402 BUILDING ENVELOPE

Overview

DESIGN CONSIDERATIONS

The building envelope is important to building energy efficiency. When it is cold outside, heat loss and air leakage through the building envelope add to the heating load. On hot days, solar gains through windows contribute to the air-conditioning load. The building envelope requirements are intended to reduce heat gains and losses through the building envelope while encouraging daylighting.

Finding the right amount and type of fenestration and optimizing levels of insulation is a complicated process that depends on climate, schedules of operation, internal gains, and other factors. The code sets minimum levels of thermal performance for all components of the building envelope and limits fenestration solar gain. While these limits assure a minimum level of performance, they do not necessarily result in an optimum design. The designer is encouraged to use the 90.1 Code as a starting point; minimum compliance may not be the optimum solution.

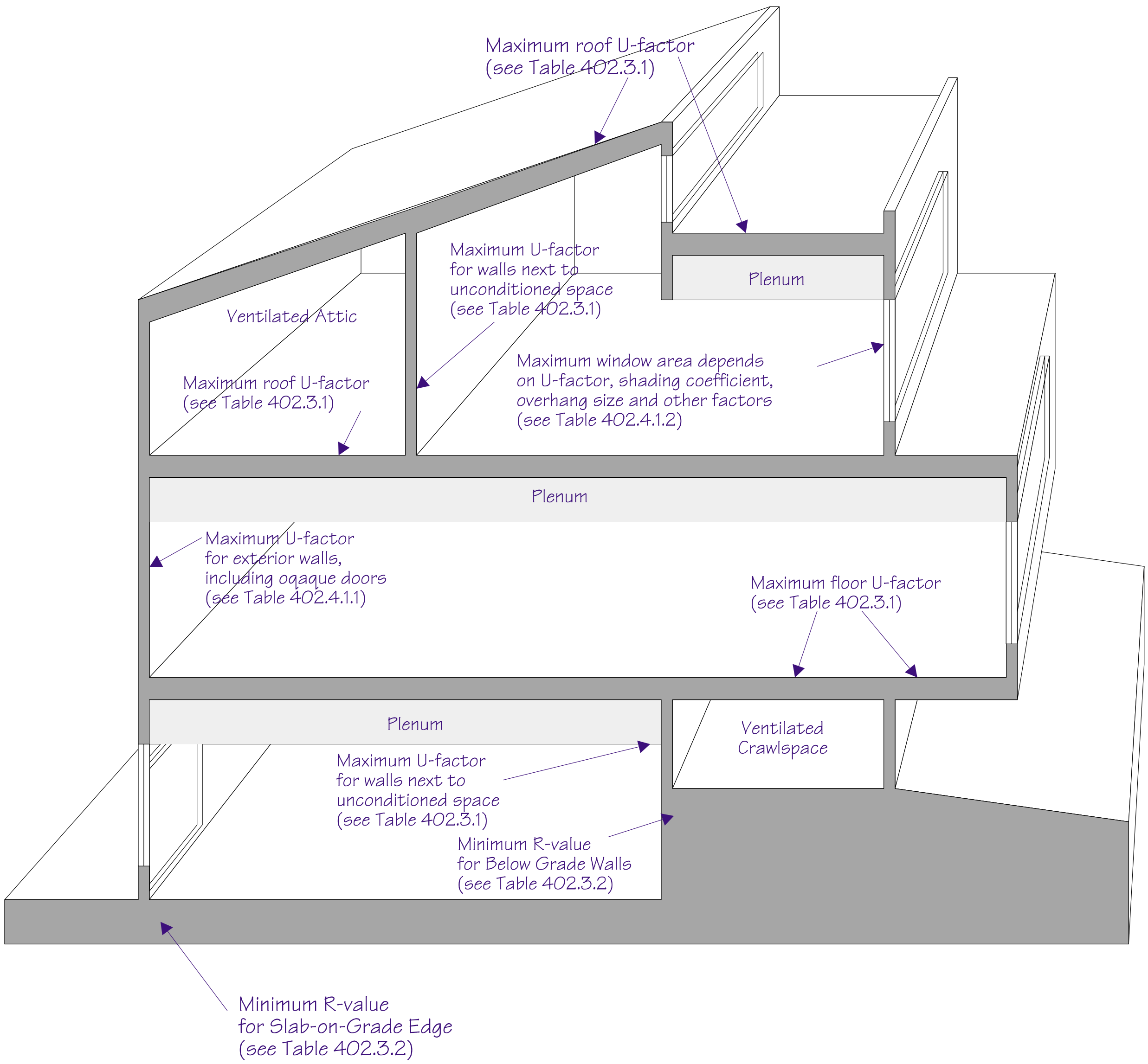
SCOPE

The building envelope requirements apply only to buildings or portions of buildings that are heated and/or cooled for human comfort. For example, the 90.1 Code does not apply to refrigerated warehouses that are cooled for purposes other than human comfort. A building is considered heated for human comfort if a heating system is installed that is capable of maintaining a temperature of 50°F or more at design conditions or if the output of the heating system exceeds 10 Btu/h-ft^2.

