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.

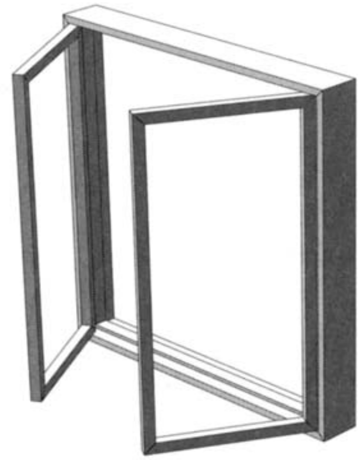

Figure 6.2: Casement window

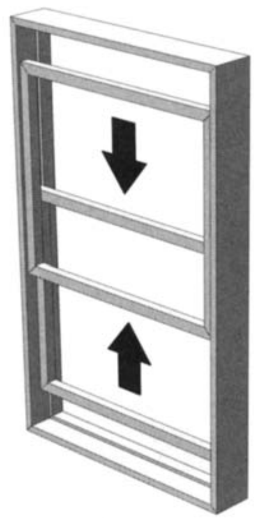

Figure 6.3: Double-hung slider

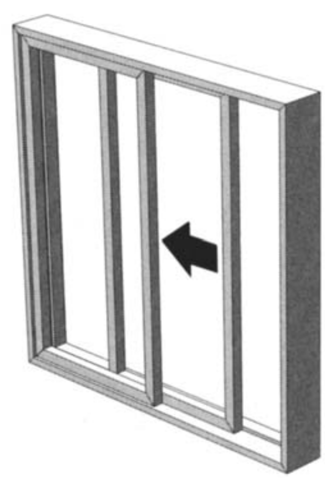

Figure 6.4: Horizontal slider

Sliders

Whether they are side sliders, single or double hung (Figures 6.3, 6.4), this style window has minimal or no hardware 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.

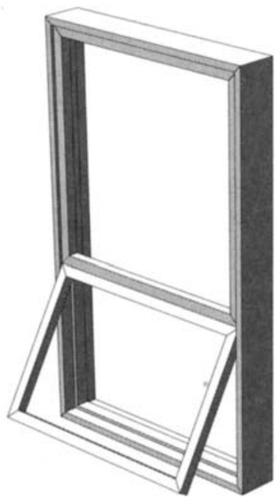

Figure 6.5: Awning below fixed window

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.

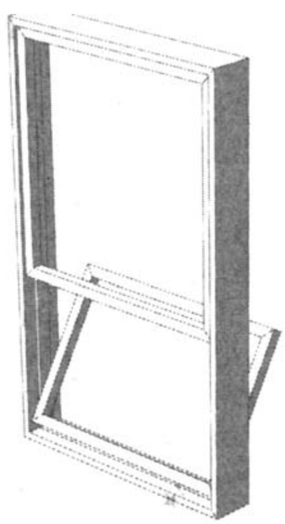

Figure 6.6: Hopper below fixed window

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.

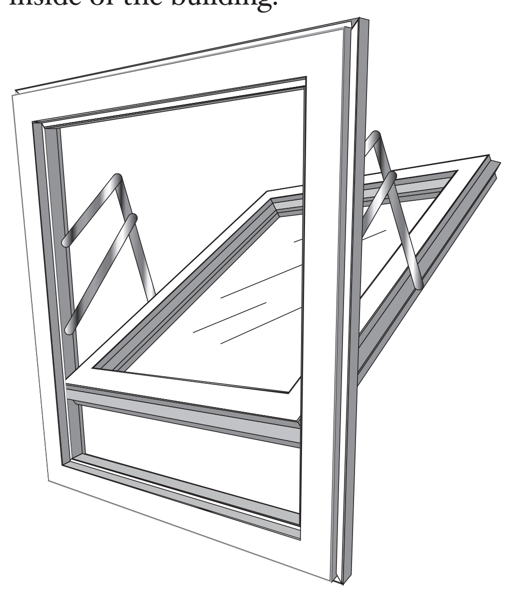

Figure 6.7: H-window

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 wraparound 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

