PDHonline Course A140 (3 PDH)

Windows for Buildings: An Introduction

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2020

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Windows for Buildings: An Introduction

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1. Introduction

Welcome! This curriculum was created to provide an insider view of windows, window walls, curtainwalls and the building envelope from the point of view of someone who spent a 30 year career involved with manufacturing, engineering, testing, furnishing and installing these products.

This is the first in a set of courses that are arranged in a progressive sequence. If you want to start from the beginning and work your way through the courses, you will develop a solid platform from which to operate. If you already have a knowledge base and wish to select the courses of greatest interest, the courses are also designed to stand alone.

2. The Significance of Windows

Windows, and their related products window walls, curtainwalls and skylights are a special and important aspect of nearly every building. These products are infinitely configurable design elements. Used well, they bring lasting beauty to the building through the use of proportion, texture, color, shadow and light.

Windows allow building occupants to connect with the world outside, and afford people on the street a chance to peek inside. Just as eyes have been described as windows into the soul, windows are the eyes of the building. We see through them and others gaze into them to learn our true nature.

Design professionals who truly grasp the significance of windows in buildings will succeed in creating or modifying people-friendly, truly functional buildings.

This course will not address esthetic design, however – that is your domain. Instead this course intends to empower you with tools and understandings that will support your efforts to effectively and optimally use windows and glass in your unique building designs.

3. The Drawbacks of Windows

Having sung the praises of windows, it is also important to recognize their drawbacks. Good design should always include recognizing and managing negatives, and windows are an excellent example of this.

The drawbacks of windows fall into two categories:

Managing energy

Managing the interior environment

4. Managing Energy with Windows

This topic will be expanded upon at length in future courses, but here's the fundamental. **A window can lose twelve times more energy than a wall** simply through thermal conductivity, not even including air infiltration.

5. U-Factor and R-Value

Contrary to the way wall and roof insulation is measured using an "R-value", window products are measured instead using a "U-factor", also called a "U-value." The R-value is the reciprocal of the U-factor and vice versa. Some quick examples:

U-Factor and R-Value Equivalents	
U-Factor (Thermal conductivity)	R-Value (Thermal resistance)
1.0	1
.50	2
.333	3
.25	4
.2	5
.1	10
.09	11
.07	15

Figure 1. U-Factor and R-Value Equivalents

It is tempting to blame the odd disconnect of having two sets of parallel measurement systems on the window industry because it certainly helps to mask the generally poor thermal performance of windows. Such marketing maneuvers are not the reason different product types speak different languages, however, at least not in the way you might think.

In actuality, the U-factor came first. It had to. U-factor is an actual measurement of thermal conductivity, and started out being physically measured in a guarded hot box, as is described in ASTM C1363. These days it is also modeled and calculated – see the reference to THERM software in the footnotes.

U-factor counts the number of BTU's lost through the tested assembly per square foot, per temperature difference from one side to the other side of the tested material, per hour.

In the US, the units of measure for U-factor are:

BTUs / Square Foot / °F Differential / Hour

In countries that use SI units, the units of measure for U-factor are:

Watts / Square Meter/ °K Differential / Hour

Conversion between US and SI units for U-Factor:

1 US U-factor = 5.678 SI U-factor

1 SI U-factor = 0.176 US U-factor

According to www.BuildingGreen.com:

> Everett Shuman, a researcher at Penn State University, proposed the R-value measure in 1945. Prior to that, the primary measure for insulating value was U-factor, which measures heat flow. U-factor is the inverse of R-value (U = 1/R, and R = 1/U), which measures resistance to heat flow. While “good” insulation has low U-factors—an R-13 fiberglass batt has a U-factor of 0.08—R-value caught on because people apparently find it easier to understand that higher numbers are “better.” Round numbers also don’t hurt.

So the R-Value took root because it was easier for the public to understand, and is further simplified by being rounded to the closest integer.

Design professionals who span the globe with their designs must remember that not all U-factors are the same, even if they have the same name. Sometimes one must consider the context in order to determine which U-factor is being used.

Because U-factor in either measurement system refers to the amount of energy passing through a material, where energy conservation is concerned, a smaller U-factor is better. Consider these relationships:

Typical U-factors (US)	
Single thickness (monolithic) glass	1.11
1” insulating glass (2 lites)	.47
3 ½” fiberglass insulation (R11)	.09

Figure 2. Typical U-Factors

When mentioned earlier that **a window can lose twelve times more energy than a wall,** the above chart and calculation below demonstrates the point:

Divide the amount of heat lost through single thickness glass:

U=**1.11** BTUs / Square Foot / °F Differential / Hour

by the amount of heat lost through 3 ½” of insulation

U=**.09** BTUs / Square Foot / °F Differential / Hour

The result is **12.33**

Single glazing is little more than a hole that reduces air infiltration in the building envelope.

A generic insulated glass unit with no enhancements other than two lites of glass and an airspace, will have a U-factor of .47. The thermal improvement is a significant 58% over single thickness glass, but still abysmal compared to

3 ½” of insulation. Unimproved insulated glass loses over 5 times the heat as fiberglass batt insulation in a typical wall.

Future courses will show how, through the use of clever strategies, glass will approach and even exceed the insulating performance of our insulated wall. There is much more to learn on this subject, but the tip of this iceberg has now been clearly sighted.

