the original index code of the Norwegian "Byggdetaljer" series so that specific translations can be directly cited. All questions on these translations should be directed to Richard D. Seifert, Cooperative Extension Service, P.O. Box 756180, University of Alaska Fairbanks, Fairbanks, Alaska 99775-6180. Phone: 907-474-7201

0 GENERAL

01 This bulletin describes construction of a cistern for collecting and storing rainwater for household use. The design for a collection system and the construction and maintenance of such a cistern are described.

02 In many places along the coast, collecting rainwater is the only realistic method for obtaining useful drinking water. Usually, it is collected from the roof and diverted to a cistern (water tank) (Figure 02).

03 The rainwater, which is collected and stored under appropriate conditions, will be sanitary and safe as drinking water. The water can be purified, and the taste, color, and appearance can easily be improved.

04 Air pollution from industrial emissions has caused some rainwater to be relatively acidic and to contain soot and similar particles. However, evidence shows that there is no reason to warn against the use of rainwater.

05 Plant debris, soot, and dirt from the collection surface, will be flushed into the cistern. This will gradually reduce the quality of the water. A filter can be used to collect some of these contaminants. If the filter is installed in front of the cistern it must be large enough to accommodate all the water that will flow through it. If the filter is placed on the outlet side of the cistern, only the water that is used will be filtered. A filter will last longer if water for washing, irrigation, and so on is diverted and bypasses the filter. The simplest design is to place a filter in front of the drinking water outlet. If a filter is used, be sure that it has a sufficient capacity. If the filter clogs and this goes undetected, large amounts of water can be lost. Install an overflow to drain the water away if the filter is clogged. The overflow should empty where it will be noticed.

06 Before choosing a cistern design, select a location where sufficient water can be collected. It is

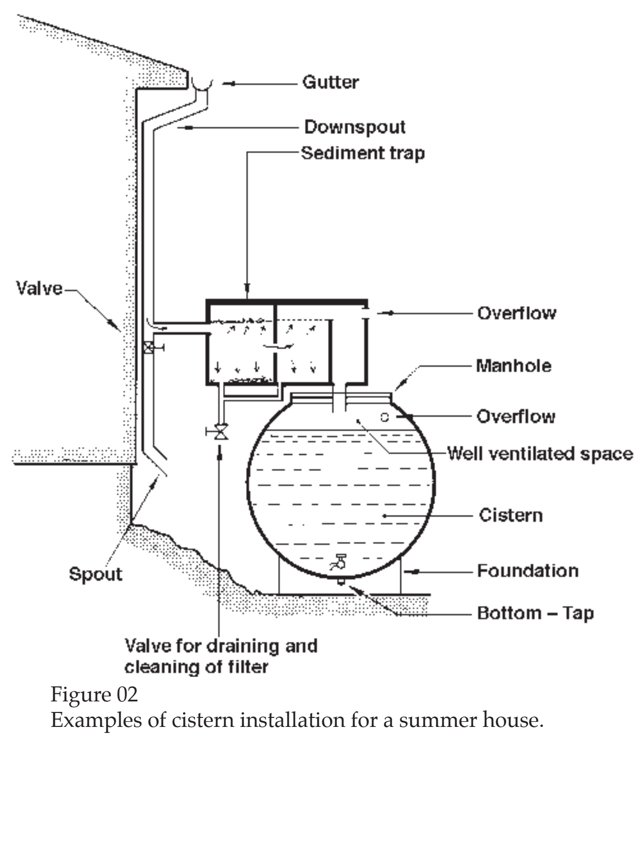

Figure 02
Examples of cistern installation for a summer house.

important to realize ahead of time that a cistern will require regular maintenance in order to provide water of good quality.