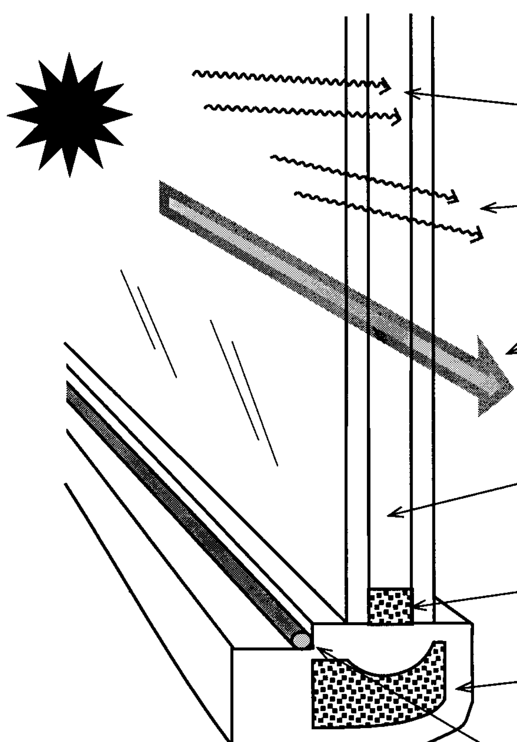

Figure 6.9: Energy-efficient window

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-

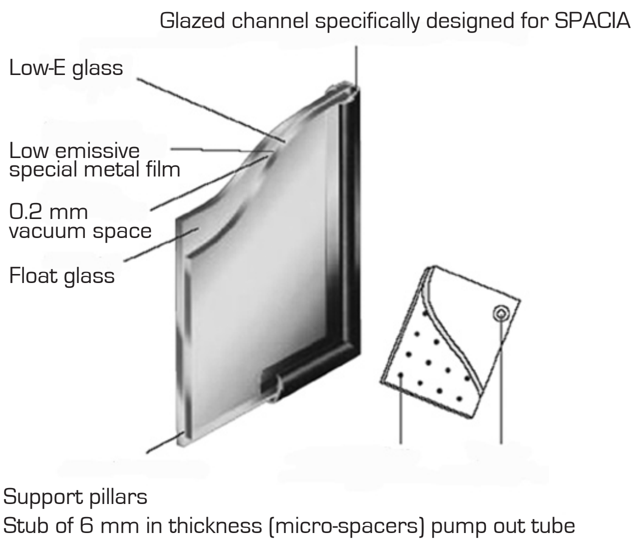

Figure 6.10: Structure of the vacuum glazing unit.