6. Managing the Interior Environment with Windows

Here we will begin our exploration of the window as an object that allows light to pass through it. This is a truly unique property. You will not see bricks, concrete or wood conducting light, but windows do. This singular property has huge ramifications for building design.

7. The Electromagnetic Spectrum

Light is small segment of a much larger scale known as the electromagnetic spectrum. This is a spectrum of variations of energy known as electromagnetic radiation. At one end of the spectrum are gamma rays with extremely short wavelengths. At the other end are radio waves, some with wavelengths many miles long.

In the middle of this mysterious spectrum is visible light sorted by color. From longer wavelength to shorter, the colors are red, orange, yellow, green, blue, indigo, and violet. If you paid attention in 5th grade science, this sequence of colors will be quite familiar. Some even used the hard to pronounce acronym ROYGBIV to remember these fundamental colors long enough to take the test.

Clear glass readily allows the wavelengths of visible light to pass through it. This is another way of saying glass is transparent. We do not really “see” through glass. Our eyes don’t reach through the glass and capture the image of objects. Instead, the transparency of glass allows light, reflected off of outdoor objects, to reach our eyes and be perceived.

The visible light section of the electromagnetic spectrum is flanked by interesting transitional waves, ultraviolet at one end (next to violet), and infrared at the other (next to red).

Infrared is of particular interest to the window industry. In addition to the use of this group of wavelengths for communicating between televisions and their remote controls, infrared light is really special because it is the embodiment of none other than heat. Thermal energy and infrared light is essentially the same thing.

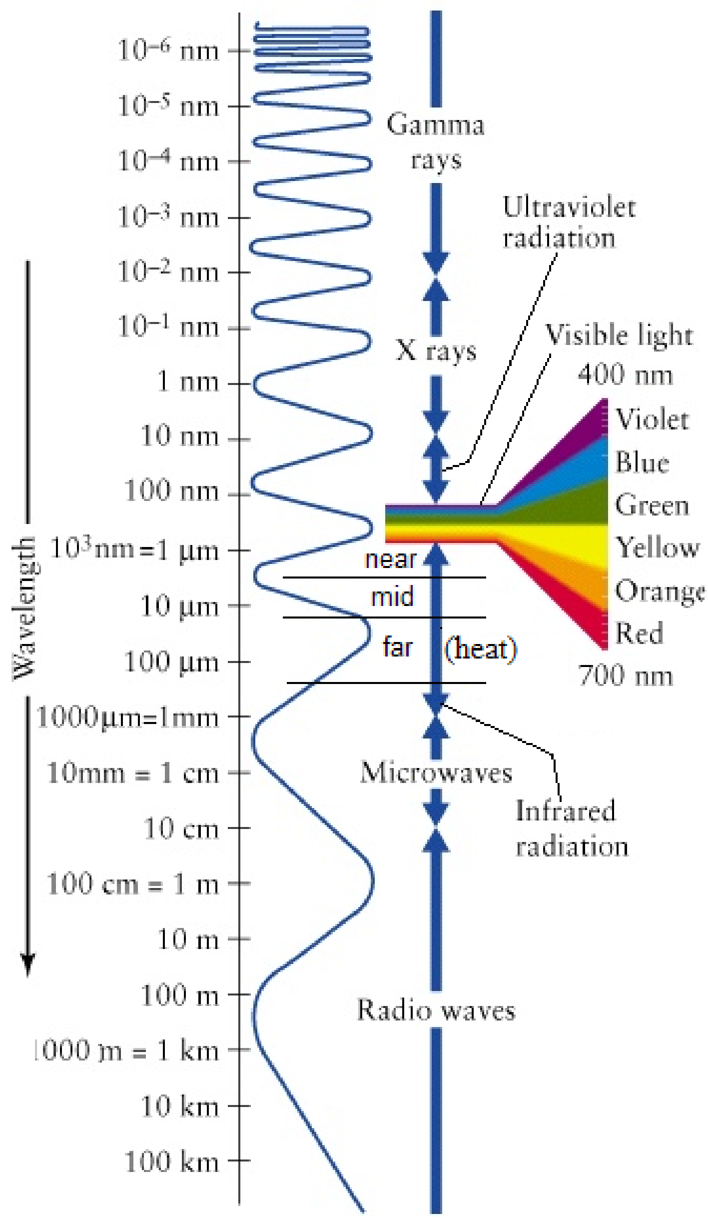


Figure 3. The Electromagnetic Spectrum

This Einsteinian-sounding concept, the convergence of light and heat, allows glass manufacturers to place coatings on the glass that allow only some parts of the spectrum – the visible part – to pass through the glass while the part of the spectrum that is heat is reflected away.

8. Comfort Near the Windows

Consider the poor office worker whose cubicle has been placed next to a west-facing window. In the afternoon he bakes in the infrared rays, some that come straight from the sun and some that come reflected from objects. Asphalt parking lots and interior objects that absorb the visible and infrared light will re-radiate all of this energy as infrared. We say they "heat up".

Closing the shades doesn't always seem to help. The infrared waves have already passed the glass boundary and are freely bouncing around the office heating up the blinds, the space and the workers. Clearly the architect of this building did not anticipate this uncomfortable situation.

Then winter comes, and the same worker feels permanently chilled because the space next to the windows is cold. The warm air on the ceiling eventually finds the top of the window, where the air becomes progressively cooled as it flows down the face of the glass, eventually wafting along the floor to cool the worker's feet. This worker will have a difficult time being productive.