1 COLLECTION SYSTEM

11 Collection surfaces

The collection surfaces must not contain impurities that can be carried into the cistern. If a roof surface is used for water collection, it should not contain tar or lubricants. Asbestos cement plate can also be unhealthy. If questionable materials are used, ask the manufacturers if they will affect water quality. Sod roofs are not suitable as a collection surface. Roof covering materials that are normally useful as collection surfaces include tile, concrete, or slate shingles, aluminum, and corrosion-proofed steel. Plastic materials can also be used as a coating material or as a separate cover. If rock surfaces are used for collection, they must be protected against traffic and soiling. The area must be fenced in. If water can seep in from uncontrolled areas, it must be drained away.

111 Birds are the most common source of pollution on roofs. They can, however be prevented from landing by putting wires low over the roof surface (Figure 111).

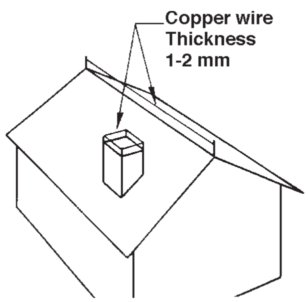

Figure 111
Bird wire to protect from birds landing on the roof.

112 Leaves, conifer needles, and pollen will, together with soot and dust, create a constant problem for the cistern user. Trees that are close to the house can be advantageously removed. After long, dry spells and during the flowering periods of plants and trees, let the first rain shower bypass the cistern until the collection surface has been flushed clean.

12 COLLECTION SYSTEM

121 Gutters and downspouts must be dimensioned and constructed so that a permanent water collection system is achieved. Collection plumbing must be corrosion resistant. Gutters can be made from many materials, such as plastic, zinc, copper, and steel. Most manufacturers have gutters of different sizes, shapes, and materials. To ensure good results with tight joints, use components made by the same manufacturer. If these guidelines are carefully followed, installation of a water collection system is usually easy, even for do-it-yourselfers.

122 A 100mm (4 in) roof gutter, correctly installed, will usually have sufficient collection capacity for a house with a floor area of 150m^2 (1,500 sq ft). A large enough gutter allows for easy removal of plant debris. Steeply sloping roofs can cause water to gush over the edge of the gutter during heavy rainstorms. This should be considered when dimensioning the gutter. The roof gutter should have a 1% slope towards the downspout. (Figure 122).

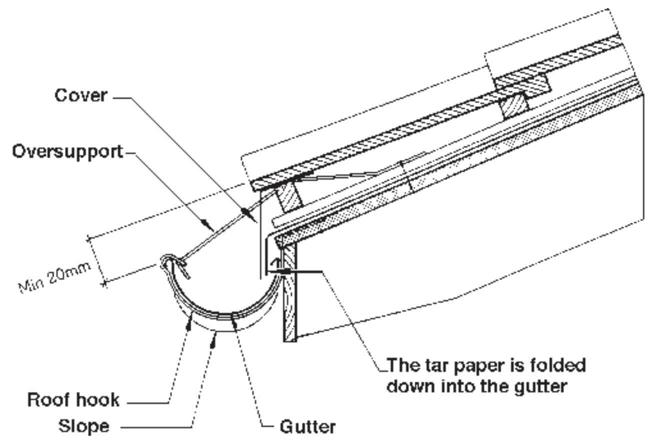

Figure 122
Installation of gutter

123 Downspouts from the gutter to the filter or intake box should be selected after evaluating the manufacturers specifications. Downspouts must be large enough for leaves to flow into the silt separator. From the filter installation, use a soft pipe of polyethylene or ABS plastic. This pipe can be as small as 32mm (1.5 in) in diameter.

2 CISTERNS

21 Sizing and selection of cistern

To determine the most economical cistern size, first evaluate the annual house demand for water and determine the annual precipitation and distribution of precipitation throughout the year. In parts of the country where most of the precipitation falls during the fall, it may be necessary to have the cistern volume equal to the entire annual usage. If the precipitation is evenly distributed throughout the year, a cistern volume of one-third of the annual need is reasonable.

