3. FENESTRATION HEAT TRANSFER BASICS

3.1. Overview

Much of the information in this chapter is taken from the book *Residential Windows: A Guide to New Technologies and Energy Performance* by John Carmody, Stephen Selkowitz, and Lisa Heschong. Additional information can also be found in the ASHRAE *2001 Handbook of Fundamentals*.

3.2 Energy Flow Mechanisms

Overall energy flow through a fenestration product is a function of:

- **Temperature Driven Heat Transfer:** When there is a temperature difference between inside and outside, heat is lost or gained through the fenestration product frame and glazing by the combined effects of conduction, convection, and radiation. This is indicated in terms of the U-factor of a fenestration assembly.
- **Solar Gain:** Regardless of outside temperature, heat can be gained through fenestration products by direct or indirect solar radiation. The amount of heat gain through products is measured in terms of the solar heat gain coefficient (SHGC) of the glazing.
- **Infiltration:** Heat loss and gain also occur by infiltration through cracks in the fenestration assembly. This effect is measured in terms of the amount of air (cubic feet or meters per minute) that passes through a unit area of fenestration product (square foot or meter) under given pressure conditions. In reality, infiltration varies with wind-driven and temperature-driven pressure changes. Infiltration also contributes to summer cooling loads in some climates by raising the interior humidity level.

The *2001 ASHRAE Handbook of Fundamentals* contains the following equation for calculating the energy flow through a fenestration product (assuming no humidity difference and excluding air infiltration):

$$q = U_t * A_{pf}(t_{out} - t_{in}) + \left(SHGC_t * A_{pf} * E_t\right) \qquad [3\text{-}1]$$

Where:

q = instantaneous energy flow, W (Btu/h)

U_o = overall coefficient of heat transfer (U-factor), W/m^2-^{o}K (Btu/h-ft^2-^{o}F)

t_{in} = interior air temperature, ^{o}C (^{o}F)

t_{out} = exterior air temperature, ^{o}C (^{o}F)

A_{pf} = Total projected area of fenestration, m^2 (ft^2)

$SHGC_t$ = overall solar heat gain coefficient, non-dimensional

E_t = incident total irradiance, W/m^2-^{o}K (Btu/h-ft^2-^{o}F)

This equation shows that the properties of U-factor, SHGC, and infiltration are major factors which determine the energy flow through a fenestration product. For this reason, the NFRC rating system rates the U-factor,

SHGC, and air infiltration of products, and the *NFRC 100, NFRC 200,* and *NFRC 400* documents define the procedures for calculating these values for the total product.

3.3 Temperature Driven Heat Transfer

Fenestration product heat loss/gain due to temperature is a combination of three modes of heat transfer:

1. Conduction (heat traveling through a solid material, the way a frying pan warms up) through glazing, spacer, and frame elements
2. Convection (the transfer of heat by the movement of gases or liquids, like warm air rising from a candle flame) through air layers on the exterior and interior fenestration product surfaces and between glazing layers
3. Radiative heat transfer (the movement of heat energy through space without relying on conduction through the air or by movement of the air, the way you feel the heat of a fire) between glazing layers, or between IG units and interior or exterior spaces.

Solar radiation absorbed by glazing layers will contribute to the temperature driven heat transfer, while solar radiation transmitted by the glazing system will be independent of the temperature driven heat transfer. Absorbed solar radiation will partially be transmitted into the conditioned space and will be included in SHGC. These three modes of heat transfer are shown schematically in Figure 3-1. Heat flows from warmer to cooler bodies, thus from inside to outside in winter, and reverses direction in summer during periods when the outside temperature is greater than indoors.

The amount of heat transfer due to these three processes is quantified by its U-factor (W/m^2-^oC or Btu/h-ft^2-^oF). The inverse of heat flow, or resistance to heat transfer, is expressed as an R-value. NFRC's rating system quantifies and predicts U-factors.

