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 oversizing 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.

<u>Third Step</u>: 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.

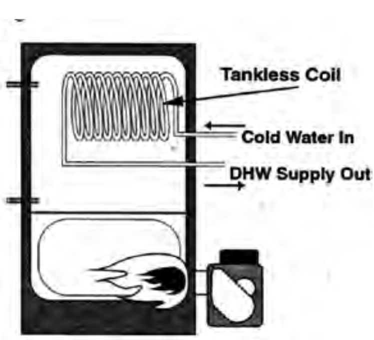
• Energy costs based on hot water needs for typical family of four and energy costs of 16¢/kWh for electricity, $1.297/therm for gas, $3.15/gallon for oil.

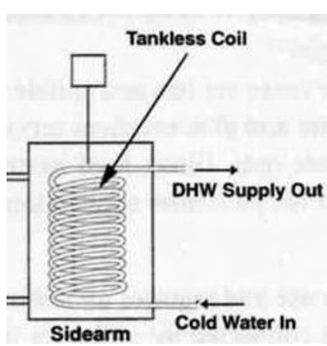
• Future operation costs are neither discounted nor adjusted for inflation.

Source: American Council for an Energy-Efficient Economy. Energy costs interpolated to Fairbanks, Alaska in February, 2008

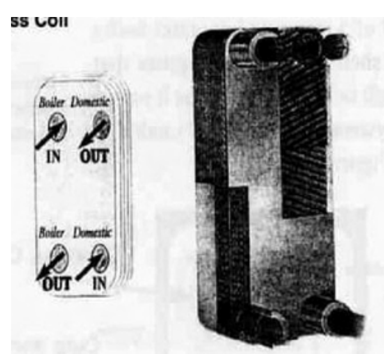
may be available locally. Here is a cost-breakdown of many different types of water heaters, along with their expected longevity.

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.

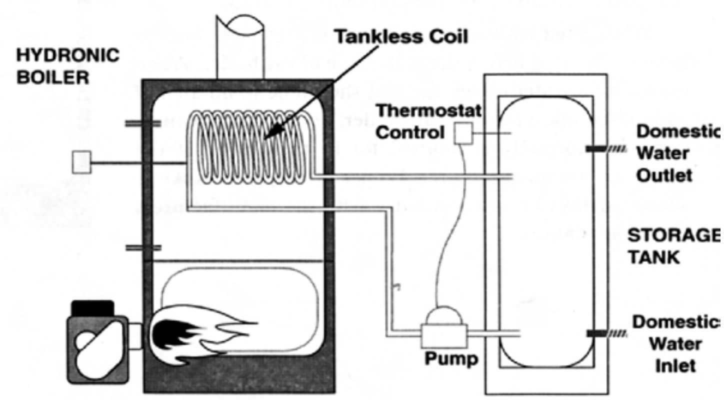


Figure H-4.

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.

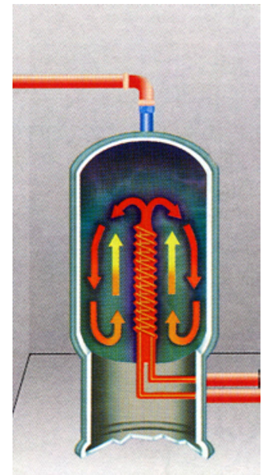


Figure H-5.

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.

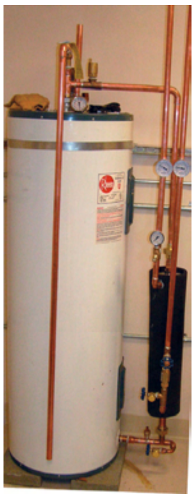


Figure H-6. Here is an example of a low-cost electric water heater that has been converted to a boiler-mate using the side-mounted heat exchanger.

Installing a Domestic Hot Water Storage Tank

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.

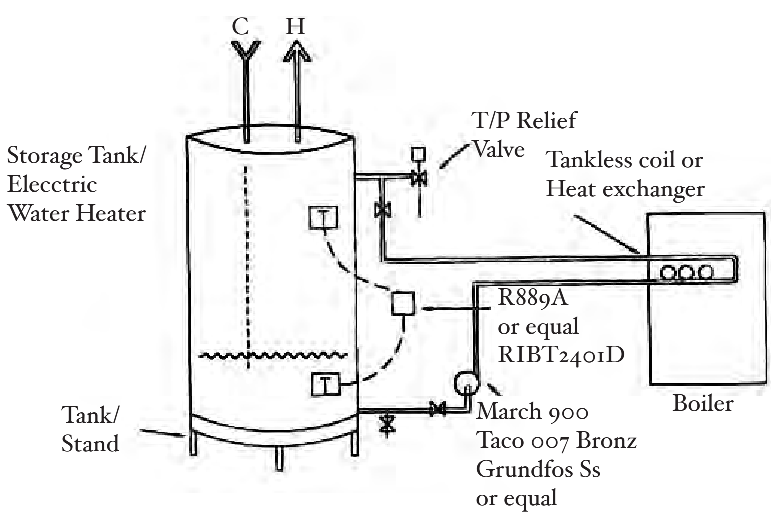


Figure H-7.

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.

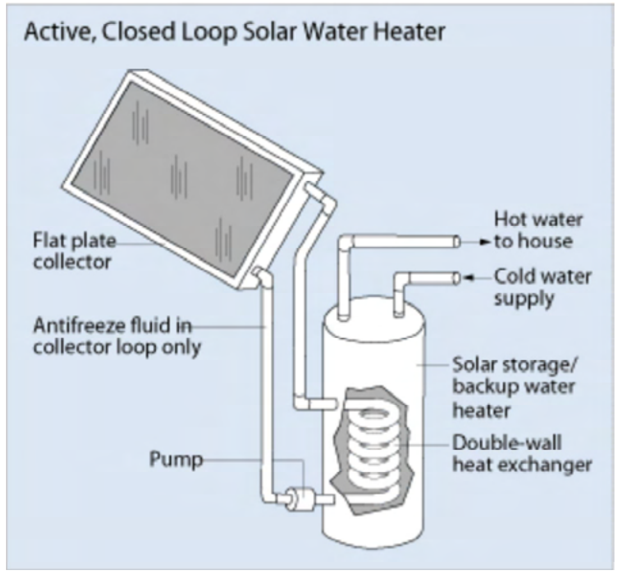


Figure H-8.

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