Since the requirements do not apply to buildings that are neither heated nor cooled, shell buildings present a special problem. Shell buildings are built before it is known how they will be used or even if they will be heated or cooled. While building officials have discretion in dealing with shell buildings, a common approach is to postpone compliance until a permit application is filed for a heating and/or cooling system. At that time, the permit applicant documents compliance with the building envelope requirements as well as the HVAC requirements. It may be necessary to upgrade the building envelope for those areas that are heated or cooled, e.g. install additional insulation. In colder climates, however, some building officials may want to assume that heating will always be installed for freeze protection and therefore require a minimum level of insulation during the initial construction of shell buildings. This most often applies to ceiling insulation based on the rationale that it is more costly to add insulation after the roof is finished.

Even with shell buildings, the designer should consider the requirements of the 90.1 Code to avoid problems at the time of future tenant improvements. It would be good professional practice to assume that the entire building will be heated and/or cooled and to establish a plan for upgrading the building envelope in the event that it is. While it may be easy to insulate the inside of tilt-up concrete walls at a later time, windows should be carefully sized and selected (U-factor and shading coefficient) to reasonably achieve compliance.

Figure 402A Graphic Summary of Envelope Requirements



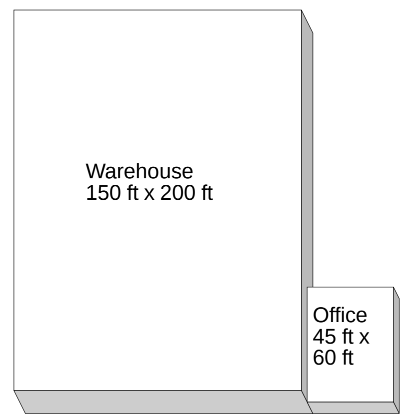
Example 402A Refrigerated Warehouse

Q A refrigerated warehouse in a food processing facility in Denver, Colorado must be maintained at a temperature of 45°F. Do the building envelope standards apply to this facility?

A No. The envelope requirements apply only to *buildings that provide shelter for human occupancy and use energy primarily to provide human comfort*. The refrigeration used in this warehouse is considered a process use and the code does not apply. This does not mean that the envelope of the refrigerated warehouse should not be insulated – quite the contrary. Since the temperature difference between the inside and the outside of the building is much greater in the summer, more insulation than required by the code may be justified.

Example 402B Warehouse with Attached Office

Q A 30,000 ft^2 warehouse in Montgomery, Alabama will be used to store household appliances until they are distributed to retail outlets. A 2,700 ft^2 office is attached to the warehouse. The heating system for the warehouse has an output of 60,000 Btu/h and is designed to keep the temperature at 55°F. The warehouse will not be air conditioned. A packaged single zone heating and cooling system will serve the office area. How do the building envelope standards apply to this facility?



A The envelope requirements clearly apply to the office portion of the building – the portion that is both heated and cooled. Because the heating system in the warehouse area is capable of maintaining a space dry-bulb temperature of 50°F or more and has an output capacity greater than 10 Btu/h, then the envelope requirements also apply to the warehouse. If the heating system was only capable of maintaining 40°F and had an output capacity less than or equal to 10 Btu/h (i.e., for freeze protection), then the principal purpose of the heating system that serves the warehouse would be to prevent damage to the goods, not to provide human comfort. The wall that separates the office from the warehouse would then need to be insulated according to the requirements for walls adjacent to unconditioned space.

CHAPTER ORGANIZATION

The Envelope Summary form, annotated in Figure 402B, provides an organizing element for this chapter. The form itemizes each requirement and provides a place to reference on the drawings where compliance with each requirement is documented. This form is filled out by the permit applicant and is then used by the plan's examiner and the field inspector to verify energy code compliance. The text of this chapter follows the order of the Summary form. As each requirement is addressed, an icon of the Summary form appears in the margin highlighting the appropriate 90.1 Code reference on the form.