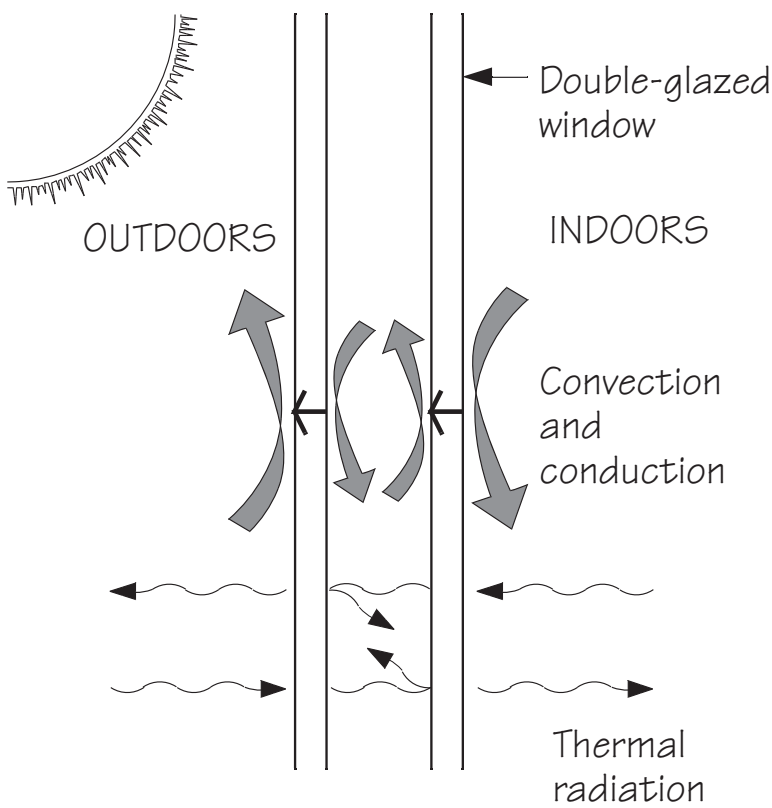

Figure 3-1. Mechanisms of heat transfer in a fenestration product.

3.3.1. Conduction

Compared to a well-insulated wall, heat transfer through a typical older fenestration product is generally much higher. A single-glazed fenestration product has roughly the same insulating qualities as a sheet of metal—most of the insulating value comes from the air layer on each surface of the glass. Such a product can be considered a thermal hole in a wall and typically has a heat loss rate ten to twenty times that of the wall. A product with such a poor insulating value allows heat to flow out of a space almost unimpeded. If the temperature inside is 21°C (70°F) and outside is -18°C (0°F), the glass surface of a single-glazed product would be about -8°C (17°F) — cold enough to form frost on the inside of the glass.

3.3.2. Convection

Convection affects the heat transfer in many places in the assembly: the inside glazing surface, the outside glazing surface, inside frame cavities, and inside any air spaces between glazings. A cold interior glazing surface cools the air adjacent to it. This denser cold air then falls to the floor, starting a convection current which is typically perceived as a "draft" caused by leaky fenestration products. One remedy for this situation is to install a product with lower heat loss rates that provides a warmer glass surface.

On the exterior, a component of the heat transfer rate of a fenestration product is the air film against the glazing surface. As wind blows across the product (causing convection), and the insulating value of this air film diminishes which contributes to a higher rate of heat loss. Finally, when there is an air space between layers of glazing, convection currents can facilitate heat transfer through this air layer. By adjusting the space between the panes of glass, as well as choosing a gas fill that insulates better than air, double-glazed fenestration products can be designed to minimize this effect.

3.3.3. Radiation

All objects emit invisible thermal radiation, with warmer objects emitting more than colder ones. Hold your hand in front of an oven window and you will feel the radiant energy emitted by that warm surface. Your hand also radiates heat to the oven window, but since the window is warmer than your hand, the net balance of radiant flow is toward your hand and it is warmed. Now imagine holding your hand close to a single-glazed window in winter. The window surface is much colder than your hand. Each surface emits radiant energy, but since your hand is warmer, it emits more toward the window than it gains and you feel a cooling effect. Thus, a cold glazing surface in a room chills everything else around it.

3.3.4. U-factor

The U-factor is the standard way to quantify insulating value. It indicates the rate of heat flow through the fenestration product. The U-factor is the total heat transfer coefficient of the fenestration system, in W/m^2-°C (Btu/hr-ft^2-°F), which includes conductive, convective, and radiative heat transfer for a given set of environmental conditions. It therefore represents the heat flow per hour, in Watts (Btu per hour) through each square meter (square foot) of fenestration product for a 1°C (1°F) temperature difference between the indoor and outdoor air temperature. The smaller the U-factor of a material, the lower the rate of heat flow. The total R-value, which measures thermal resistance, is the reciprocal of the total U-factor (R=1/U).

The U-factor depends on the thermal properties of the materials in the fenestration product assembly, as well as the weather conditions, such as the temperature differential between indoors and outside, and wind speed. NFRC has standardized the exterior conditions (called environmental conditions) for U-factor calculations for product ratings using the following temperatures and wind speeds:

- Wind Speed: 12.3 km (5.5 mph/hr)
- Indoor air temperature: 21°C (70°F)

- Outdoor air temperature: -18°C (0°F).

Skylights and roof fenestration products are simulated at a 20 degree slope from horizontal.