9. Advanced Strategies for Managing Energy and Interior Environment

Problems of managing building energy consumption and the interior environment near the windows are real challenges for architects and engineers alike.

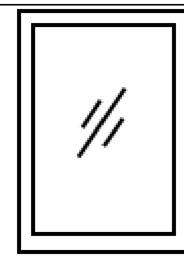
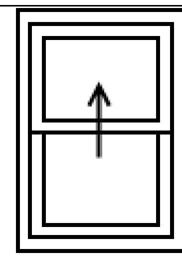
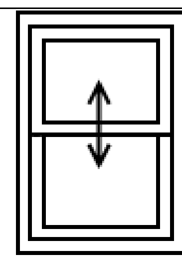
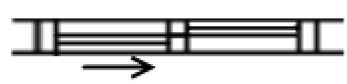
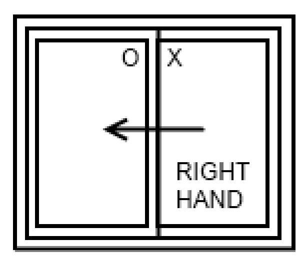
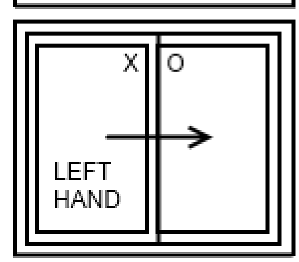
Thankfully, the window and glass industry is making great strides toward fixing these problems, such as:

- Low-E glass that reflects heat already in the building, back inside to help in the winter while reflecting the outside heat, helping in the winter.
- Tinted glass that reduces the glare and solar heat gain
- Additional glazing layers, such as triple glazing or suspended films that increase the U-factor of the glass
- Thermal breaks in aluminum frames to reduce thermal conductivity
- Warm edge glass spacers that reduce thermal conductivity
- Argon or krypton fill in the insulated glass airspace to reduce thermal conductivity

- Vacuum glass, where instead of air or argon in the airspace, there is a vacuum, dramatically improving U-factor
- Self-heating glass, which allows the window to remain warmer and eliminate cold spots in the space
- Variable-tint glass that dynamically modified the solar heat gain through the glass
- Glass that generates electricity to defray the cost of operating a building
- Glass and windows that pull more daylight into the building interior, to reduce daylighting costs

I hope you will stick with this curriculum and discover how to use the exciting new set of tools available for managing the building envelope.

10. Types of Windows

	Weatherstrip Type	Plan view (exterior is up)	Exterior view
Fixed (picture window)	None		
Single hung	Sweep		
Double hung			
Sliding window	Sweep		
Sliding door			

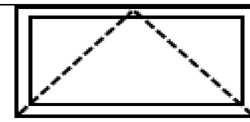
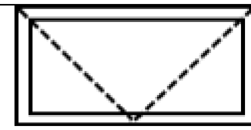
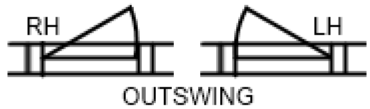
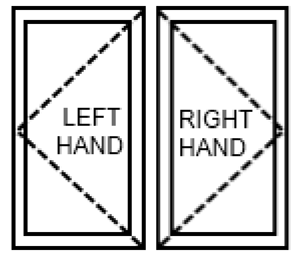
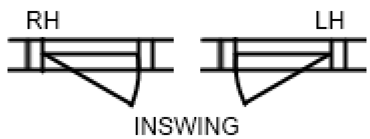
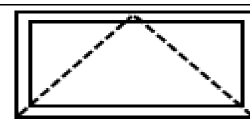
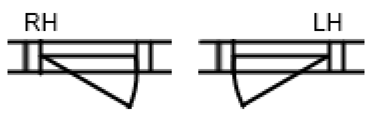
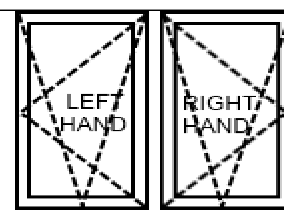
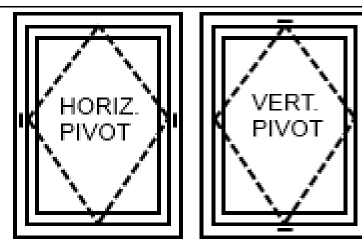
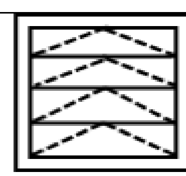
Project out (awning)	Compression		
Project in (hopper)			
Casement (outswing or inswing)	Compression		
Balcony door (inswing or outswing)	Compression		
Top hung inswing	Compression		
Tilt-turn	Compression		
Pivoted (Horizontal or Vertical)	Sweep or compression		
Jalousie	None or compression		

Figure 4. Types of windows

11. Fixed Windows

The simplest type of window is a fixed window. It has no moving parts and does not open. It usually consists of a single frame, within which glass is installed.

12. Single and Double Hung Windows

Single and double hung windows are named "hung" because the original design involved having the operable sash hung from ropes or chains which then were placed over a pulley at the top of each jamb. The rope or chain then was attached to a counterweight concealed in the jamb, allowing the sash to be easily raised and also to stay at the height to which it was raised.