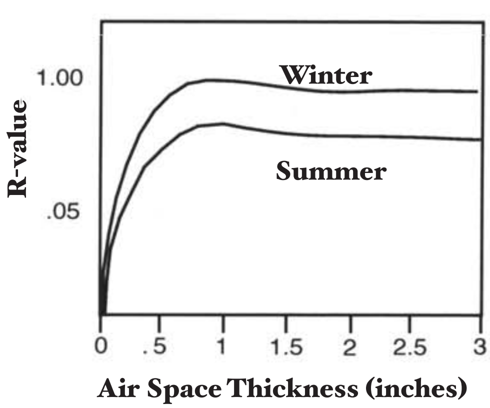

Figure 6.11a: Thermal resistance of air space

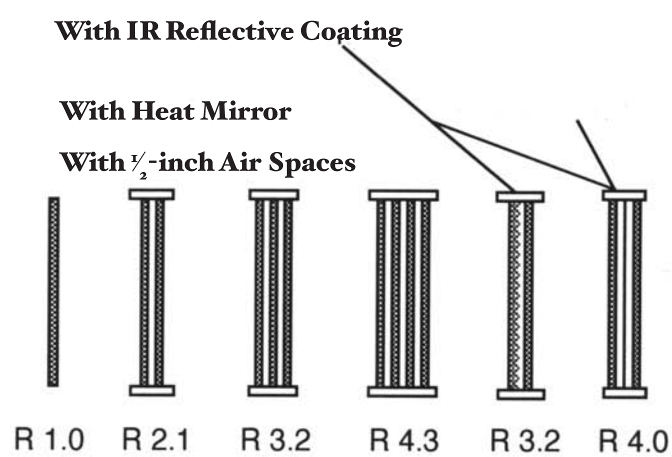

Figure 6.11b: Insulation values of glazings

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

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.

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.

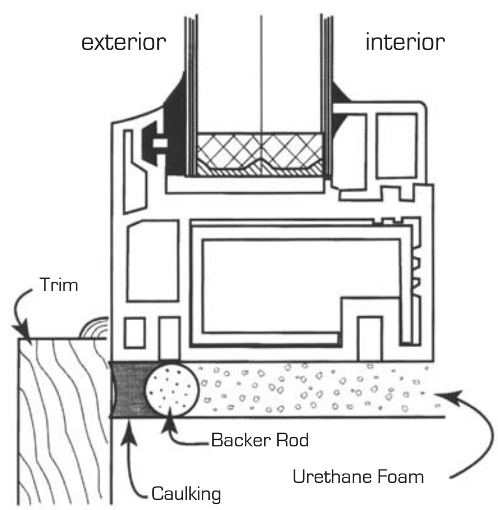

Figure 6.23: Sealing and framing details for PVC window frame

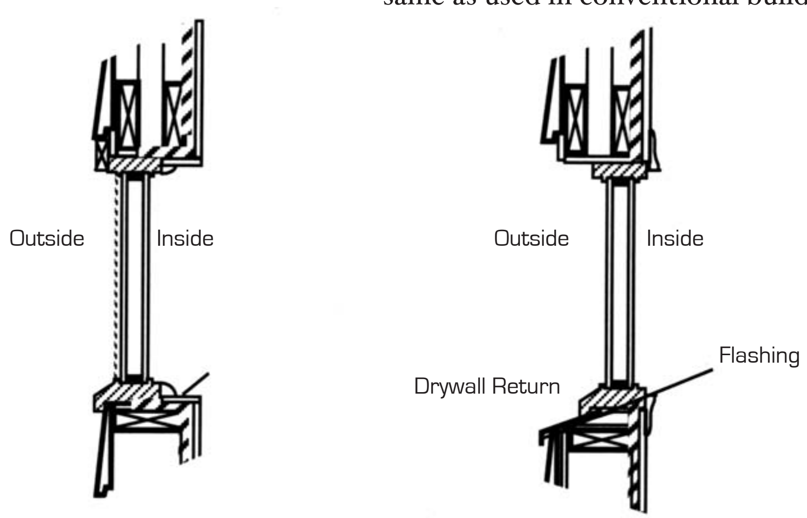

Figure 6.24: Window mounting options: left, window mounted on the outside of the rough opening; right, on the inside.