3.3.4.1. Total Product U-factor

The U-factor of a total fenestration assembly is a combination of the insulating values of the glazing assembly itself, the edge effects that occur in the insulated glazing unit, and the insulating value of the frame and sash.

3.3.4.2. Center-of-Glazing U-factor

The U-factor of the glazing portion of the fenestration unit is affected primarily by the total number of glazing layers, the dimension separating the various layers of glazing, the type of gas that fills the separation, and the characteristics of coatings on the various surfaces. The U-factor for the glazing alone is referred to as the center-of-glass U-factor.

3.3.4.3. Edge Effects

A U-factor calculation assumes that heat flows perpendicular to the plane of the fenestration product. However, fenestration products are complex three-dimensional assemblies, in which materials and cross sections change in a relatively short space.

For example, metal spacers at the edge of an insulating glass unit have much higher heat flow than the center of the insulating glazing, which causes increased heat loss along the outer edge of the glazing. The relative impact of these "edge effects" becomes more important as the insulating value of the rest of the assembly increases.

3.3.4.4. Frames and Sashes

The heat loss through a fenestration product frame can be quite significant: in a typical 1.2 by 0.9 m (4′ by 3′) double-hung wood frame product, the frame and sash can occupy approximately 30 percent of the product area.

In a frame with a cross section made of one uniform, solid material, the U-factor is based on the conduction of heat through the material. However, hollow frames and composite frames with various reinforcing or cladding materials are more complex. Here, conduction through materials must be combined with convection of the air next to the glazing and radiant exchange between the various surfaces.

Furthermore, frames rarely follow the same cross section around a fenestration product. For example, a horizontal slider has seven different frame cross sections, each with its own rate of heat flow.

3.3.4.5. Overall U-factor

Since the U-factors are different for the glazing, edge-of-glazing zone, and frame, it can be misleading to compare U-factors if they are not carefully described. In order to address this problem, the concept of a total fenestration product U-factor is utilized by the National Fenestration Rating Council (NFRC). A specific set of engineering assumptions and procedures must be followed to calculate the overall U-factor of a fenestration unit using the NFRC method. In most cases, the overall U-factor is higher than the U-factor for the glazing alone, since the glazing remains superior to the frame in insulating value.

The U-factor of a product is calculated with the product in a vertical position. A change in mounting angle can affect its U-factor.

3.4 Solar Heat Gain and Visible Transmittance

The second major energy performance characteristic of fenestration products is the ability to control solar heat gain through the glazing. Solar heat gain through fenestration products tends to be the single most significant factor in determining the air-conditioning load of a residential building. The intensity of heat gain from solar radiation can greatly surpass heat gain from other sources, such as outdoor air temperature or humidity.

Visible transmittance (VT) is an optical property that indicates the amount of visible light transmitted through the glazing. Although VT does not directly affect heating and cooling energy use, it is used in the evaluation of energy-efficient fenestration products and therefore is discussed following the solar heat gain section.

The origin of solar heat gain is the direct and diffuse radiation coming directly from the sun and the sky or reflected from the ground and other surfaces. Some radiation is directly transmitted through the glazing to the space, and some may be absorbed in the glazing and then indirectly admitted to the space. Sunlight is composed of electromagnetic radiation of many wavelengths, ranging from short-wave invisible ultraviolet, to the visible spectrum, to the longer, invisible near-infrared waves. About half of the sun's energy is visible light; the remainder is largely infrared with a small amount of ultraviolet. This characteristic of sunlight makes it possible to selectively admit or reject different portions of the solar spectrum. While reducing solar radiation through fenestration products is a benefit in some climates and during some seasons, maximizing solar heat gain can be a significant energy benefit under winter conditions. These often conflicting directives can make selection of the "best" product a challenging task. See Section 2.6.9 for a more detailed discussion of these properties of fenestration products.

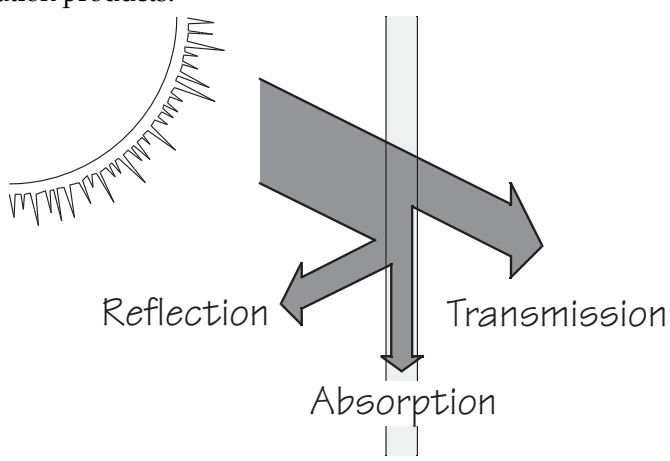

Figure 3-2. A glazing system's properties of reflection, transmission and absorption determine what happens to solar gain.