Form
402.3.1

The Compliance and Enforcement section of this chapter describes how to fill out this form in more detail, and introduces the Exterior Wall and Roof/Floor worksheets. These additional worksheets are provided for the applicant to calculate the area-weighted averages for fenestration, opaque exterior walls (including doors), walls adjacent to unconditioned space, roofs (including skylights) and floors over unconditioned space. It will be helpful for the reader to refer to these forms as each requirement is addressed below. Blank copies of all forms are found in Appendix D.

Figure 402B Annotated Envelope Summary Form

Building department may require applicant to certify here that plans comply with the code

Applicant completes this basic information

Section numbers and requirements follow the order of the 90.1 Code

Circle "yes" if the requirement has been met or if "no", circle "yes" to the exception that applies

Enter appropriate values in blank spaces

Write page number(s) or location of drawings where information is identified

Check box if compliance documentation has been reviewed and is acceptable

Note any special features that should be checked in the field

Verify in the field during suggested time of inspection

Check box when relevant inspection has been completed

ENVELOPE SUMMARY

October 1994

Project Information	Project Address:	Date:
	Applicant Name:	For Building Department Use
	Applicant Address:	
	Applicant Phone:	
Project Description:		

Applicant to Complete				Building Department Use Only		
Code Section Number	Requirements	Enter value or circle "yes" or "no"	List reference in plans or enter "n.a."	Check if documentation is acceptable. Provide notes to inspector, when necessary	Inspection type	Check when inspection performed
402.2.1	Air Leakage			❑	Framing	❑
402.2.2	Ext. Env. Joints/Penetrations			❑	Fo. /Fr. /In	❑
402.2.3	Moisture Migration			❑	Insulation	❑
402.3.1	Roofs (incl. skylights)					
	Proposed U-factor (w/sky.)			❑	Insulation	❑
exception:	Skylights					
	Proposed U-factor			❑	Framing	❑
	Proposed area			❑		
	Auto daylight controls	yes / no		❑	Electrical	❑
	Skylight curb U-factor			❑	Framing	❑
	Infiltration c/swft?			❑	Framing	❑
402.3.1	Floors over Uncond. Sp.					
	Proposed U-factor			❑	Insulation	❑
402.3.1	Walls Adj. to Uncond. Sp.					
	(includ. doors in this wall)					
	Prop. U-factor (w/door)			❑	Insulation	❑
402.3.2	Below-Grade Walls					
	Proposed R-factor			❑	Foundation	❑
402.3.2	Slabs-on-Grade (unheated)					
	Proposed R-value			❑	Foundation	❑
	Horizontal/vertical			❑	Foundation	❑
	Insulation width			❑	Foundation	❑
402.3.2	Slabs-on-Grade (heated)					
	Proposed R-value			❑	Foundation	❑
	Horizontal/vertical			❑	Foundation	❑
	Insulation width			❑	Foundation	❑
402.4	**Exterior Walls**					
	Gross wall area			❑		
	Fenestration area			❑		
	Window to wall ratio			❑		
	Internal load density			❑		
402.4.1.1	**Opaque Wall Data**					
	Prop. U-factor (w/door)			❑	Insulation	❑
	Heat capacity			❑	Framing	❑
	Insulation position			❑	Insulation	❑
402.4.1.2	**Fenestration Data**					
	Proposed U-factor			❑	Framing	❑
	Shading coefficient			❑	Framing	❑
	Projection factor					
	Perimeter daylighting	yes / no		❑	Electrical	❑
	Visible light transmittance			❑	Framing	❑
Worksheets	Roof/Floor	yes / no		❑		
	Exterior Wall	yes / no		❑		
Other	ENVSTD output	yes / no		❑		

Applicant provides information requested in these two columns

Plans Examiner fills out this column

Field Inspector verifies proper installation of system or equipment at inspection time indicated

Requirements

CALCULATIONS AND SUPPORTING INFORMATION (402.1)

This section of the 90.1 Code references acceptable methods and procedures for calculating the U-factor of building envelope components. Since this section of the code does not contain design requirements per se, it is not included on the Summary form.

Thermal Performance of Envelope Components (402.1.1 and 402.1.2)

The 90.1 code requires that the performance of envelope components be calculated in a certain way. Based on these procedures, the Reference section of this chapter contains precalculated U-factors for many common construction assemblies. These data may be used in all code compliance calculations. The Reference section also explains how to calculate the U-factor of building envelope assemblies that are not included in the precalculated tables.