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

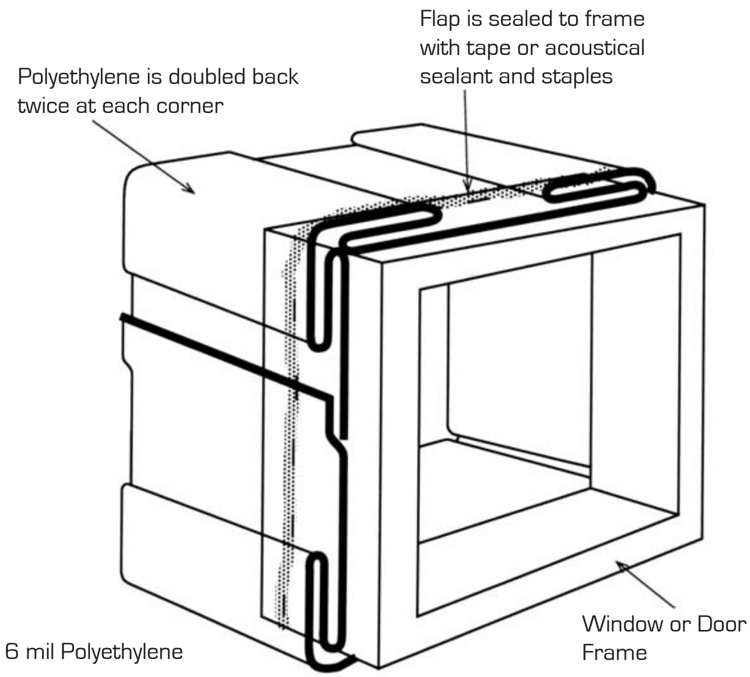

Figure 6.25: Wrapping the window frame

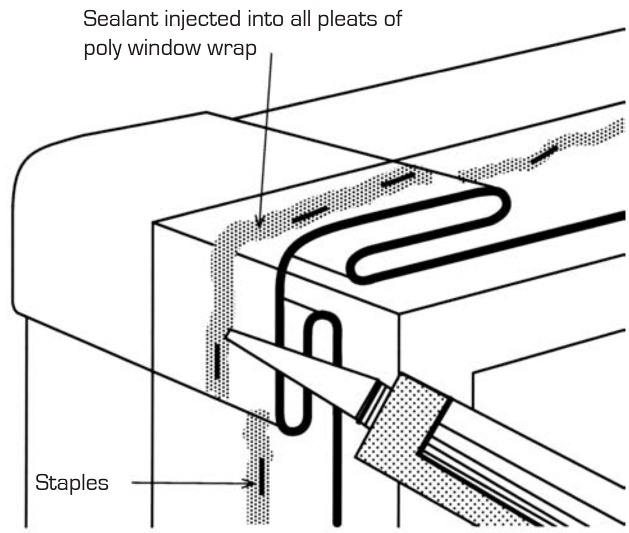

Figure 6.26: Sealing the pleats

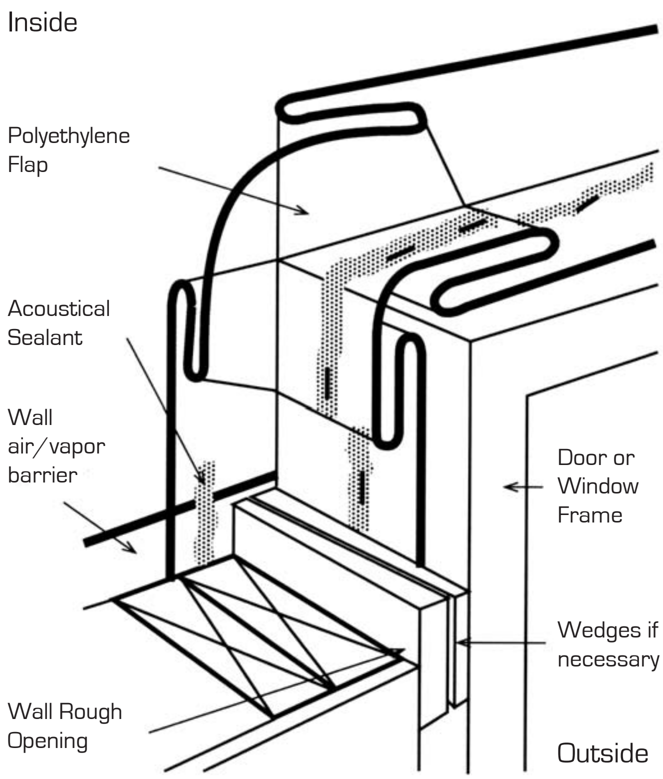