Figure 5. Double hung window showing rope, pulley and counterweight

These days, numerous styles of balances are available, but they usually involve springs rather than counterweights.

Double hung windows have the top and bottom sash operable. Single hung windows only operate the bottom sash. The horizontal rail where the upper and lower sash meet is called the *meeting rail.*

13. Sliding Windows and Doors

The family of sliding windows and doors utilize wheels or rollers at the bottom of the operable sash. The sash travels horizontally in tracks at the top and bottom of the master frame. Usually only one of the sash operate, however when both sash operate, the window is called a "*double slide*."

Due to the presence of a track at the sill of a sliding window or door, water can accumulate in the track. These products must have provisions to "weep" the water to the exterior. This poses a design challenge because weep holes can conduct air infiltration to the interior.

14. Projected Windows and Doors

As can be seen in Figure 4, second page, operation of all windows and doors that swing (as opposed to slide) is indicated by dotted lines that converge at an edge of the window, forming a V shape. The point of this V is the theoretical hinge location. I use the term "theoretical' because the actual hinge is not always positioned at this location. Example: the project-out window has the V pointing to the top, at the theoretical hinge location. If butt-hinges were used, that would also be the exact location. Instead, scissors hinges are used at the sides. These are far preferable because they hold the sash open in any position.

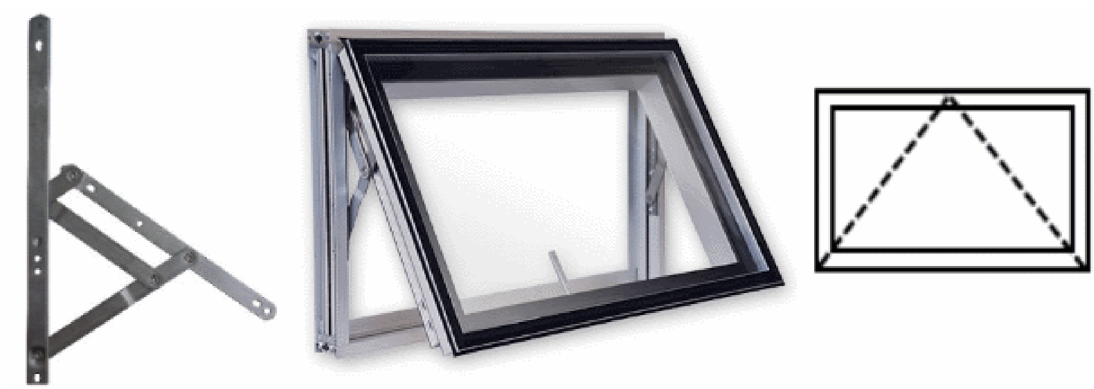


Figure 6. Project out vent (center). At left is the scissors hinge that is installed in the jambs (sides), yet at right, the convention for indicating operation with dotted lines formed into a V, point at the theoretical hinge location at the top, as if the hinges were butt hinges as used on a typical door.

Project out (awning) and project in (hopper) windows are usually combined with a fixed window above or below. A common design in high-rise construction is to place these near the floor.

15. Tilt-turn Windows

This European design involves a sash that operates in two directions: inswing casement (typically for cleaning) and project-in (for ventilation). Both functions can be controlled by a single handle. These windows have not really gained a foothold in the US for reasons of cost. Other impediments to their widespread acceptance include having the ventilation near the ceiling, interference with window treatments, and widespread use of window washers who can work from the outside efficiently without needing to gain entry into the living units.

16. Jalousie Windows

This design involves multiple project-out sash, usually comprised of single-thickness (*monolithic)* glass. They are gang-operated and frequently not weatherstripped. This is a product that is designed for a tropical environment or sunrooms that are only used in summer.

17. Window Safety

Every year hundreds of people, especially children, die and are injured because they either fell from windows or were injured by windows or broken glass, or any combinations of the above. Design professionals cannot be too careful when designing around this serious set of issues.

Care must be taken to limit the opening of any windows near the floor (preferably ALL windows) to a maximum of 4”. All glass at or near walking surfaces, and in or near doors and bathtubs/showers must be safety glass.

Be sure to check all of the prevailing codes, including local building codes, local amendments to the code, local property maintenance codes, local ordinances and any industry specific guidelines (such as for hotels, hospitals, etc.) to ensure compliance. Do not be deterred if, for example, window limits are not mandated in any of the codes. Check with the fire department and life-safety codes to ensure proper egress, and then limit those windows and use safety glass!

18. Glazing and Sash – Definitions

Installing and sealing glass into a surrounding frame is called ***glazing*** the glass into the frame. The term ***glazing*** also refers to the glass or whatever other material (sheet plastic or metal panels, for example) that may be glazed into a frame or sash.

A ***sash*** is the operable frame that resides within the outer frame, called the ***master frame***. In the aluminum window industry, only operable windows have sash. In the wood or wood-clad window industry, both fixed and operable windows often consist of an inner and outer frame, and so the frame immediately adjacent to the glass is sometimes called a ***fixed sash***.

19. Weatherstrips and Gaskets

Operable windows can be grouped by the type of *weatherstripping* they use, either *sweep* or *compression*. Weatherstripping is flexible material that runs continuously between operable and fixed elements of a window to repel air infiltration and water penetration.