3.4.1. Determining Solar Heat Gain

There are two means of indicating the amount of solar radiation that passes through a fenestration product. These are solar heat gain coefficient (SHGC) and shading coefficient (SC). In both cases, the solar heat gain is the combination of directly transmitted radiation and the inward-flowing portion of absorbed radiation (Figure 3-3). However, SHGC and SC have a different basis for comparison or reference. The SHGC value is calculated for NFRC rating and certification. SHGC replaces SC because it more correctly accounts for angle-dependent effects. SC represents the ratio of solar heat gain through the system relative to that through 3 mm (1/8-inch) clear glass at normal incidence.

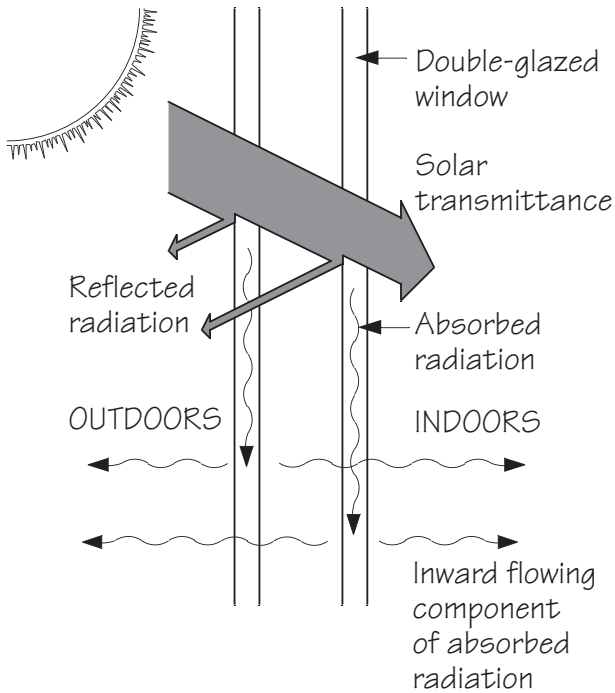

Figure 3-3. A glazing system's properties of reflection, transmission and absorption determine what happens to solar gain.

3.4.2. Solar Heat Gain Coefficient (SHGC)

The solar heat gain coefficient (SHGC) represents the solar heat gain through the fenestration system relative to the incident solar radiation. Although SHGC can be determined for any angle of incidence, the default and most commonly used reference is normal incidence solar radiation. NFRC rated SHGC's are at 0° incidence. The SHGC refers to total fenestration product system performance and is an accurate indication of solar gain under a wide range of conditions. SHGC is expressed as a dimensionless number from 0 to 1.0. A high SHGC value signifies high heat gain, while a low value means low heat gain.

3.4.3. Visible Transmittance

Visible transmittance is the amount of light in the visible portion of the spectrum that passes through a glazing material. This property does not directly affect heating and cooling loads in a building, but it is an important factor in evaluating energy-efficient fenestration products. Transmittance is influenced by the glazing type, the number of layers, and any coatings that might be applied to the glazings. These effects are discussed in more detail later in this chapter in conjunction with a review of various glazing and coating technologies. Visible transmittance of glazings ranges from above 90 percent for water-white clear glass to less than 10 percent for highly reflective coatings on tinted glass.

Visible transmittance is an important factor in providing daylight, views, and privacy, as well as in controlling glare and fading of interior furnishings. These are often contradictory effects: a high light transmittance is desired for view out at night, but this may create glare at times. These opposing needs are often met by providing glazing that has high visible transmittance and then adding attachments such as shades or blinds to modulate the transmittance to meet changing needs.

NFRC reports visible transmittance as a rating on the label. Note that NFRC's rating is a whole product rating that combines the effect of both glazing and frame. There are many cases where the transmittance of glazing alone will be required, so it is important to make sure that the appropriate properties are being compared.

In the past, products that reduced solar gain (with tints and coatings) also reduced visible transmittance. However, new spectrally selective tinted glasses and selective coatings have made it possible to reduce solar heat gain with little reduction in visible transmittance.

3.5 Condensation Resistance

Condensation has been a persistent and often misunderstood problem associated with windows. In cold climates, single-glazed windows characteristically suffer from water condensation and the formation of frost on the inside surface of the glass in winter. The surface temperature of the glass drops below either the dew point or frost point of the inside room air.

Excessive condensation can contribute to the growth of mold or mildew, damage painted surfaces, and eventually rot wood trim. Since the interior humidity level is a contributing factor, reducing interior humidity is an important component of controlling condensation.