Figure 6.27: Corner pleating

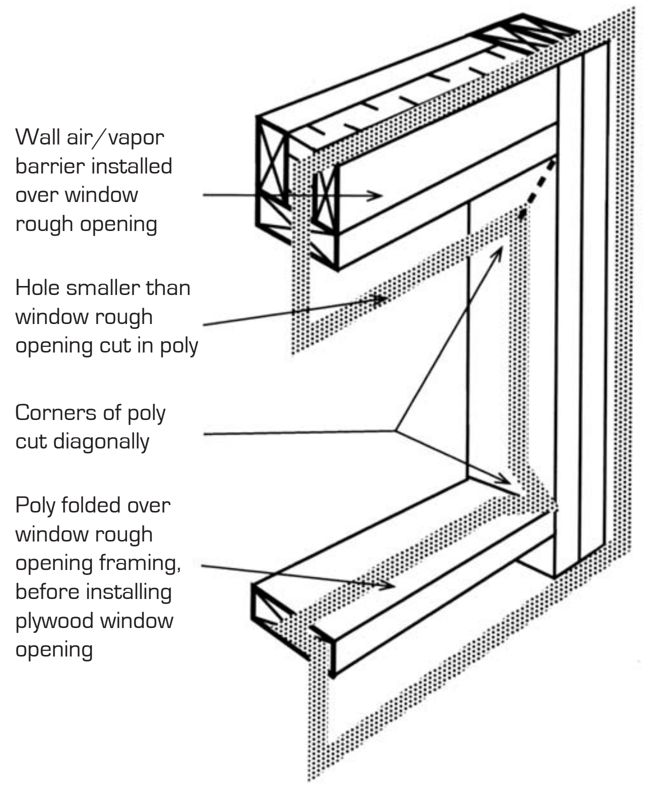

Figure 6.28: Plywood wrap: prior window penetration

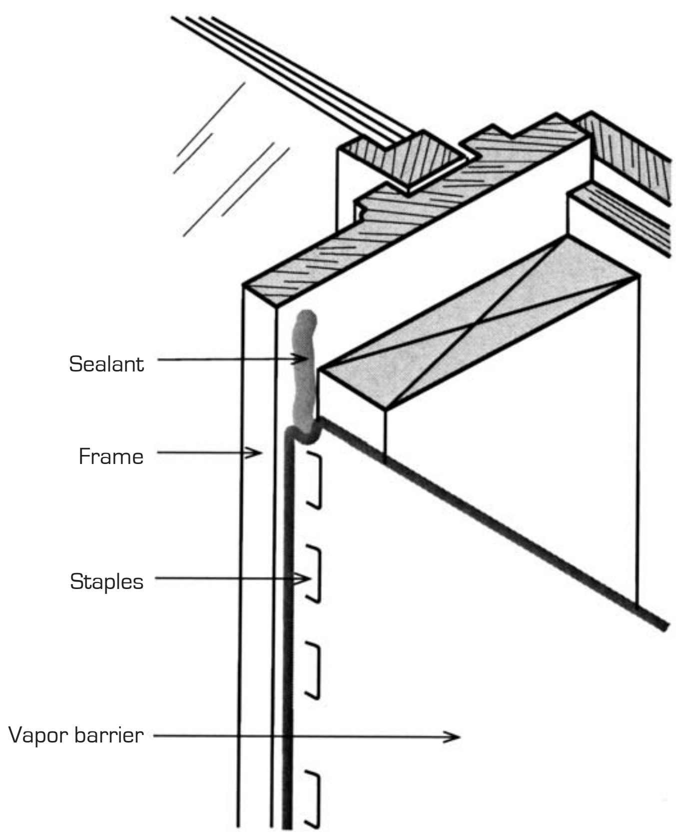

Figure 6.29: Vapor barrier sealed to window frame at edge

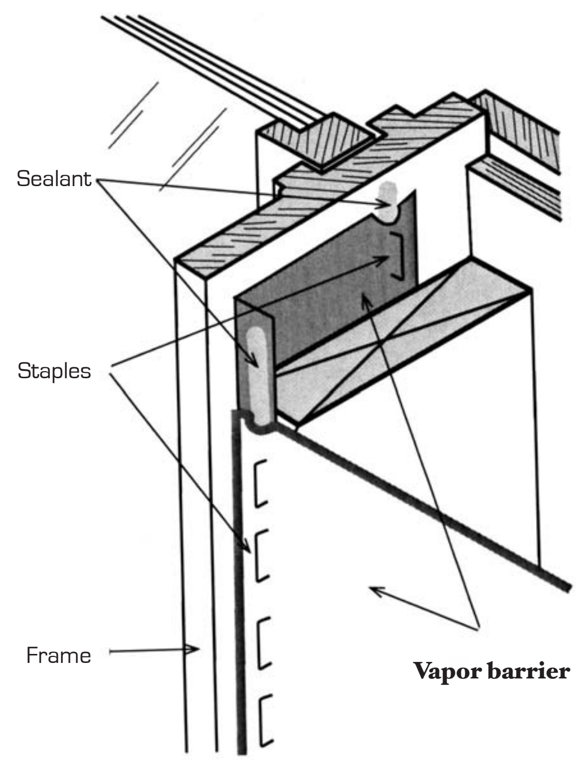

