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Selecting and Installing Energy-Efficient Windows to Improve Dwelling Sustainability

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ABSTRACT

Windows play a significant role in achieving comfort in buildings by letting in natural light, solar warmth, fresh air and permitting outdoor views. On the other hand, poor quality windows can be the source of overheating or unwanted infiltration or exfiltration of air. Quality windows, therefore, influence the dwelling's energy consumption and consequently its sustainability. Heat losses through the building envelope can occur in any of three mechanisms: conduction, convection and radiation. In all cases, windows are the "weakest link". As such, windows represent the most important investment in the construction or renovation of any dwelling. They are also highly variable in price, appearance and performance, making their selection an ambiguous and sometimes difficult process. This paper examines a window unit's energy performance and provides guidelines for its selection, installation and integration into the home's design.

KEYWORDS

Windows, energy-efficient, heat loss, air leakage, condensation, glazing

1. WINDOW DEVELOPMENT

A window is a filter of conditions between the indoors and the outdoors. Proper window design is not only energy-efficient, but also prevents interior glare, fading and improves comfort. Since a window is, in fact, an opening in the building envelope, it must be made of high quality materials and be properly installed to protect against the elements and unwanted moisture and heat migration (Jones 2008).

Historically, windows were the “weak links” in dwelling design for their heat loss, unwanted heat gain, air leakage and infiltration. Since glass is a good conductor, windows can account for up to 30 percent of a home’s heat loss (Wenz 2008). With improved technologies, however, it is possible to have views without sacrificing comfort or energy efficiency. The selection of windows is based on four aspects: appearance, function, energy performance and cost. Criteria based on function and energy performance are of particular interest in sustainable residential design. Function includes daylighting, glare control, thermal comfort, durability, ventilation, sound control, maintenance and resistance to condensation. With respect to energy performance, the National Fenestration Rating Council (NFRC) provides standard rating and labelling systems for total window systems including glazing and frame (NFRC 2005). The labels include U-factors, solar heat-gain coefficients (SHGC), air leakage (AL) rates and visible transmission (VT) (Jones 2008). Furthermore, with newly improved window technologies, several attributes can be emphasized in sustainable residential projects: innovative glazing unit structure, low-emittance coatings, low-conductance gas fills, warm edge spacers, thermally improved sash and frame, solar control glazings and coatings and improved weather stripping. Those principles and concepts will be explained and illustrated below.

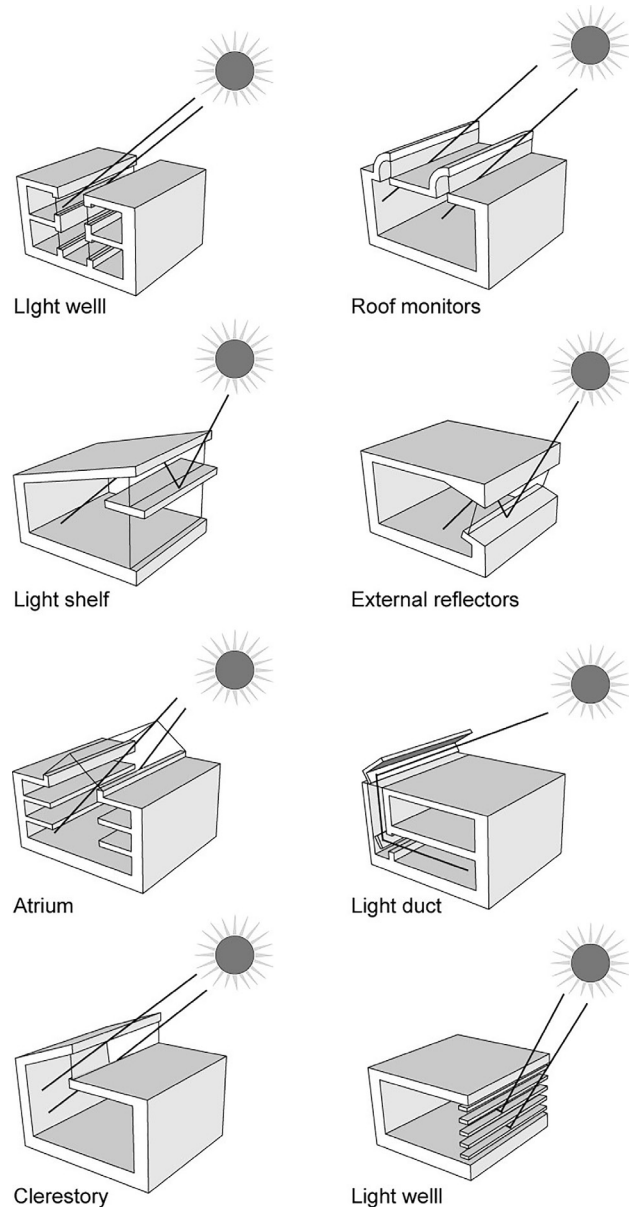


Figure 1.
Daylighting systems and devices.