Fenestration performance includes not only the U-factor or thermal transmittance, but also information about its light transmitting capabilities. Visible light transmission (VLT) is a measure of the amount of visible light that passes through a window or skylight. Shading coefficient (SC) is a measure of all solar radiation that contributes to cooling loads (or offsets heating loads) in buildings. Both VLT and SC are affected by the composition of the glass, coatings that may be applied to the surface(s) of glass, and internal shading devices such as draperies or blinds. Solar heat gain and daylighting are also affected by overhangs and other external shading devices. The whole subject of fenestration performance is presented in the Reference section of this chapter, including default values for U-factor, SC, and VLT.

Gross Area of Envelope Components (402.1.3)

Some of the envelope requirements are based on surface area. For instance glazing area is limited to a percentage of the gross wall area and exempt skylight area is limited to a percentage of the gross roof area. In addition, when more than one type of construction exists, the surface area is needed in order to perform an area-weighted average calculation. The rules for measuring surface areas are summarized in Figure 402C and in the following bullets.

1. **Gross Roof Area.** Roof surfaces are all those with a tilt of less than 60 degrees from the horizontal. The gross area of the roof includes all roof surfaces exposed to outside air or unconditioned space. Roof surfaces are measured from the exterior faces of exterior walls and the centerline of walls separating buildings and should include all roof or ceiling components through which heat can flow, with the exception of *service openings*. Service openings include roof hatches, duct penetrations and or pipe penetrations. Skylights are not considered service openings.

2. **Gross Floor Area.** The gross floor area over outside or unconditioned spaces is measured from the exterior face of exterior walls and the centerline of walls separating buildings. The floor area shall include all floor components through which heat may flow. Note that this definition is different from gross lighted area (see Chapter 401), which is measured to the inside surface of exterior walls.

3. **Gross Wall Area.** The gross wall area is measured on the exterior and includes between-floor spandrels, peripheral edges of flooring, window areas (including sash), and doors. Mechanical openings such as vents, grilles, and pipes may be excluded.

4. **Fenestration Area.** Fenestration area is the entire glazing area including the frame. For premanufactured windows and skylights, the area is generally the same as the rough frame opening. Windows located in walls adjacent to unconditioned space should not be included with the fenestration area. They should be included in the area-weighted average U-factor of the wall adjacent to unconditioned space.