211 The demand for water varies from person to person.

Twenty gallons per person per day is generally used as an average number if there is no flush toilet in the house. If a flush toilet is used or if a garden is watered, daily use can be as much as 70 gallons a day per person . As a rule, it is impossible to cover a large demand for water with a cistern. So called “cabin toilets,” which flush to a closed tank, use about 1.5L (0.5 gallons) / flush. Normal toilets use about 9L /flush (3 gal). It is normal to calculate about 5 flushes/person /day. For year-round occupancy the necessary cistern volume is 20 – 30 m^3 (5,000 to 7,000 gal) where 1m^3 is 1000 L. For cabins and seasonally occupied buildings, the necessary volume generally ranges from 500 to 3,000 gal.

212 Cistern volume should be determined by the local average annual precipitation and the available collection surfaces.

Two inches of precipitation yields one gallon of water per square foot of collection surface. The collection surface is measured horizontally. For a roof, it is the floor area of the house plus the area of eave overhang. A good rule of thumb is to subtract about 10% of the calculated water volume to allow for loss by flushing, overflow, and so on.

213 The shape of the cistern should allow for easy placement and maintenance. Divide the cistern into several separate compartments so that water flow will enhance bacteriological self–cleaning. For systems designed for year-round use, it is necessary to have a minimum of two separate tanks so that cleaning and maintenance can be done without having to empty the cistern. All cisterns must have a manhole lid in order to clean the entire internal surface.

214 The construction material for the cistern must be water tight. In addition, the inside surface must not give off substances that make the water unsuitable for drinking. Traditionally, poured concrete systems have been the rule, but lately prefabricated systems made of plastic or glass fiber–reinforced polyester are popular. These systems are especially the well–suited for summer houses, cabins, and seasonal-use buildings.

215 Poured concrete cisterns are generally used for buildings which have year-round occupancy. The shape is totally arbitrary and, with careful design, the cistern will blend into the overall landscaping. The year-round cistern must be protected against freezing to avoid leaks and to assure a continual water supply throughout the winter. If the concrete cistern is buried, groundwater must not penetrate the cistern. On frost susceptible soils, cracks in the cistern may occur, increasing the danger of groundwater infiltration. See recommendations for placing of poured cisterns (Figure 22).

216 Prefabricated tanks of plastic are an appropriate cistern solution. Plastic materials are usually maintenance–free and tight enough that they can be buried. There are several cistern types on the market. They vary in shape and hold up to 1000 gal of water. Some manufacturers deliver larger tanks by special order. To obtain good storage capability and to avoid emptying when cleaning, it is necessary to put the tanks in series or to have several separate tanks. The price of prefabricated cisterns will generally decrease with size on a relative cost-per-gallon basis, the larger the cistern, the cheaper the per gallon cost. (This also is true for special orders up to 20 or 30 m^3.)

217 Vinyl cloth or polyethylene can also be used as a liner material in cisterns. The storage tank can be buried or stand above ground (Figure 25).

22 Placement
Placement of cisterns depends on local site conditions. The tank should be protected against heat, mechanical loads, and so on. When installations will be used year-round, winter freeze protection for both the foundation and the water supply system must be considered. Figure 22 shows some placement possibilities.

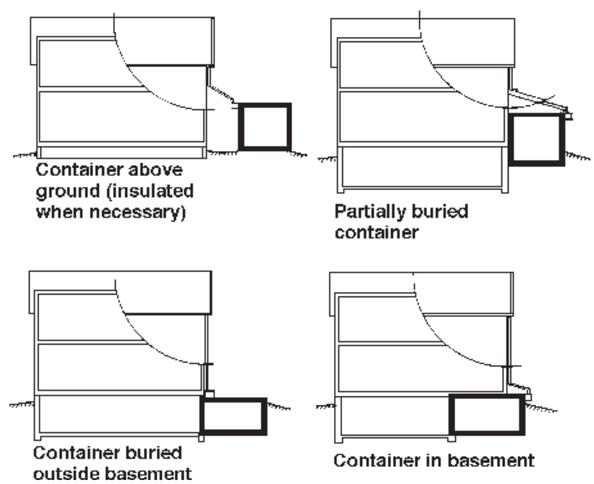

Figure 22
Examples of placement of systems.