2. DAYLIGHTING

Well daylit spaces are considered to be desirable to work and live in. In addition, according to Adams (2004), a deficiency of daylight in Northern latitudes can lead to health problems, such as Seasonal Affective Disorder (SAD) and Vitamin D deficiency. Substituting artificial light for daylight will also lead to substantial energy savings.

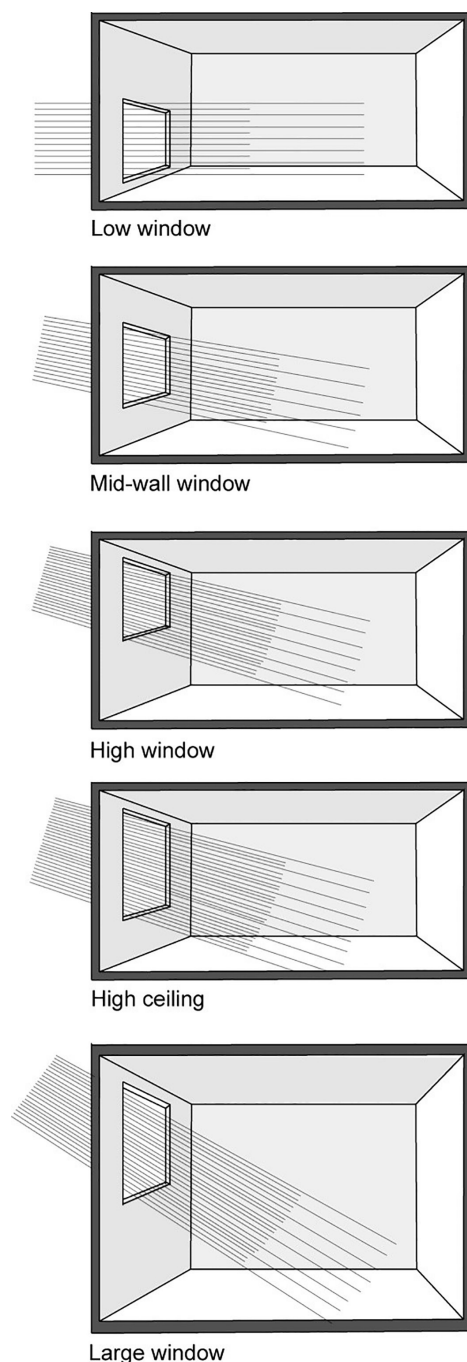
Proper daylighting design addresses both the amount and the quality of light entering a room. Daylighting requirements will depend on the function of the building, hours of use, type of users, requirements for views, need for privacy, ventilation and energy use. Design for good daylighting depends on the position, form and dimensions of the openings, the glazing materials, as well as the location, form and dimensions of the shading, shown in Figure 1. As a rule of thumb, a window's size should account for approximately 20 percent of a room's floor area to provide enough light, even during overcast days. Good planning for natural light depends on the size and shape of both the windows and the room. Light from a window can travel a distance of one and a half to two times the height of the window header. For a typical header located 84 in. (2.1 m) from the floor, light will reach a maximum of 12 ft. 4 in. (3.8 m) into the room, not including sunrise or sunset times (Ireland 2007). Shallow-plan buildings, therefore, provide more opportunities for daylighting as well as natural ventilation and cooling than deep-plan ones. Also, the level of daylighting at a point in a room depends to a large extent on the amount of sky visible through the window from that point. As a result, the provision of a significant amount of glazing near the ceiling is beneficial from a daylighting point of view. Tall narrow windows, for example, will provide a better daylight distribution in a room than low wide ones. For corner rooms or those on top floors, windows in more than one façade or skylights, will also improve daylight distribution. Locating windows on more than one wall will lead to better light distribution and uniformity (Gonzalo and Habermann 2006).

The shape and size of the window will depend on factors such as the depth of the room and its

orientation. Often the window may be placed to cope with different demands. For instance, high windows will ensure good daylight penetration into the rear part of the room, whereas wide ones will offer a better view (Ireland 2007). Large windows and those located high up near the ceiling are better at distributing light. Small windows create a spotlight effect on a specific area and a sharp contrast. To have light penetrate deeper into a room, a designer needs to use tall and narrow windows, since wider ones will cause a broader area of light to enter as illustrated in Figure 2. Operable windows are commonly known to be an important contributor to occupant satisfaction. In the design of the glazed areas, therefore, attention should be directed to window size, orientation, glazing type, frame type, construction details to prevent infiltration, means of solar control and insulation. In addition, devices can be used to distribute the light more evenly. One example is the *light shelf*, shown in Figure 1 above. They are designed to reflect light onto the ceiling and to the back of the room while reducing excessive light levels near the windows, thereby saving energy (Jones 2008).