Condensation can also be a problem on the interior surfaces of window frames. Metal frames, in particular, conduct heat very quickly, and will "sweat" or frost up in cool weather. Solving this condensation problem was a major motivation for the development of thermal breaks for aluminum windows.

Infiltration effects can also combine with condensation to create problems. If a path exists for warm, moisture-laden air to move through or around the window frames, the moisture will condense wherever it hits its dew point temperature, often inside the building wall. This condensation can contribute to the growth of mold in frames or wall cavities, causing health problems for some people, and it encourages the rotting or rusting of window frames. Frames must be properly sealed within the wall opening to prevent this potential problem. In some instances, the infiltration air will be dry, such as on cold winter days, and it will thus help eliminate condensation on the window surfaces.

Condensation can cause problems in skylights and roof windows as well as typical windows. "Leaky" skylights are frequently misdiagnosed. What are perceived to be drops of water from a leak are more often drops of water condensing on the cold skylight surfaces. A skylight is usually the first place condensation will occur indicating too much moisture in the interior air. Insulating the skylight well and providing adequate air movement assists in reducing condensation. Also, the use of more highly insulating glazing with a well-designed frame can help solve this problem. In many systems, a small "gutter" is formed into the interior frame of the skylight where condensate can collect harmlessly until it evaporates back into the room air.

The *NFRC Publication NFRC 501: User Guide to NFRC 500* contains more information about condensation resistance.

3.5.1. Impact of Glazing Type and Spacers on Condensation

Figure 3-4 indicates condensation potential for four glazing types at various outdoor temperature and indoor relative humidity conditions. Condensation can occur at any points that fall on or above the curves. As the U-factor of windows improves, there is a much smaller range of conditions where condensation will occur. Figure 3-4 must be used with caution, since it shows condensation potential for the center of glazing area only (the area at least 63.5 mm (2.5 inches) from the frame/glazing edge). Usually condensation will first occur at the lower edge of the product where glazing temperatures are lower than in the center.

As Figure 3-4 shows, double-glazed products create a warmer interior glazing surface than single-glazing, reducing frost and condensation. The addition of low-E coatings and argon gas fill further reduce condensation potential. The triple-glazed product with low-E coatings has such a warm interior surface that condensation on any interior surfaces may be eliminated if humidity levels are maintained at reasonable levels.

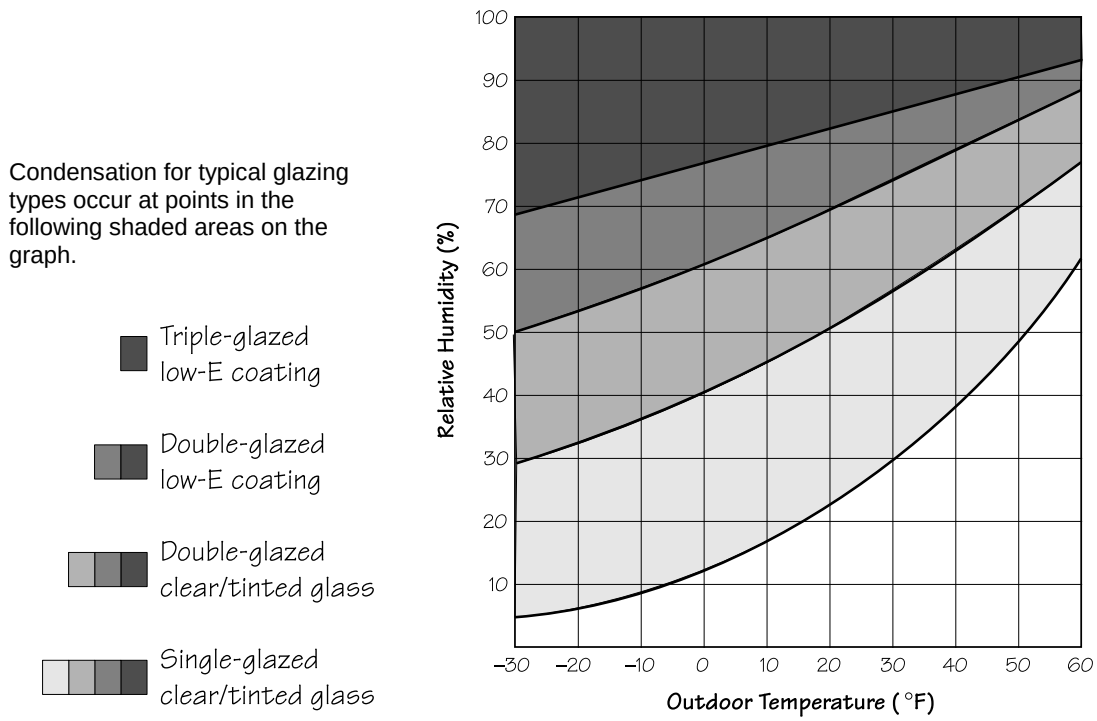

Figure 3-4. Condensation potential on glazing (center of glazing) at various outdoor temperature and indoor relative humidity conditions.