221 In the case of seasonal use or installations where there is no electricity, the tanks should be placed so that gravity feed can be used to deliver the water. This can be accomplished by placing the cistern in sloping terrain, in the attic, or on a support under the eaves. The water can be pumped by hand from the cistern to a day tank in the attic or to another place higher than the outlet pump (Figure 221)

The cistern can be placed underneath the building in the basement or buried outside for some freeze protection.

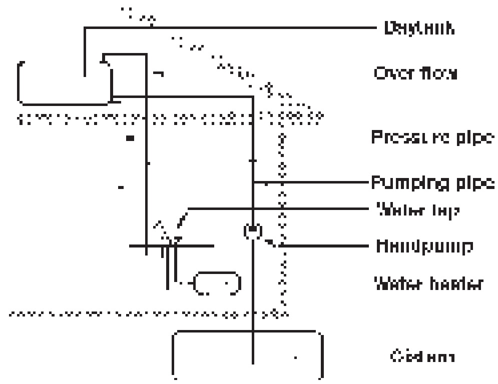

Figure 221
Schematic drawing for a gravity–fed pressure system with a cistern pump and a day tank.

222 If the cistern is buried as shown in Figure 222, the fill material must be packed in tightly around the tank, especially the lower quarter of the tank. Fill material, such as sand or gravel with a diameter of less than 0.5 in can be used. Mechanically crushed rock must not be used. Nor should fill material that contains frost–susceptible material such as clay be used. If the cistern is subjected to uplift pressure due to a high groundwater table, it must be secured. Avoid placing the cistern where there will be mechanical loads, such as vehicle traffic, on the tank.

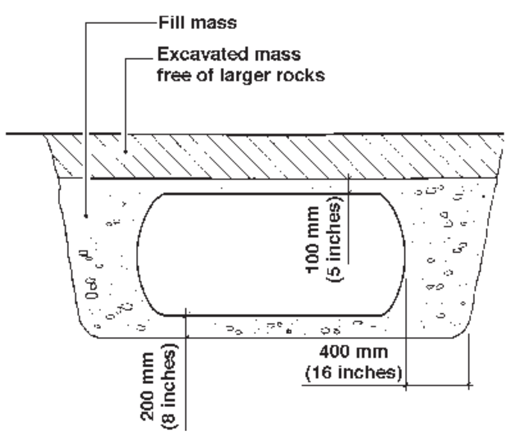

Figure 222
Schematic drawing for placement and backfill of buried cistern.

23 Cisterns cast in place

231 The container should be constructed at one end of the house for ease in collecting water from downspouts on either side of the roof. There must be a lid for each chamber with an opening of .7m x .7m (2 ft x 2 ft). The lids must be lockable.

The bottom of the container must have a gradient of 1 to 50 to a drain so that the container can be totally emptied of water. The container must be buried at a frost-free depth, and in many locations, the walls and roof must be insulated (see point 3). The container must never be placed where the water from a sewer line can infiltrate the system.

232 A tank with crawl space over the concrete deck is shown in figure 232. The roof water is directed from the downspouts over the tank's inclined roof to the intake box. Between the container and the wooden walls of the house, there must be a water–tight barrier made of roof tar paper with the joints glued together (Figure 232). Ensure good drainage under and around the container so that contaminated or polluted water cannot penetrate. The terrain must always slope away from the container to ensure drainage.