3. SHADING

Overheating is a challenge affecting window design, since heat gain can be significant. Summertime cooling costs, according to Jones (2008), can double in homes with unshaded windows. The right shading choice depends on the solar path across the site, surrounding landscape or buildings that obstruct the sun, the season and time of day, the building orientation and latitude. Depending on orientation and location, a window's need for shading may be reduced if sensible glazing ratios are adopted. When the sun strikes, that radiation is partly reflected by the glass, partly absorbed by it, and partly transmitted through it to the indoors (Kwok and Grondzik 2007). Where the solar effect is excessive in summertime, the most effective way to reduce heat gain is to prevent or block it by using shading devices. A wide and ever-growing competitive range of devices is available, including internal and external products



such as blinds, shutters, louvers and structural add-on devices that can be fixed or adjustable to the sun's movement (Kwok and Grondzik 2007, Mintz 2009). A common device is the overhang, which was used in a Vancouver Olympic Village's building, designed by GBL Architects.

A single-glazed window has an R-1 (RSI 0.18) resistance value to heat flow. The objective is to increase that number as much as possible by adding insulation, sealants, curtains and shading devices. Just by closing the shutters or drawing the drapes, for example, the value will increase slightly to R-2 (RSI 0.35). Double-glazing, for example, will elevate the value a bit more to R-3 (RSI 0.53). These R-values, however, are unfortunately still not high enough to make any significant difference in balancing heat loss (Smith 2005).

When windows have fixed overhangs to minimize summer solar gains, they will also reduce daylight entry throughout the year. Moveable shading or blinds, on the other hand, will reduce daylight only when they are in place. While direct sunlight can be an attractive feature, particularly in winter, if it falls directly on occupants or worktops, it may be undesirable. Venetian blinds may be used to reflect direct sunlight towards the ceiling, thereby avoiding discomfort and achieving greater penetration at the same time. Occupants, however, need to use such blinds properly to achieve the best effect (Prowler 2008).

A good window system may have insulated shutters which can achieve R-values of R-9 to R-11 (RSI 1.6 to RSI 1.9), which according to Wenz (2008), is almost as effective as a wall with R-13 (RSI 2.3). Insulating shutters, such as rigid foam panels with a heat-reflective foil facing are made from recycled plastics, recycled aluminum, and the foam is blown with zero-ozone depleting agents (Wenz 2008). When closed after dark, insulating shutters can be useful in reducing heat loss. Creating a well-sealed air-gap

Figure 2.

The amount of daylight that enters a room will depend on a window's size and height above the floor.

between the shutters and the glazing increases the shutters' effectiveness, but can be difficult to achieve. External shutters are, therefore, preferable to internal ones. Managing the operation of external shutters is, however, not easy. In cold weather the occupants are unlikely to open windows to close shutters, defeating the very purpose of using them (Harvey 2006).

4. CONTROLLING AIR MOVEMENT

Fresh air may be supplied by natural or mechanical means, or a hybrid system containing elements of both. Operable windows can aid in removing excess heat, humidity, and odours from the home via natural ventilation. This is particularly important for removing cooking odours and moisture created in kitchens and bathrooms, which can also reduce mechanical ventilation costs. Overheating may be reduced by ventilated mechanisms in carefully designed windows. Well-designed naturally ventilated buildings generally have shallow-plans. A guide for zoning daylight is the

"2.5 H" rule where the depth of the room does not exceed 2.5 times the height (H) from the window's header to the floor (Kwok and Grondzik 2007). To maximize air movement through a space, at least one window should be on the façade that has prevailing winds and breezes for the air to enter, and windows need to be placed on the opposite side of the room as well as to direct the air flow exit, as illustrated in Figure 3. In the Northern hemispheres, the prevailing summer winds are typically from west to east. As a result, western-facing windows are good for cooling during this season. Another inlet/outlet combination includes cool air entering from a low-lying window pushing up and out the warmer and lighter air through a higher opening in the wall or ceiling on the opposite side, such as a cooling or wind towers (Ireland 2007, Harvey 2006). A wind catcher works in reverse, catching the cool breezes from the top and transporting them down the tower to the rest of the home.