Double hung, single hung, and sliding windows and doors all utilize weatherstripping that slides or sweeps between the sash and the frame. Such weatherstripping must be tolerant of shearing movement while still maintaining a seal. Fuzzy piles, sometimes accompanied by a plastic or Mylar fin, are frequently used for this purpose at the perimeter of the sash, or along the frame where the sash meets the frame.

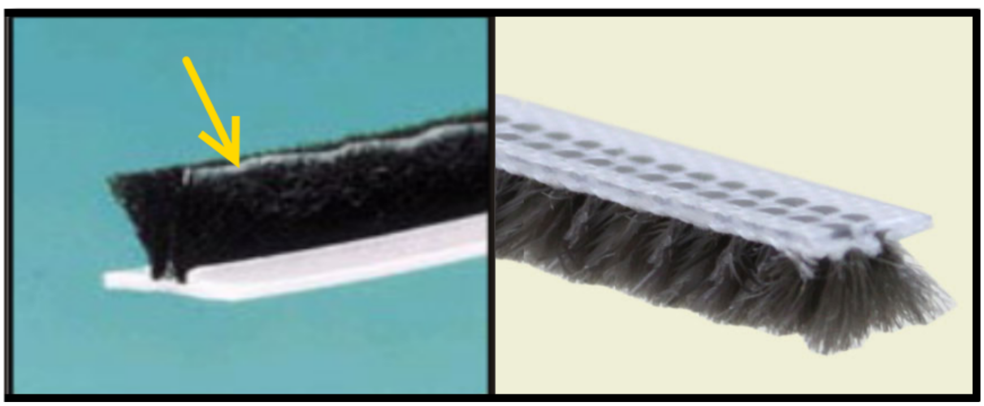


Figure 7. Left: Sweep-type weatherstripping with Mylar fin (arrow) embedded in the pile for better control of air infiltration. The original trade name, fin-seal, has now been popularized to represent all such products. Right: Sweep weatherstrip without fin. The rigid backer threads into receiving slots that run along the sash or frame.

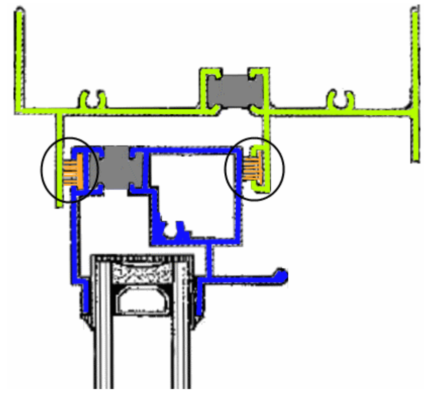


Figure. 8. Sectional detail through aluminum thermally broken double hung window. The master frame has been coded yellow. The sash is blue. The two thermal breaks are gray. The two weatherstrips are colored orange and circled. The weatherstrip on the left is threaded into the sash and weathers against the master frame. The weatherstrip on the right is threaded into the master frame and weathers against the sash.

All other operable window types utilize compression weatherstripping, such as bulbs or fins. These tend to seal better that sweep-type weatherstrips because they are actually compressed between sash and frame when the sash is locked in the closed position. Compression weatherstrips can also be called *gaskets.*

Figure 9. Left: Bulb weatherstrip with a rigid backer for threading into a slot which has been extruded into an aluminum or PVC sash or frame. Right: Bulb weatherstrip equipped with a “double-dart” designed to be permanently pressed into a slot cut along the edge of a wood window frame or sash. These weatherstrips are extruded from vinyl, TPEs (thermoplastic elastomers), PVC, silicon, polypropylene and jacketed foams.

There are literally thousands of weatherstrips available on the market, varying by material, size, thickness, and backer configuration. If replacement weatherstrips are needed, the best way to achieve success is to obtain a sample of the material, measure it using a caliper-type micrometer, detail it and send it to various suppliers, even accompanied by photos of the material. If any suppliers claim to have a matching product, request a sample and compare it with your original.

20. Weatherstrip and Gasket Compression

Weatherstrips and gaskets are designed to be compressed when in service. The window manufacturer will select a particular weatherstrip type for the product, and will decide, possibly in coordination with the weatherstrip manufacturer, to what extent the weatherstrip should be compressed.

This decision must be made judiciously. If the weatherstrip is compressed too hard, meaning it is too thick, the window will be difficult to operate. If weatherstripping is too loose, excessive air infiltration or even water penetration could result. As windows are operated year after year, many weatherstrips will remain compressed even while not under compression. This is called "*taking a set*." Other products may erode over time, loosening the seal. Therefore the choice of weatherstripping material and its initial compression has large ramifications for the functionality of the window product not only when it is new, but also for many years in the future.

21. How Windows are Made

Here we will discuss the frame of the window. Glass, the thing that makes a window a window, will be discussed later. Window frames are commonly made from extruded aluminum, extruded PVC, wood and wood with aluminum or PVC exterior cladding. A newer product, combining the strength of aluminum with the thermal resistance of PVC, is a fiberglass pulltrusion.

Historically, windows were also made from rolled section or hollow metal steel and there is a market for these products now.

The material chosen for the window frame, combined with its accompanying manufacturing processes have evolved frame designs that are peculiar to the material.