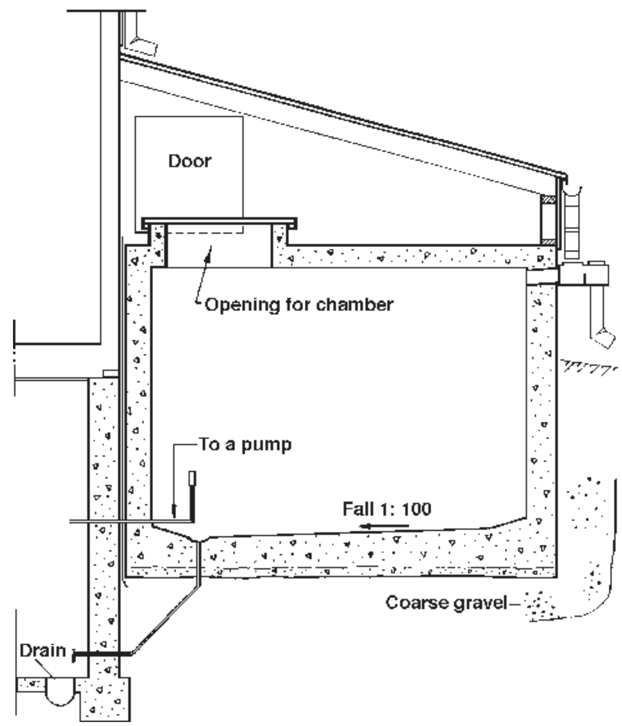

Figure 232
Cistern built partly above ground.

233 The concrete should be C-20 1:2.5:2.5 (cement/sand/gravel). Use clean aggregate with a maximum diameter of 25mm (1 in). The floor is poured, compacted, and leveled after the initial set. Smooth it with wood and steel trowels. When the forms are removed, after about a week, cover the interior and exterior walls with a mixture of cement and fine sand. (The walls can also be polished and smoothed with steel trowels instead of being covered with a layer of cement mortar. This will ease the cleaning process.)

There are additives that can be added to the mortar to reduce water penetration.

24 Masonry cisterns

Cisterns can be made of masonry, such as lightweight concrete. Special blocks are used that have room for mortar and reinforcement (Figure 24).

The inside of the cistern is covered with a good cement mortar and the surface is coated with a water–sealing layer. The watersealing layer can also be added directly to the mortar.

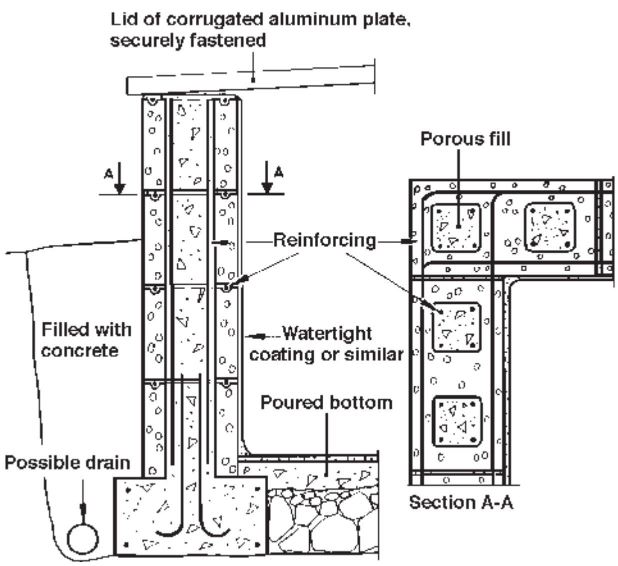

Figure 24
Cistern made of lightweight concrete

25 Cisterns of fabric or foil

A cistern can also be made like a pool, with a plastic liner as the impermeable layer. Manufacturers of swimming pools sell premade vinyl cloth. Fill the excavation with sand that is carefully compacted, or mount the pool on a special frame that is placed above ground (Figure 25).

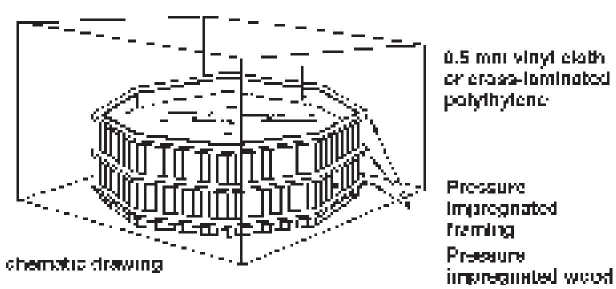

Figure 25
Cistern pool of vinyl cloth.
The cistern must be built-in, or provided with a solid lid.