Condensation forms at the coldest locations, such as the lower corners or edges of an insulated product even when the center of glazing is above the limit for condensation. Generally, as the insulating value of the glazing is improved, the area where condensation can occur is diminished. Condensation potential increases as the outdoor temperature is lowered and the indoor relative humidity increases.

3.5.2. Condensation Resistance

NFRC has developed a Condensation Resistance (CR) value for rating for how well a fenestration product can resist the formation of condensation on the interior surface of the product at a specific set of environmental conditions. The CR calculation method is defined in the *NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values*.

3.5.3. Outdoor Condensation

Under some climate conditions, condensation may occur on the exterior glazing surface of a window. This is more likely to occur on higher-performance windows with low-E coatings or films, and low-conductance gas fills that create very low U-factors. By preventing heat from escaping from the interior, the exterior surfaces of the window approach outside air temperature. These exterior temperatures may be below the exterior dew point causing condensation on the exterior glazing surfaces. This is most likely to happen when there is a clear night sky, still air, and high relative humidity, in addition to the right temperature conditions. Like other dew formed at night, exterior window condensation will disappear as surfaces are warmed by the sun. It is the excellent thermal performance of well-insulated glazing that creates the condition where the outer glazing surface can be cold enough to cause condensation to form.

3.5.4. Condensation Between Glazings

A more annoying problem can arise with double-pane windows, which is condensation between the panes. Moisture can migrate into the space between the panes of glass and condense on the colder surface of the exterior pane. This condensation is annoying not only because it clouds the view and stains the interior surfaces, but because it may mean that the glazing unit must be replaced if it is a sealed insulating glazing unit. In a non-sealed unit, simpler remedies may correct the situation.

Factory-sealed insulated glazing utilizes a permanent seal to prevent the introduction of moisture. The void may be filled with air or dry gases, such as argon. A desiccant material in the edge spacer between the panes is used to absorb any residual moisture in the unit when it is fabricated or any small amount that might migrate into the unit over many years. These windows will fog up when moisture leaking into the air space through the seals overwhelms the ability of the desiccant to absorb it. This could happen early in the window's life (the first few years) if there is a manufacturing defect, or many decades later because of diffusion through the sealant. Quality control in manufacture, sealant selection, window design, and even installation can influence the rate of failure. Once a sealed window unit fails, it is not generally possible to fix it, and the sealed unit must be replaced. Moisture in the unit is also likely to reduce the effectiveness of low-E coatings and suggests that gas fills may be leaking out. Most manufacturers offer a warranty against sealed-glazing failure which varies from a limited period to the lifetime of the window.

When condensation occurs between glazings in a non-sealed unit, there are several possible remedies. Most manufacturers who offer non-sealed double glazing include a small tube connecting the air space to the outside air, which tends to be dry during winter months. Check to be sure that the inner glazing seals tightly to the sash, and clear the air tube if it has become obstructed. In some cases, reducing interior room humidity levels may help alleviate the problem.

3.6 Infiltration

Infiltration is the leakage of air through cracks in the building envelope. Infiltration leads to increased heating or cooling loads when the outdoor air entering the building needs to be heated or cooled. Fenestration products and doors are typically responsible for a significant amount of the infiltration in homes. In extreme conditions, depending on the type and quality, infiltration can be responsible for as much heat loss or gain as the rest of the product. The level of infiltration depends upon local climate conditions, particularly wind conditions and microclimates surrounding the house. Typically, U-factor and SHCG effects far outweigh infiltration effects. Tight sealing and weatherstripping of the fenestration product, including sash, and frames is of paramount importance in controlling infiltration.

High quality fixed fenestration products help to reduce infiltration because they are easier to seal and keep tight. Operable fenestration products are necessary for ventilation, but they are also more susceptible to air leakage. Operable units with low air leakage rates are characterized by good design and high-quality construction and weatherstripping. They also feature mechanical closures that positively clamp the product shut against the wind. For this reason, compression-seal products such as awning, hopper, and casement

designs are generally more effectively weatherstripped than are sliding-seal products. Sliding products rely on wiper-type weatherstripping, which is more subject to wear over time and can be bypassed when it flexes under wind pressure.