As for window size, the best air flow for achieving natural ventilation is when air inlet windows are small and the exits are large to increase the velocity of the

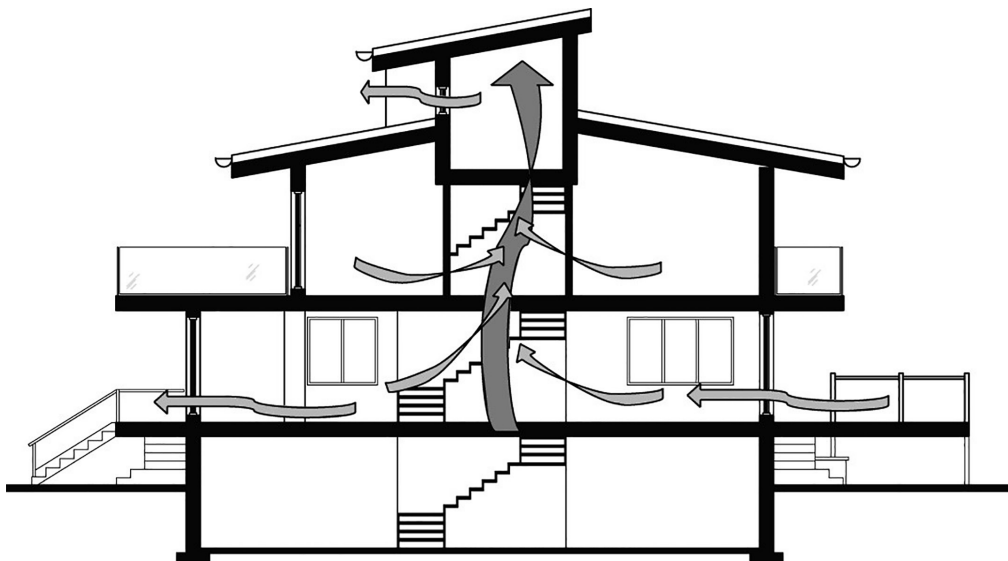


Figure 3.
*Natural ventilation is best allowed
by opposite windows and a Chimney Effect.*

air entering the room. For cellular rooms with single-sided windows, natural ventilation will be effective only to a depth of about twice the room height, which may need to be higher than those in a mechanically ventilated building. The space saved by avoiding ducting in the ceiling or floor will offset any required increase in storey height.

5. CONTROLLING HEAT LOSS

A window consists of frame and glass, which together are known as the *glazing unit*. Within the frame, there are two components: the first is the outer frame, or *casing*, which is anchored to the wall, and the second is the interior one, also known as the *sash*, which encloses the glazing units and can be opened in a variety of ways. The glazing unit consists of two or

more glass or synthetic plastic panes, separated by spacers and coated in various ways to control heat gains and losses (Figure 4) (Jones 2008).

A window's thermal and optical properties will play a large role in the effectiveness of the building envelope. Heat transfer in windows may involve one or more of the following processes: transmitting solar radiation, emitting infra-red radiation, conducting heat through all components (i.e. the glass, the air between the panes, the frame, and the spacers between the panes), convection in the air between the panes of glass, and outside air infiltration (Keeler and Burke 2009).

Conduction represents the heat component lost through the materials themselves, especially in metal-frame windows. It occurs both through the frames and the glass, and depends on the properties of the materials themselves.

Convection represents the heat transfer that occurs by

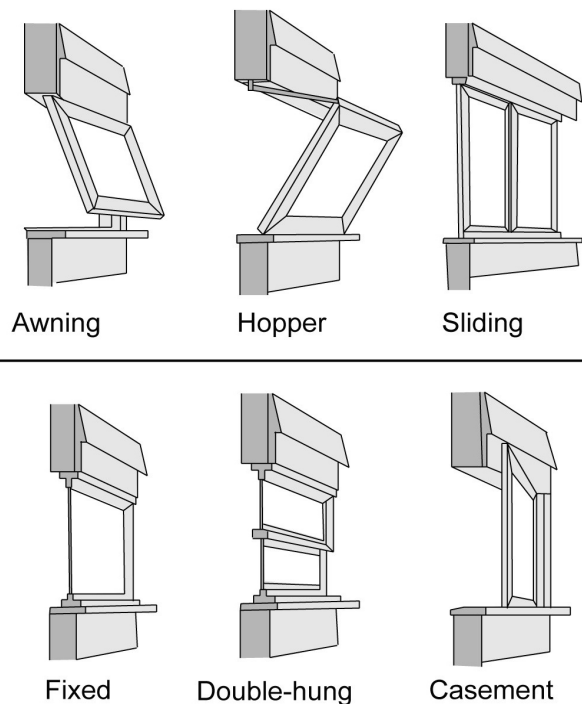
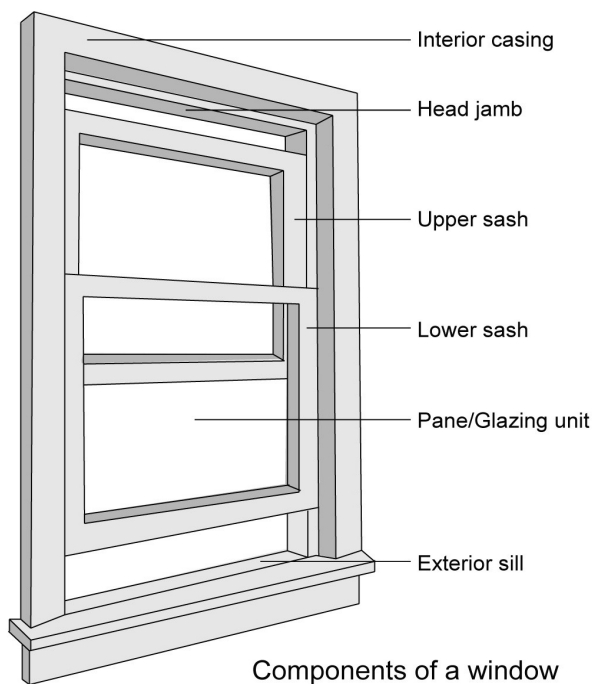