26 Prefabricated cistern

Most cisterns are now made of plastic. Different plastic materials are available; the most common is fiberglass-reinforced polyester (GAP) and polyethylene (PE) (Figure 26a). Larger cisterns are made in the form of cylinders, preferably of fiberglass-reinforced polyester, a material that is both strong and light weight. Smaller cisterns of polyethylene are made in a variety of shapes and dimensions that make them easier to place (Figure 26b).

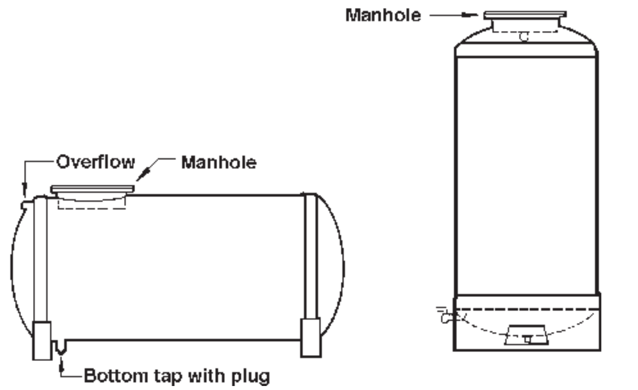

Figure 26 a
Examples of GAP cisterns

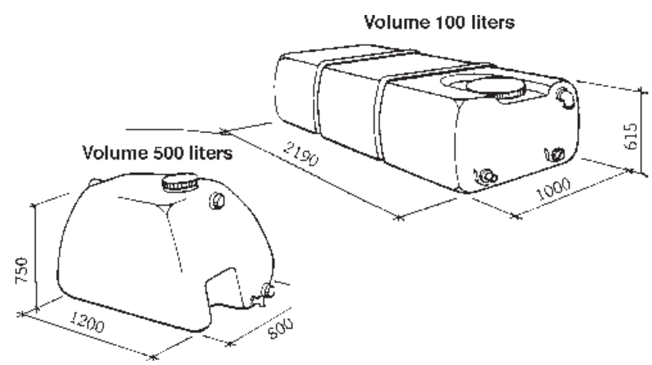

Figure 26b
Examples of polyester cisterns (daytanks)

3 FROST PROTECTION

Even in coastal areas wintertime temperatures can cause a cistern system to freeze. To avoid problems, a system designed for year-round use must be insulated against freezing.

31 Placement

311 If the cistern is placed on the ground with the top surface exposed to open air, the walls and top must have extra insulation. If the bottom of the cistern is deeper than about 4 or 5 ft it can remain uninsulated. To avoid cold bridges and to maintain higher ground temperatures, insulation should be placed as shown in (Figure 311).

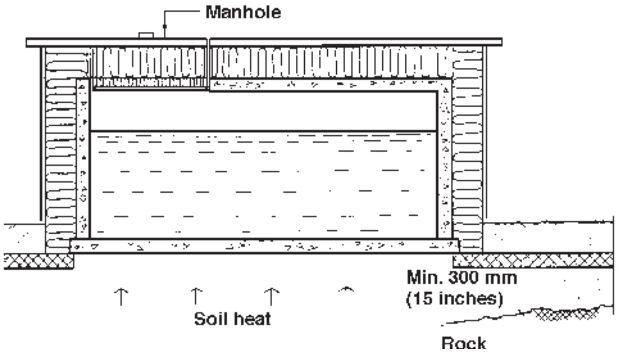

Figure 311
Frost protection using the soil geothermal heat (in nonpermafrost areas only).

312 If the cistern is placed on solid rock, significant warming by the soil is not likely and the bottom must usually be insulated (Figure 312a). If the cistern cover is more than 8 to 10 square meters (80 - 100 sq ft) it may be advantageous to insulate as shown in figure 311. Boards of extruded polystyrene are recommended for this application because they resist moisture and normal loads. As small a surface area as possible is recommended. Cylindrical cisterns should be insulated with batt insulation (Figure 312b).