3.7 Solar Properties of Glazing Materials

Three things happen to solar radiation as it passes through a glazing material. Some is transmitted, some is reflected, and the rest is absorbed. These are the three components of solar that determine many of the other energy performance properties of a glazing material, such as the solar heat gain coefficient and shading. Manipulating the proportion of transmittance, reflectance, and absorptance for different wavelengths of solar radiation has been the source of much recent innovation in fenestration energy performance.

Visible light is a small portion of the electromagnetic spectrum (see Figure 2-3). Beyond the blues and purples lie ultraviolet radiation and other higher-energy short wavelengths, from X rays to gamma rays. Beyond red light are the near-infrared, given off by very hot objects, the far-infrared, given off by warm room-temperature objects, and the longer microwaves and radio waves.

Glazing types vary in their transparency to different parts of the spectrum. On the simplest level, a glass that appears to be tinted green as you look through it toward the outside will transmit more sunlight from the green portion of the visible spectrum, and reflect/absorb more of the other colors. Similarly, a bronze-tinted glass will absorb the blues and greens and transmit the warmer colors. Neutral gray tints absorb most colors equally.

This same principle applies outside the visible spectrum. Most glass is partially transparent to at least some ultraviolet radiation, while plastics are commonly more opaque to ultraviolet. Glass is opaque to far-infrared radiation but generally transparent to near-infrared. Strategic utilization of these variations has made for some very useful glazing products.

The basic properties of glazing that affect solar energy transfer are:

- Visible transmittance
- Reflectance
- Absorptance

Each is described below.

3.7.1. Transmittance

Transmittance refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., “visible light transmittance,” “UV transmittance,” or “total solar energy transmittance.” Each describes a different characteristic of the glazing. Visible transmittance is the total fenestration product system's transmittance across the visible portion of the solar spectrum. Although VT can be determined for any angle of incidence, the default and most commonly used reference is normal incidence solar radiation. Transmission of visible light determines the effectiveness of a type of glass in providing daylight and a clear view through the fenestration product. For example, tinted glass has a lower visible light transmittance than clear glass.

With the recent advances in glazing technology, manufacturers can control how glazing materials behave in these different areas of the spectrum. The basic properties of the substrate material (glass or plastic) can be altered, and coatings can be added to the surfaces of the substrates. For example, a product optimized for daylighting and for reducing heat gains should transmit an adequate amount of light in the visible portion of the spectrum, while excluding unnecessary heat gain from the near-infrared part of the electromagnetic spectrum.

On the other hand, a product optimized for collecting solar heat gain in winter should transmit the maximum amount of visible light as well as the heat from the near-infrared wavelengths in the solar spectrum, while blocking the lower-energy radiant heat in the far-infrared range that is an important heat loss component. These are the strategies of spectrally selective and low-emittance coatings, described later in the chapter.

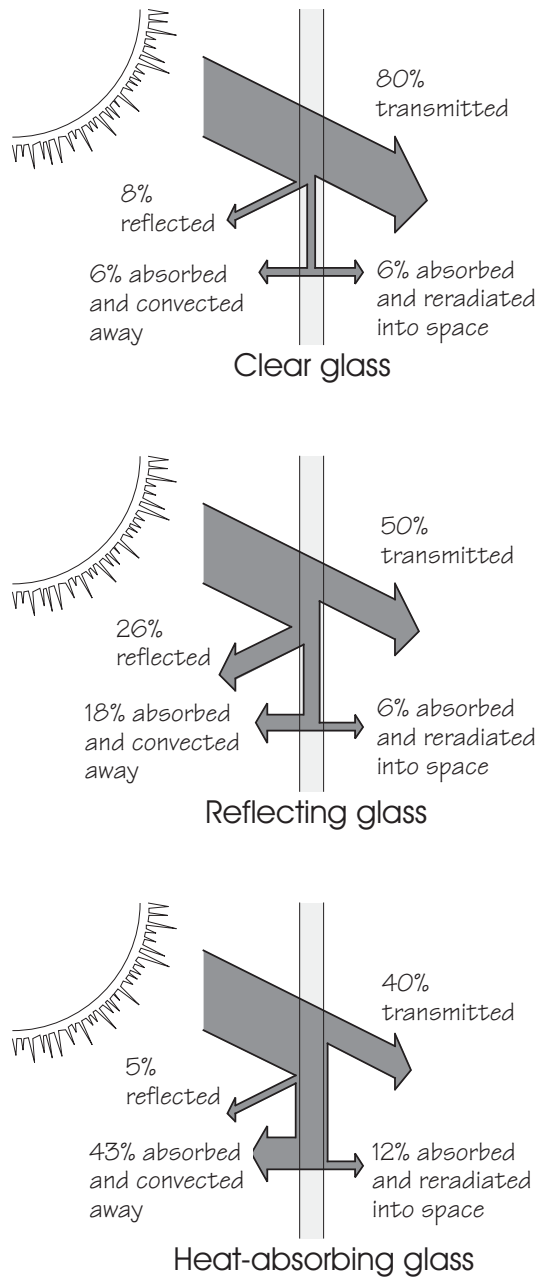

Figure 3-5. Different glass types have different characteristics for the amount of solar radiation reflected, transmitted, absorbed, and re-radiated.