Figure 6.30: Vapor barrier sealed in single frame wall

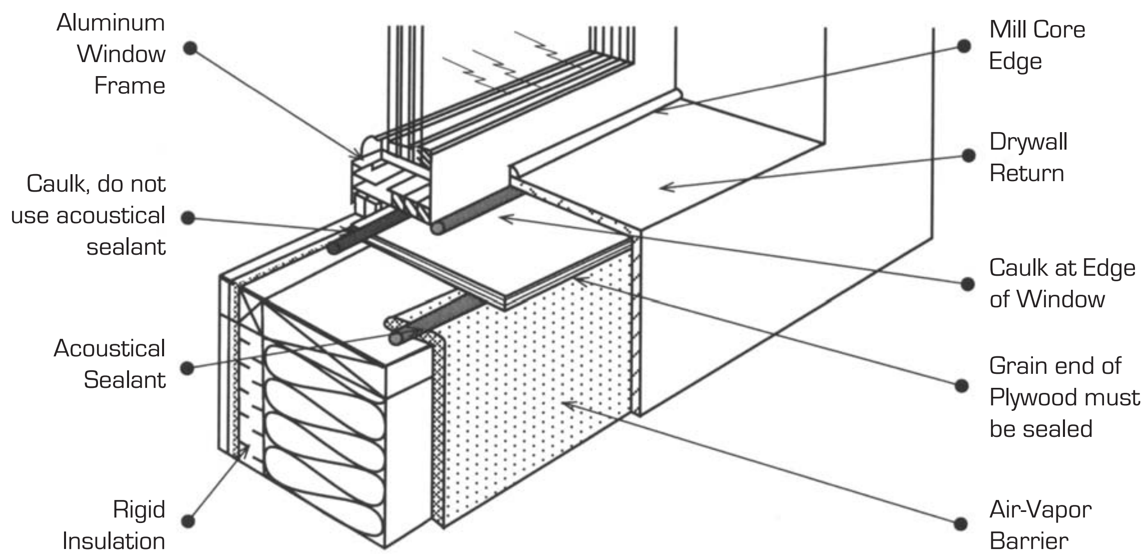

Figure 6.31: Vapor barrier sealed in single frame wall

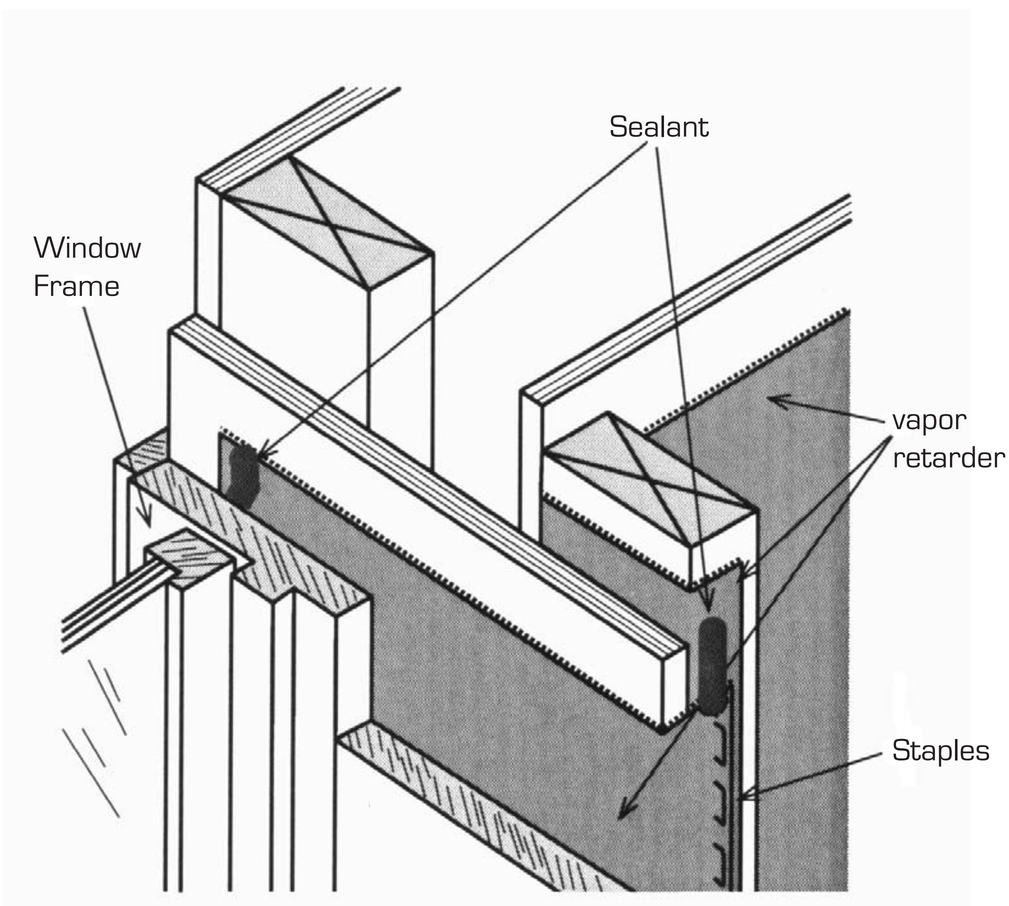

Figure 6.32: Vapor barrier sealed in Saskatchewan type double wall

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.

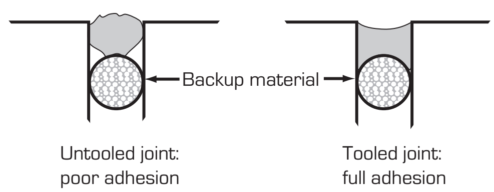

Figure 6.33: The wrong way (left) and the correct way (right) to seal the joint between the window and the rough opening.