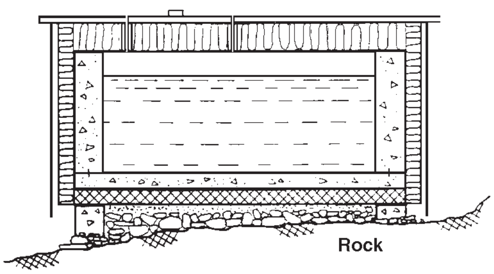

Figure 312a
Frost protection of cistern on rock.

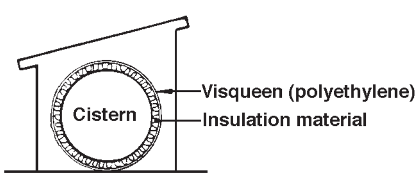

Figure 312b
Frost protection of prefabricated cisterns above ground.

313 If the cistern is excavated down to a frost free depth, frost problems are avoided. However, this in itself leads to several other problems, such as difficulties in cleaning, and may not be practical. A better solution would be to insulate the ground above the cistern as shown in figure 313. The necessary depth of soil cover will depend on the thickness and the extent of the insulation.

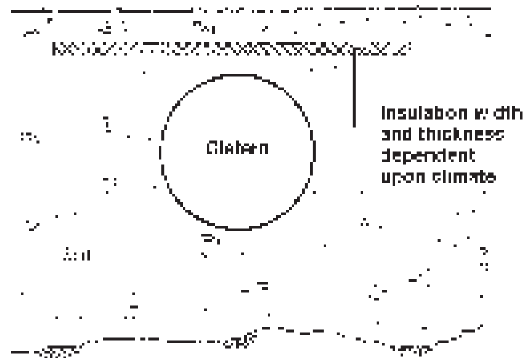

Figure 313
Frost protection of cistern buried in soil.

314 In maritime coastal climates there are often large variations in temperature during the winter. With a large, insulated, year-around cistern, the stored heat in the water will often be sufficient to prevent freezing during a short cold period. If the cold period is prolonged, freezing will usually start at the coldest surfaces. By placing the intake a bit above the bottom of the cistern, longer frost-free operation can be maintained. The intake pipe should be insulated and heated with a heat tape. The heat tape can be threaded inside the pipe or wrapped around it. If thermostatically controlled, 2 to 4 watts per meter might be sufficient. If the heat tape itself can be frozen, then freezing can take place, and the heat tape can be used as a thaw cable. This type of heat tape can be operated manually and should have a capacity of 25 watts per meter. See Figure 314. In a well–insulated installation thawing will take about 30 minutes. The electricity must be shut off after thawing to avoid overheating.

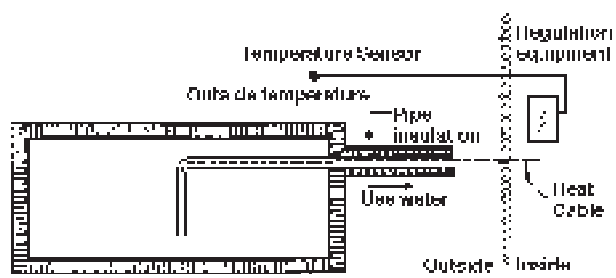

Figure 314
Placement and frost protection of intake pipe in the cistern with temperature sensor in the outside air.

315 Heating with a thermostatically controlled heat tape will afford good protection against freezing. The tape is placed in loops on the tank bottom and intake and wired to an automatic thermostat that will turn on at the appropriate temperature (Figure 314 and 315). A well–insulated cistern will need heat tape with a capacity of about 10 watts per square meter of surface. There are two main types of heat tape.

Traditional cables have a fixed resistance per length. If the electricity is used directly, the cable can be used in a fixed length. If a change in length is desired, use a transformer. There are also self–regulating cables that can be cut to the desired length without changing the heating capacity. A transformer is unnecessary. The heating increases with a decrease in temperature in such cables. The temperature sensor is placed inside the cistern and the tape will operate whenever the temperature is below freezing (Figure 315).