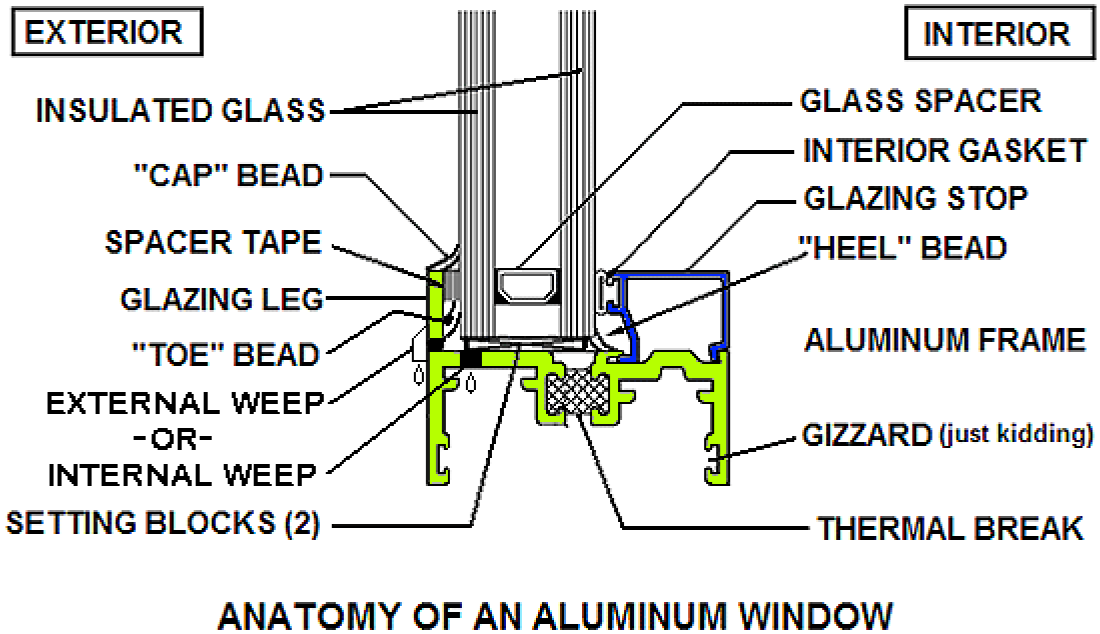


Figure 10. Anatomy of an Aluminum Window. Sectional detail of a fixed aluminum window shows that the core of the frame (yellow) is a highly detailed series of walls. In commercial windows, these walls are often 1/8” (.125”) thick.

The extrusion process, along with the formability of aluminum, allows intricate shapes that are highly functional. A thermal break can be added to the frame to reduce thermal conductivity. A separate glazing stop (blue) can be extruded to neatly snap into the main extrusion and hold the glass in place.

Aluminum is reactive to changes in temperature, and its coefficient of thermal expansion must be considered, especially when designing larger assemblies.

Figure 11. Sectional detail of an inswing casement PVC window

PVC is easily and accurately extruded, but its strength does not compare to that of aluminum. PVC's softness and low melting point allow the extruding of multiple hollows within a single frame section – something far more expensive in aluminum, which increases the much needed strength of the PVC frame.

PVC is highly reactive to temperature changes and is available predominantly in white. These factors should be considered when selecting product for a project.

Figure 12. Sectional detail of a fiberglass pultruded window

Sectional details and thermal conductivity of fiberglass windows are similar to extruded PVC, however the fiberglass is much stronger than the PVC.

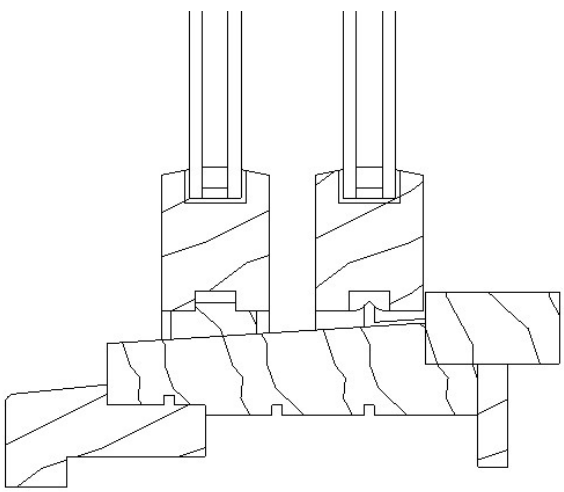


Figure 13. Sectional detail of a wood double hung window sill

The wood profiles (there are at least 6 unique shapes in this detail) are milled from larger pieces of lumber, making the fundamental manufacturing process quite different from the extruding processes of aluminum and PVC. Because of this, the sections tend to be solid, rather than being comprised of a series of extruded walls.

Wood is reactive to changes in humidity. It swells in the presence of moisture and usually shrinks back when moisture reduces. Protecting the wood against weather and moisture is a necessity, and ongoing maintenance is critical.

Figure 14. Aluminum clad wood window. Wood (at right) is exposed to the interior while protected on the exterior by aluminum cladding. This design, sometimes using a PVC cladding in lieu of aluminum, is commonly used in residential construction.