Figure 4. Basic components and types that influence a window's level of thermal performances.

the movement of the air itself. Air is a relatively good insulator in terms of conduction and motionless air provides no opportunity for convection to occur. Air trapped between two glass panes in a double-glazed or storm window, therefore, immediately improves the window's heat resistance ability. The optimum thickness of the gap between two panes of glass depends on the temperature difference between the inside and outside. The greater the temperature difference, the narrower the optimum gap spacing needs to be because convection will be triggered by large air spaces and large temperature gradients (Harvey 2006). Glazing units are usually built with a half inch (12.7 mm) airspace and two quarter inch (6.4 mm) sheets of glass, to give a total width of 1 in. (2.5 cm). As for the glass, the thickness is determined according to structural considerations. Harvey (2006) suggests that coupled with edge losses from the glazing unit, conductive heat losses through the frame can account for 10 percent to 30 percent of the total heat losses from a window. The selection of an appropriate frame material is, therefore, not simply a question of appearance. Wood, for instance, is a good insulator, but is easily damaged and has a high maintenance requirement. Metal requires much less maintenance, but is a very good conductor. The

selection of an aluminum frame, for example, which also requires a small amount of maintenance, must ensure that it is designed with a *thermal break*. A thermal break is a separation that uses materials with a lower thermal conductivity such as cellular foam, rigid PVC, polyurethane and wood to keep frost from entering. Metal frames are also susceptible to temperature changes, and will expand and contract significantly on a seasonal, daily or even hourly basis. The joint between the glazing unit and the sash must, therefore, be flexible enough to accommodate any movement without breaking the glass. Vinyl frames are maintenance free, but, like metal frames, are susceptible to temperature changes. Finally, some frames use a combination of materials, usually a wood core covered with either aluminum or vinyl. These are intended to take advantage of thermal qualities of wood while protecting it with either vinyl or aluminum and reducing the maintenance requirement (Baker-Laporte et al. 2001). *Infiltration* of cold air, or *exfiltration* of warm air across a barrier occurs by air flowing through an opening or cavity (Kwok and Grondzik 2007). There are three joints where this can take place in a window: between the frame and the wall, between the frame and the sash and between the sash and the glazing unit.

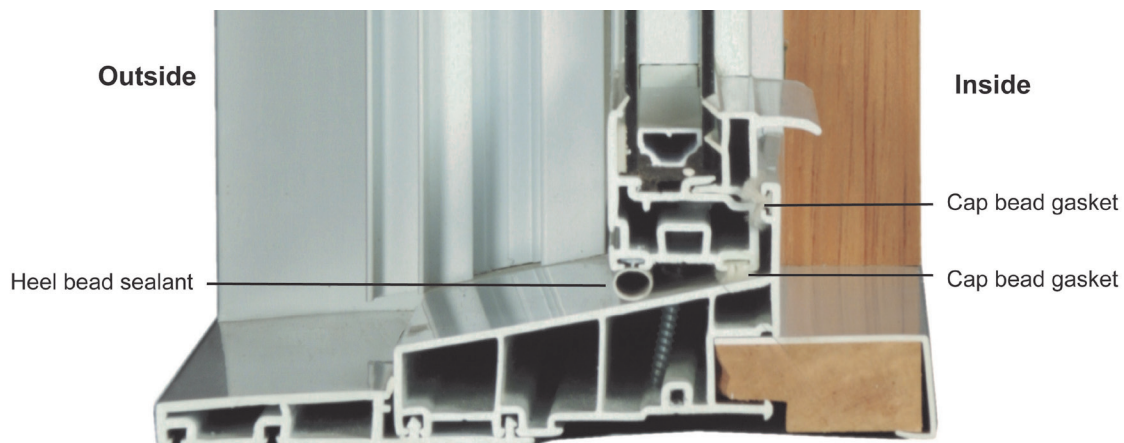


Figure 5.
Air infiltration losses between the frame and the sash depend on the type of operable components and the type of gaskets.