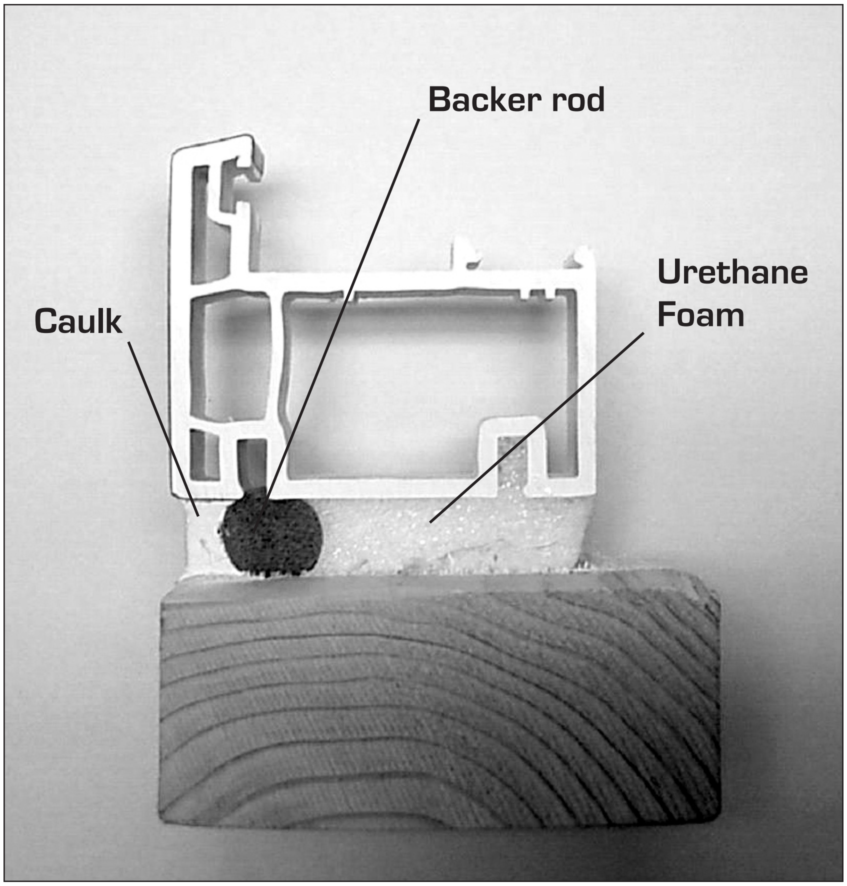

Figure 6.34: The correct way to seal a PVC window frame to the rough opening using caulk, backer rod, and urethane foam.

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

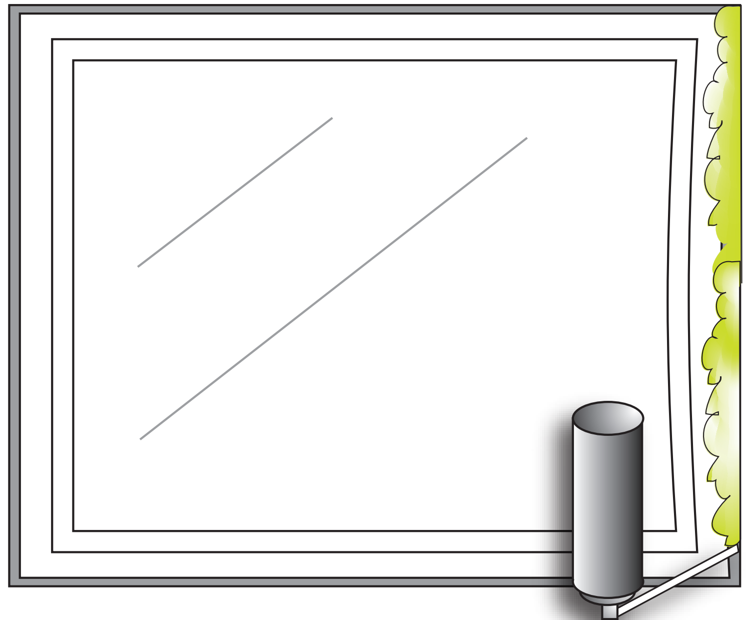

Figure 6.36: Use low-expanding spray urethane foam to insulate between the framing and the window. Note this is insulation, not the air seal.

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.