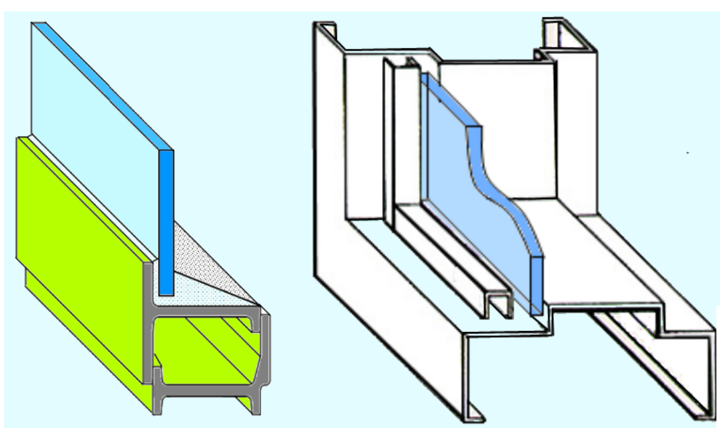


Figure 15. Rolled section steel (left) and hollow metal steel (right) still have a place in current construction and are both available. The rolled section steel provides some of the narrowest sightlines available. They are favored in historic renovations as well as interior partition applications. Hollow metal sections are frequently used in fire-rated partitions along with hollow metal doors.

22. Movement of Materials

Thermal Conductivity & Thermal Expansion		Thermal conductivity (U-factor)	Coefficient of thermal expansion (linear)
US Units:		**BTU/hr/ft²/°F**	**x10-6 in/in/°F**
SI Units:		**W/hr/m²/°K**	**x10-6 m/m/°K**
Conversion US to SI:		**1 US = 5.678 SI**	**1 US = 1.796 SI**
Conversion SI to US:		**1 SI = 0.176 US**	**1 SI = .557 US**
Window materials			
Aluminum (non thermal)	US	1.32	12.3
	SI	7.5	22.2
Aluminum (w/ thermal break)	US	.85	12.3
	SI	4.8	22.2
Glass Single pane	US	1.1	5
	SI	6.24	9
Glass, double 1/4" airspace	US	.59	5
	SI	3.36	9
Glass, double 1/2" airspace	US	.49	5
	SI	2.78	9
Glass, triple 1/2"airspaces	US	.31	5
	SI	1.76	9
PVC 2 hollows	US	.39	28
	SI	2.2	50.4

PVC 2 hollows	US	.35	28
	SI	2.0	50.4
Wood, softwood 2” (50mm) thick	US	.42	19.5 Length 15.04 Thickness
	SI	2.4	Length 3.5 Thickness 27
Wood, hardwood 2” (50mm) thick	US	.35	2.7 Length 3 Thickness
	SI	2.0	Length 4.9 Thickness 5.4
Fiberglass pultrusion 3” (75 mm) thick, 1 hollow	US	.27	4.1
	SI	1.53	7.4
Other construction materials			
Brick, common (4”)	US	1.25	3.1
	SI	7.1	5.5
Brick, face (4”)	US	2.27	3.1
	SI	12.9	5.5
Concrete (8”) 80 lb/ft3	US	.25	8
	SI	1.4	14.5
Concrete (8”) 140 lb/ft3	US	.67	8
	SI	3.8	14.5

Figure 16. Thermal Conductivity & Thermal Expansion

Movement of materials in buildings must always be considered in the design process. Where windows are concerned, this is especially true. Windows face the elements every day and must remain functional even when severe delta-T's (difference in temperature from exterior to interior) are present and fluctuating.

23. Movement at Glazing Sealants

Glass remains relatively stable across design temperatures, but very little else does. Therefore there will usually be shearing actions between glass and the surrounding sash or frame. These glazing sealant joints must be carefully designed and many manufacturers fail miserably on this point, especially in the PVC and wood products.

24. Movement at Frame and Sash Joints

Where frame joints come together, movements are an ever-present issue. Some PVC windows solve this problem by "welding" the corners which are mitered, or cut on a 45 degree diagonal. Others use sealants which will hopefully have the movement capability and longevity to do the job over time.

25. Movement Between Frame and Sash

In order for operable windows to work properly, a consistent margin must be maintained between frame and sash. This is difficult to maintain when the opening around the window changes shape over time. The most severe instances of windows being thrown out of adjustment due to building movement is at balcony swing and sliding doors.

26. Movement at Window Perimeter

Windows also need to have relative movement tolerated at their perimeter. Too often architects obsess about tight sightlines and they design caulk joints that are far too small for long term performance. The best sealants can only tolerate movements of plus or minus 50% of their own unrestricted thickness in any direction. If the original joint is zero, movement capability is also zero and failure will soon follow.

If using a sealant that has plus or minus 50% movement capability, study and tabulate all anticipated movements at a caulk joint location and double that total. That should be your minimum caulk joint size. Relative substrate movements at caulk joints can be in the direction of tension, compression or shear.

Movement sources could be thermal expansion, moisture expansion, live load deflection, dead load deflection, long term creep, column foreshortening and even wind loading.

27. Glass

It is indicative of the breadth and complexity of this topic that so many words have been written so far in this introduction to windows without addressing the fundamental of all windows: glass.

Glass is an amorphous (non-crystalline) solid material. It is brittle and optically transparent. The most familiar type of glass, used for centuries in windows and drinking vessels, is soda-lime glass, made of about 75% silica (SiO2) plus Na2O, CaO, and several minor additives.

Glass thicknesses for window usage include 1/8”(3.2 mm), 3/16”(4.7 mm), ¼”(5.7 mm), and in some instances, 5/16” (8mm).