Infiltration is minimized by providing as airtight a joint as possible. In the joint between the frame and the wall, this is controlled entirely by the installation procedure. Infiltration losses between the frame and the sash depend on the number and type of operable components and on the type of gasket, as shown in Figure 5. Finally, radiative heat losses, which occur across an air space, are dependent on the ability of the glazing unit to transmit, absorb and reflect *radiation*. These heat losses can be minimized by special coatings, which are applied to the glass surface.

Generally, windows with fewer operable parts are more energy-efficient. The longer the joints, the more heat loss will occur through leakage. Fixed windows are best in this regard, but they have no ventilation capabilities. As far as the type of operation is concerned, pivoting components are more energy efficient, since they make use of compression seals. Sliding parts are least effective in terms of air leakage, but seal joints can also be provided (Winchip 2007). Controlling the direction of heat flow is a complex task. When heat flows into a home from the outside on a warm sunny day, it increases the indoor temperature and, as a result, air-conditioning costs. On a chilly winter day, heat can escape from the home if there is poor thermal resistance in the window components.

The thermal resistance of the glazing comes from the airspace between the panes of glass and from the thin films of air at the inside and outside surfaces of the assembly that slow down heat transfer. The glass itself, however, has negligible resistance to heat flow (Smith 2005).

6. AIR LEAKAGE CONTROL

Due to inside and outside temperature and pressure differentials, a window may leak air from around the frame and the connection joints of an operable unit. Well designed windows act as dynamic heat exchangers: warm air leaking to the outside will transfer heat to the frame, and infiltrating cold air is warmed up by heat conduction through the very same frame (Harvey 2006). A good window, therefore, can prevent air leakage, which affects energy control,

comfort and condensation potential.

Sealants and gaskets are used for the fixed component of the window, while weather stripping is used for the operable parts. At the glazing-sash junction, wet or dry seals are used, while in wood windows, wet seals are commonly installed. Sealants are generally applied as cap beads at the outside of the joint. The application of similar seals on the inside as cap and heel beads is also equally important. In vinyl and aluminum sashes, dry and wet seals are used: a rubber-like grip can be installed on one or both sides of the glazing unit and a heel seal will provide air tightness between the glazing and the sash (Baker-Laporte et al. 2001).

7. CONDENSATION AND RAIN PENETRATION CONTROL

Bulk moisture is large quantities of water entering the building as rain/snow or groundwater. *Capillary action*, or wicking, is another way water can be transported across the building envelope through porous materials such as wood (Jones 2008). Water vapour in the air is also a cause for concern. The control of water vapour flow through a window is linked to the control of air flow, since vapour diffusion in most window frame materials such as aluminum, steel, glass, PVC and protected wood is very small. In unsealed double glazing, for example, exfiltrated humid air can condense between the panes of glass and obstruct view.

The control of condensation is, therefore, important. Not only does it impair visibility, but the liquid matter can lead to the deterioration of the sash, frame and sill, as well as the interior finish and the supporting wall. The relative humidity of the inside air and the temperature of the glazing, sash and frame are the two conditions to act upon to solve this problem. To reduce the moisture level in indoor air, one must increase ventilation and decrease the use of humidifiers, wood for indoor heating and the intensity of human activities. To increase the temperature of the window's indoor surface, several strategies can be used. The R-value (RSI) of the window component can

be increased by additional air space, which is formed by a glass or plastic layer, inside, tightly covering either the whole window or the glazing only. In addition, the indoor warm air can be better circulated next to the windows, with the help of registers/radiators and fans, or by removing barriers such as heavy curtains, air deflectors and large furniture.

Finally, rain penetration can be avoided by applying the rain *screen principle*, which is based upon control of pressure forces that can move water through small openings, rather than the elimination of the openings themselves at the interface of glazing-sash and sash-frame components (Foster and Whitten 2008).

By the same token the function of a *spacer bar* is to seal the unit so that no air or moisture enters the air space. It consists of a hollow metal section sealed with an organic compound. To ensure that there is no moisture, a chemical drying agent is put in the spacer bar, and small holes drilled to facilitate the absorption of moisture that gets into the air space. This is an important characteristic to look for when evaluating windows. A quality window should last for years and any indication of condensation on the inner pane of the glazing is the sign of a poor quality or defective window unit.

8. GLAZING UNIT INNOVATIONS

Glazing unit design has seen the greatest technical development in recent years. It is now possible to meet the requirements for heat gain, conservation, light transmission and light direction, at different latitudes. The design and orientation approach should optimize useful solar gains and minimize heat losses during winter. The glazed areas can, therefore, balance heating, cooling and daylighting needs. Some unique glazing types are described below.