3.7.2. Reflectance

Just as some light reflects off of the surface of water, some light will always be reflected at every glass surface. A specular reflection from a smooth glass surface is a mirror-like reflection similar to when you see an image of yourself in a store window. The natural reflectivity of glass is dependent on the quality of the glass surface, the presence of coatings, and the angle of incidence of the light. Today, virtually all glass manufactured in the

United States is float glass and has a very similar quality with respect to reflectance. The sharper the angle at which the light strikes, however, the more the light is reflected rather than transmitted or absorbed . Even clear glass reflects 50 percent or more of the light striking it at incident angles greater than about 70 degrees. (The incident angle is formed with respect to a line perpendicular to the glass surface.)

Coatings can often be detected by careful examination of a reflected bright image, even if the coating is a transparent low-E coating. Hold a match several inches from a fenestration product at night and observe the reflections of the match in the glass. You will see two closely spaced images for each layer of glass, since the match reflects off the front and back surface of each layer of glass. A wider spacing between the two sets of pairs of images occurs with a wider air space between the glass panes. A subtle color shift in one of the reflected images normally indicates the presence of a low-E coating.

The reflectivity of various glass types becomes especially apparent during low light conditions. The surface on the brighter side acts like a mirror because the amount of light passing through the fenestration product from the darker side is less than the amount of light being reflected from the lighter side. This effect can be noticed from the outside during the day and from the inside during the night. For special applications when these surface reflections are undesirable (i.e., viewing merchandise through a store window on a bright day), special coatings can virtually eliminate this reflective effect.

The reflectivity of glass can be increased by applying various metallic coatings to the surface. Early processes used a liquid alloy of mercury and tin to create mirrors. A silvering process developed in 1865 improved the performance of mirrors. Today, mirror-like surfaces can be created by using vacuum-deposited aluminum or silver, or with a durable pyrolytic coating applied directly to the glass as it is manufactured. Thick coatings can be fully reflective and virtually opaque; a thinner coating is partially reflective and partially transmitting.

Most common coatings reflect all portions of the spectrum. However, in the past twenty years, researchers have learned a great deal about the design of coatings that can be applied to glass and plastic to reflect only selected wavelengths of radiant energy. Varying the reflectance of far-infrared and near- infrared energy has formed the basis for low-emittance coatings for cold climates, and for spectrally selective low-emittance coatings for hot climates.

3.7.3. Absorptance

Energy that is not transmitted through the glass or reflected off of its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the temperature of the glass.

Typical 1/8-inch (3 mm) clear glass absorbs only about 4 percent of incident sunlight. The absorptance of glass is increased by adding to the glass chemicals that absorb solar energy. If they absorb visible light, the glass appears dark. If they absorb ultraviolet radiation or near-infrared, there will be little or no change in visual appearance. Clear glass absorbs very little visible light, while dark tinted glass absorbs a considerable amount. The absorbed energy is converted into heat, warming the glass. Thus, when these “heat-absorbing” glasses are in the sun, they feel much hotter to the touch than clear glass. They are generally gray, bronze, or blue-green and are used primarily to lower the solar heat gain coefficient and to control glare. Since they block some of the sun’s energy, they reduce the cooling load placed on the building and its air-conditioning equipment. Absorption is not the most efficient way to reduce cooling loads, as discussed later.

3.8 Infrared Properties of Glazing Materials (Emittance)

When heat or light energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. This ability of a material to radiate energy is called its emissivity. Fenestration products, along with all other household objects, typically emit, or radiate, heat in the form of long-wave far-infrared energy. This emission of radiant heat is one of the important heat transfer pathways for a fenestration product. Thus, reducing the product’s emission of heat can greatly improve its insulating properties.

Standard glass has an emittance of 0.84 over the long wavelength portion of the spectrum, meaning that it emits 84 percent of the energy possible for an object at its temperature. It also means that for long-wave radiation (where there is no transmittance) striking the surface of the glass, 84 percent is absorbed and only 16 percent is reflected. By comparison, low-E glass coatings have an emittance as low as 0.04. This glazing would emit only 4 percent of the energy possible at its temperature, and thus reflect 96 percent of the incident long-wave infrared radiation.