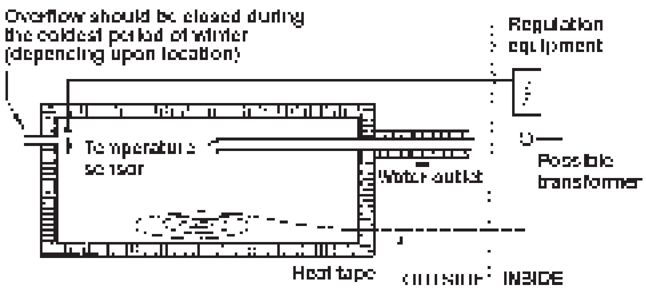

Figure 315
Frost protection of cistern with heat tape.
The temperature sensor is placed inside the cistern.

316 Sediment traps, filters, and plumbing must be secured against freezing. Cold temperatures and snow on the roof, combined with solar heat and snow melt during the day, can lead to a frozen filter system. Figure 316 shows the filter insulated together with the cistern. If this causes problems, the filter can be insulated separately and heated with heat tapes. Problems can also be solved by allowing roof water to bypass the filter outside the cistern in the winter season. If the filter and cistern temperatures are above freezing, a positive heat flow in the downspout will occur and prevent freezing.

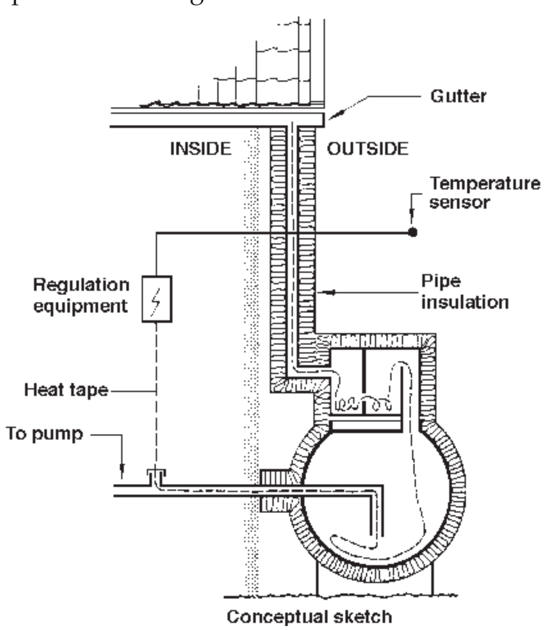

Figure 316
Frost protection of filter and cistern with heat tape.

A heat tape placed within the downspout will simplify thawing if the pipe freezes. Pipes that are in the shade or in drafts should be of a material that can resist freezing.

4 MAINTENANCE AND OPERATION

41 Cleaning

Regular cleaning of the cistern is necessary to maintain pure, potable water. Microbiological activity in the sediments causes a slime-like substance to grow on the inside of the cistern. The growth increases with temperature and the coating will, if not removed regularly, impart taste to the water. Cleaning is usually done once a year. Use a stiff brush, water, and baking soda. Finally, wash the area with ample amounts of clean water. Careful cleaning of the collection area (the roof and downspouts) along with a good intake filter and cold storage, can lengthen the time between the cleaning. Summer cisterns must always be cleaned by emptying and decommissioning at the end of the season. The cistern openings should be plugged after cleaning for winter storage.

411 Gutters and pipes normally require no maintenance but must be cleaned, usually in both the spring and the fall. Cleaning should be part of the maintenance routine whenever the filter is checked.

412 When decommissioning summer cisterns, the downspout must be vented to the ground in the normal way. Excess water spray can cause the building to rot.

413 If several collection tanks are used, they should be used in sequence so bacteriologically clean water can be stored.

414 Winter operation of cistern installations does create problems. Components that cannot withstand freezing must be frost protected or dismantled. Filter systems which are to be used during the winter must be placed in a frost free environment.

5 REFERENCES

51 Bulletin is developed by Oddvar Stensrod and edited by Johan H. Gosbak. The editing was completed September 1978.

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