8.1 MULTIPLE GLAZING

All three types of heat losses discussed earlier- i.e. conduction, convection and radiation - occur across the glazing unit. Since glass is a poor thermal insulator,

there are a number of simple ways to decrease heat loss. Double glazing (i.e. two panes of glass with an air-gap in between) is the most commonly specified energy efficient window type. This concept was extrapolated to create triple and even quadruple glazing. The R-value ranges from about R-1.1 (RSI 0.19) for single-paned windows, to R-1.8 (RSI 0.32) for double-paned windows, to R-3.3 (RSI 0.58) for triple-paned windows (Jones 2008). However, only conductive and convective heat losses are reduced, though, with no significant effect on radiative heat loss. Additional layers offer diminishing reductions: one to two layers, 50 percent reduction in energy loss, two to three layers, 33 percent further reduction in energy loss, three to four layers, 25 percent further reduction in energy loss. Triple and quadruple glazing are highly expensive, heavy and cumbersome, making them impractical for home design (Jones 2008). The effect of various glazing types on thermal performance is shown in Figure 6.

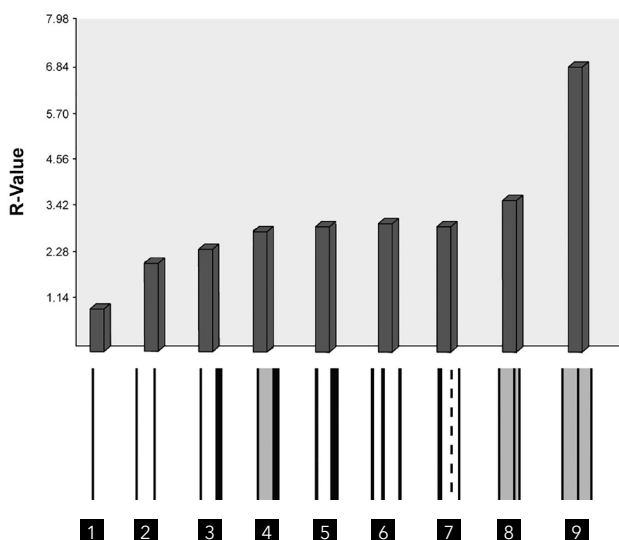
8.2 LOW-EMISSIVITY (ϵ) GLASS

An alternative that provides similar thermal resistance is to use double-paned glass with polyester or mylar films suspended between the panes. These films can also be coated with metallic low-emissivity coatings (Schaeffer 2005). The actual emissions, ϵ (W/m^2), of an object is the amount of infrared radiation emitted by it, which is just one of the ways in which heat is transferred from a window to the outdoors. It is directly proportional to its temperature and emissivity. An object's emissivity, ϵ , is a unitless ratio of its actual emissions to its maximum possible emissions if it were a blackbody with an emissivity of one. Standard glass has an emissivity of 0.84. In the interest of minimizing heat loss, therefore, one must use windows that have low emissivities. That is achieved by using glass with low- ϵ films and coatings. As for the casing and frame, low emissivities can be achieved for polished or galvanized metal surfaces too (Harvey 2006). Low emissivities also means low absorption, and any radiation not absorbed is reflected. By coating the inner side of the inner pane of glass, *infrared radiation* (IR) heat radiation is, therefore, reflected back into the

room. Low- ϵ coatings decrease radiation heat loss through glazing. The problem which remains is that of radiative heat transfer, both across the air space and through the glass to the interior. A variety of coatings can be applied at different parts of the window to control radiative heat flow. These include tinted or reflective coatings, which are intended to reduce glare and solar heat gains, or low- ϵ coatings, which allow most of the shorter wavelength IR radiation to pass through, but reflect back into the building most of the larger wavelength radiation. The result is a thermal resistance close to that of a triple-glazed unit, which tend to be heavy, cumbersome and expensive, not only because of the extra glazing, but because of the necessary heavy duty operating mechanisms (Smith 2005).

The air in a double-glazed window can be replaced with heavier gases with greater molecular weight to further reduce conductive heat transfer. Argon, krypton, and xenon are the most commonly used commercially available gases in North America and Europe (Harvey 2006).

The added advantage of using them is that, to avoid convection, their optimal thickness is narrow, making the windows thinner and lighter. To remain effective though, these panes must be well sealed to prevent these gases from leaking out.



8.3 VACUUM WINDOWS

Vacuum-sealed double-glazing units in which some, or all, of the air is extracted, have been developed and are continuously being improved. By removing the air between the panes, conduction and convection are eliminated. Typically, the air gap is very thin, 0.006 in. (0.15 mm), and so the glazing thickness is only 0.24 to 0.32 in. (six to eight mm) in total, which is a very thin window. There are a few challenges with this window type, though. It has a very energy intensive manufacturing process to fuse the edges of the panes together. It also requires finding a low-conductivity seal that will maintain such a vacuum for the typically 20-year life of a window. The large temperature difference between the outer and inner panes may cause significant thermal expansion and overstress the ridge edge seals. Commercially available vacuum-sealed glazing is a 0.24 in. (6 mm) thick window with a U-value that is half of conventional double-glazed windows (Harvey 2006).