For new windows in buildings in the US, single thickness (*monolithic*) glass is rarely used. Even warm climates benefit from the improved U-factor of insulating glass, to reduce cooling loads.

In order to improve thermal performance, two or more lites of glass are sandwiched together around a spacer at the 4 edges. The spacer may be metal or thermoplastic. There is air, not a vacuum, in the space between the glass. The spacer carries a dessicant that removes moisture from the airspace between the glass that may be residual from manufacture. This assembly is called insulated glass.

Thermal performance of insulated glass can be improved in a number of ways. These are commonly available strategies:

- Use a thermoplastic spacer around the edge to improve edge of glass temperatures
- Use tinted glass on the exterior lite to reduce cooling loads
- Use reflective coatings to reduce cooling loads
- Use Low-E coatings to reflect infrared light (heat) to the exterior in summer and to the interior in winter
- Fill the space between the glass lites with argon or krypton gas which has a better U-factor than air

- Add additional glazing layers, such as an additional lite of glass or a suspended film in the airspace.

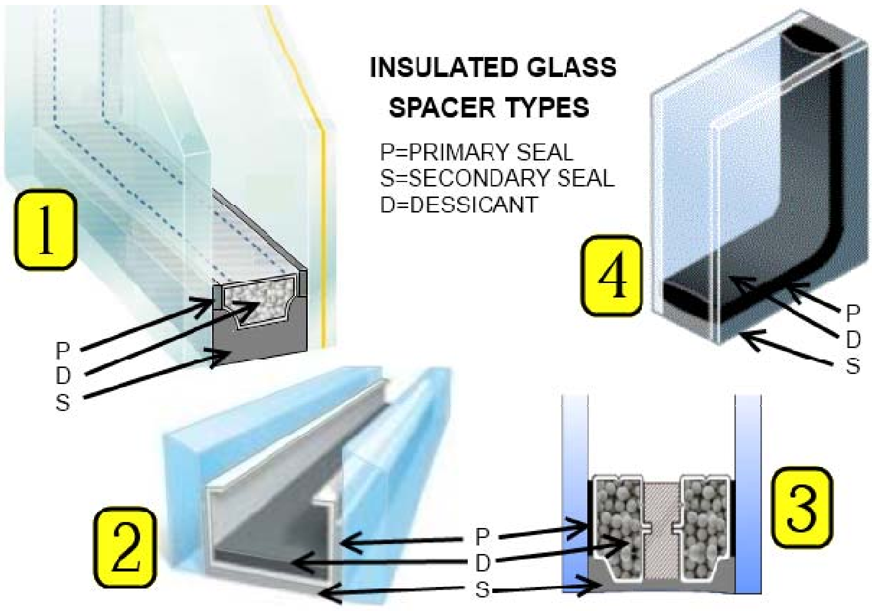


Figure 17. Insulated glass spacer types

Insulated glass edge conditions often have a (P) Primary seal to repel moisture, (S) Secondary seal to hold the assembly together, and (D) Dessicant to remove moisture from the airpace.

In the image above,

1) Metal spacer, tubular in section, containing dessicant inside the tube. Perforations in the tube facing the airspace allow the dessicant to adsorb (not absorb) the water molecules.

2) Channel shaped spacer with open area facing the airspace. The dessicant is contained in a strip that resembles a dark plastic tape.

3) Warm edge thermal break spacer consisting of two separate dessicant-filled tubes separated by a thermal break.

4) Warm edge thermoplastic spacer. The entire edge condition is a thermoplastic. It can be in two parts, as is shown here, or in a single component.

28. Resources

More on U Factor:

ASTM C1363 - 11 Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

http://www.efficientwindows.org/ufactor.cfm

http://www.efficientwindows.org/glazing_.cfm?id=1

http://en.wikipedia.org/wiki/R-value_(insulation)#U-factor

http://www.glassguides.com/index.php/archives/2578

http://www.combustionresearch.com/Infra-Spec/infra-spec/uvalue.html

http://archtoolbox.com/materials-systems/thermal-moisture-protection/24-rvalues.html

http://www.wausauwindow.com/education/ufactors/ufactor.pdf

http://windows.lbl.gov/software/therm/therm.html (THERM thermal modeling software)

More on the electromagnetic spectrum**:**

http://chicagowindowexpert.com/2009/06/30/the-lowdown-on-low-e-glass/

Online converter between US and SI units for U Value:

http://online.unitconverterpro.com/conversion-tables/convert-alpha/heat-transfer-coefficient.html

More on thermal energy:

http://tes.asu.edu/MARS_SURVEYOR/MGSTES/TIR_description.html

http://en.wikipedia.org/wiki/Infrared

More from www.BuildingGreen.com:

http://www.buildinggreen.com/auth/article.cfm/2011/7/1/How-R-Value-Is-Calculated/

More on coefficient of expansion

http://en.wikipedia.org/wiki/Thermal_expansion

http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html

http://www.gobrick.com/portals/25/docs/technical%20notes/tn18.pdf

http://matdl.org/failurecases/Masonry

More on window safety

http://chicagowindowexpert.com/2012/02/01/deadly-falls-from-windows-preventable/

http://chicagowindowexpert.com/2012/04/04/glass-breakage-and-pre-existing-damage/

http://chicagowindowexpert.com/2012/10/31/breaking-glass-shower-doors-enclosures/