8.4 ELECTROCHROMIC AND THERMOCHROMIC WINDOWS

One of technology's creative innovations are *electrochromic windows*, that are also called *smart windows*, whose principle is illustrated in Figure 7. These windows change from clear to transparent and back again by means of a small voltage which is applied to layers of electrolyte, conductors, and films between the glass panes. This is a unique feature because one can achieve the best of both window types: transparent windows in the winter to maximize both solar heat gain and minimize heating costs; opaque windows in the summer to minimize solar heat

Figure 6.

The effect of various glazing unit types on thermal performance.

1. Single
2. Double
3. Double with hardcoat low-e
4. Double with hardcoat low-e and Argon
5. Double with softcoat low-e
6. Triple
7. Double with softcoat low-e Polyester
8. Double with softcoat low-e and Argon
9. Triple with softcoat low-e and Argon

gain and cooling costs. The change of state happens in a few minutes. Although their cost is still prohibitive for most home-buyers, it is steadily decreasing. This useful technology may be used for skylights as well (Harvey 2006).

A similar technology that uses the outside temperature to control and change the opacity of the window is *thermochromic glazing*. At low temperatures, the windows are clear and transparent. At high temperatures, they become white and opaque. This is made possible with the use of hydrogels and polymer blends between the panes of glass (Smith 2007).

9. WINDOW INSTALLATION

The joint between the frame and the wall is the final but critical link in an energy efficient envelope. The performance of this joint relies entirely on the installation procedure and sealant used. Generally, installation should provide an air-tight seal while allowing for differential thermal and/or structural movement between the frame and the wall.

The air-tight qualities of the joint can be ensured by using a backer rod and sealant. Batt insulation alone is not sufficient to stop air movement; the unit must be caulked (Efficient Windows Collaborative 2010). For smaller gaps, applying a silicone sealant is also recommended. Wider gaps should be filled with polyurethane. Expanding foam can also be effective, but care should be taken not to overfill the cavity joint. This may apply stress on the window frame, causing it to deform and bend, resulting in windows that are difficult to open.

The upper part of the window should not be shimmed, so as to allow for some movement. Sufficient tolerance should be provided in the rough opening of the structural frame, no less than half inch (12.7 mm) on the top and sides (Efficient Windows Collaborative 2010). The top flange should also be secured when using metal window frames in a manner that will allow for shrinkage of the wood frame. The transfer of loads to the window frame should also be avoided.

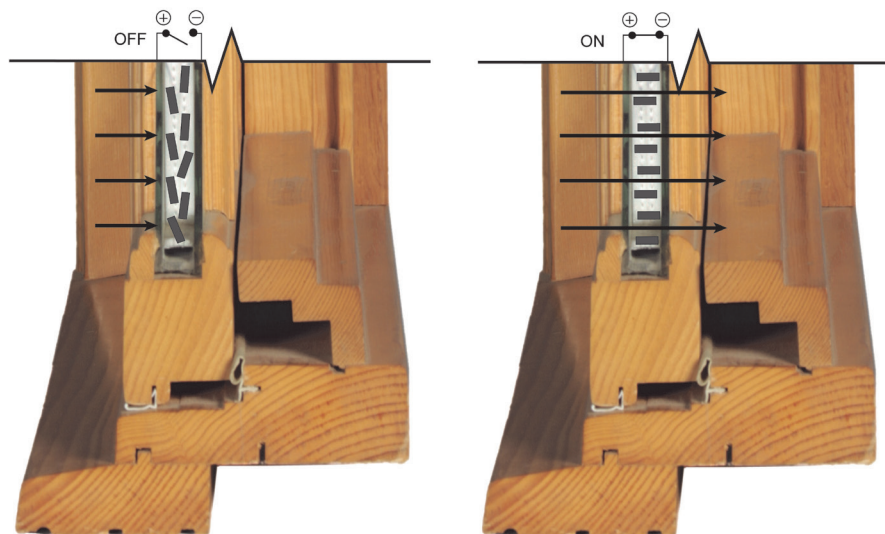


Figure 6.
Diagrammatic representation of the
function of electrochromic windows.

10. CONCLUSION

Though windows are important features in dwellings for the residents' well-being due to their provision of natural light, fresh air and views, they can pose problems if they are not selected or installed properly. For example, heat loss and unwanted infiltration and exfiltration of air are common problems with old or poorly installed windows that can drastically increase the dwelling's energy consumption, making for costly energy bills and a less sustainable home. When buyers are looking into the extensive variety of window models and styles, they should remember to consider recent innovations in window glazing that may reduce their energy bill such as low-emissivity glass or thermochromic windows. However, no matter what style is chosen, it is important to ensure that quality windows are being installed since they have a significant impact on energy consumption, and consequently the overall sustainability of the dwelling. High quality windows can often be more of an investment up front compared to cheaper models, but the payoff comes in lower energy bills throughout the years.

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