Figure 402C How to Measure Surface Areas

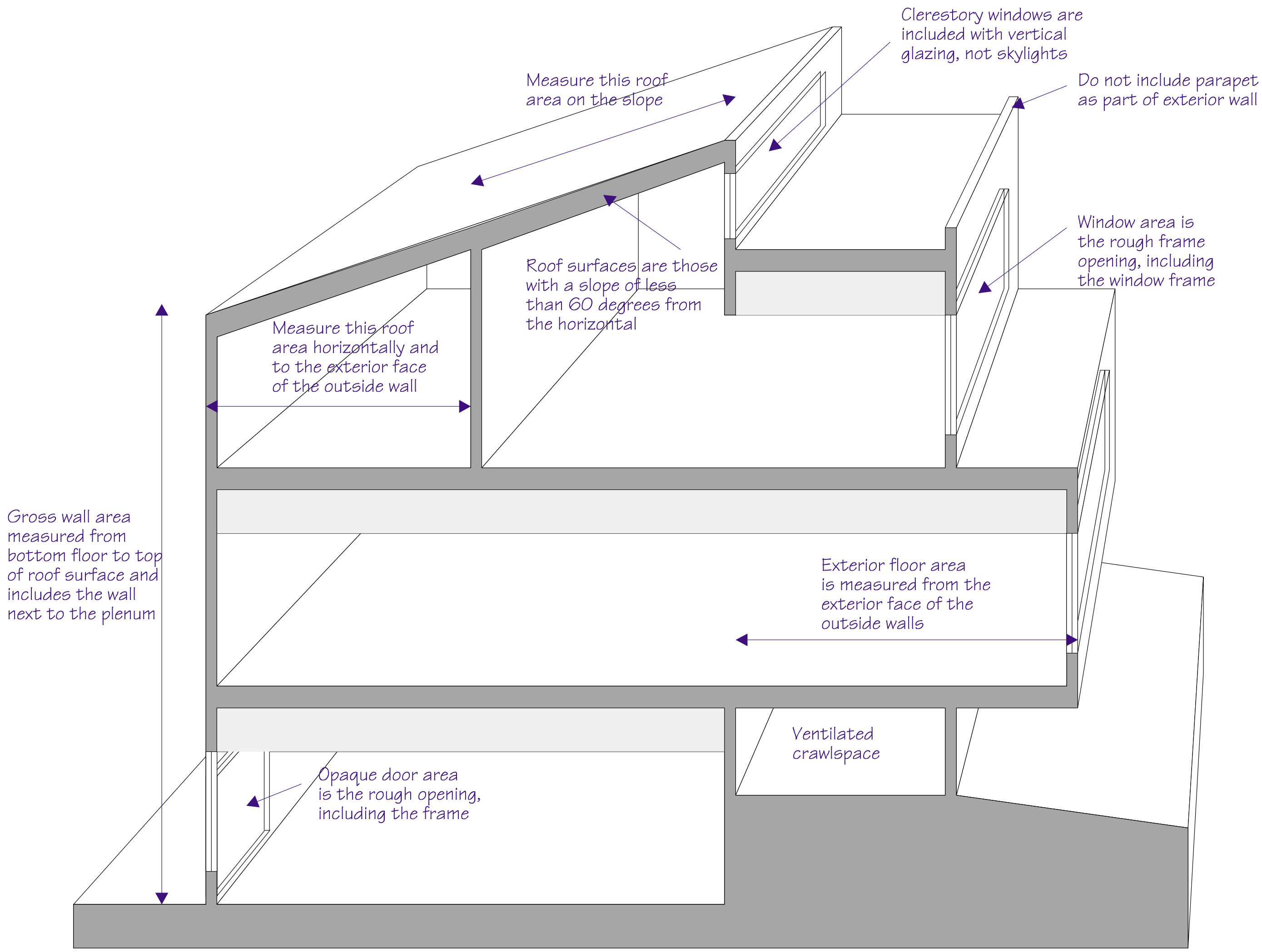


Table 402A Air Leakage Requirements for Fenestration and Doors (Table 402.2.1)

Product	Type:	Requirement	Reference Standard
Aluminum	Operable	0.37 cfm/lin ft	ANSI/AAMA 101-88, Aluminum Prime Windows and Sliding Glass Doors, American Architectural Manufacturers Association, Des Plaines, IL 60018.
	Jalousie	1.50 cfm/ft^2	
	Fixed	0.15 cfm/ft^2	
PVC	Prime Windows	0.06 cfm/ft^2	ASTM D4099-89, Specifications for Poly (Vinyl Chloride) (PVC) Prime Windows, ASTM, Philadelphia, PA 19103, 1989.
Wood	Residential	0.37 cfm/ft^2	ANSI/NWWDA I.S.2-93, Wood Window Units, National Wood Window and Door Association (formerly the National Woodwork Manufacturers Association), Des Plaines, IL 60018, 1993.
	Light Commercial	0.25 cfm/ft^2	
	Heavy Commercial	0.15 cfm/ft^2	
Sliding Glass Doors	Aluminum	0.37 cfm/ft^2	ANSI/AAMA 101-88, Aluminum Prime Windows and Sliding Glass Doors, American Architectural Manufacturers Association, Des Plaines, IL 60018.
	PVC	0.37 cfm/lin ft	ASTM D4099-89, Specifications for Poly (Vinyl Chloride) (PVC) Prime Windows, ASTM, Philadelphia, PA 19103, 1989.
Doors–Wood	Residential	0.34 cfm/ft^2	ANSI/NWWDA I.S.3-87, Wood Sliding Patio Doors, National Wood Window and Door Association (formerly the National Woodwork Manufacturers Association), Des Plaines, IL 60018, 1987.
	Light Commercial	0.25 cfm/ft^2	
	Heavy Commercial	0.10 cfm/ft^2	
Commercial	Entrance Doors	1.25 cfm/ft^2	ASTM E283-89, Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors, ASTM, Philadelphia, PA 19103, 1989.
Residential	Swinging Doors	0.50 cfm/ft^2	ASTM E283-89, Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors, ASTM, Philadelphia, PA 19103, 1989.
Wall Sections	Aluminum	0.06 cfm/ft^2	ANSI/AAMA 101-88, Aluminum Prime Windows and Sliding Glass Doors, American Architectural Manufacturers Association, Des Plaines, IL 60018.

AIR LEAKAGE AND MOISTURE MIGRATION

Form
402.2.1

Air Leakage through Fenestration and Doors

Manufactured doors and windows must meet requirements for air leakage. These requirements do not apply to glass curtain wall systems. The requirements are listed in Table 402.2.1 of the code and repeated in this manual as Table 402**A**. These are industry standards that most manufacturers comply with. Manufacturers typically perform the necessary testing to verify compliance with the requirements and provide documentation to customers. To assure that complying products are installed, designers should include a notes on the plans or language in the construction specifications. Window and door schedules are a good place to reference the standards and test procedures from Table 402A.

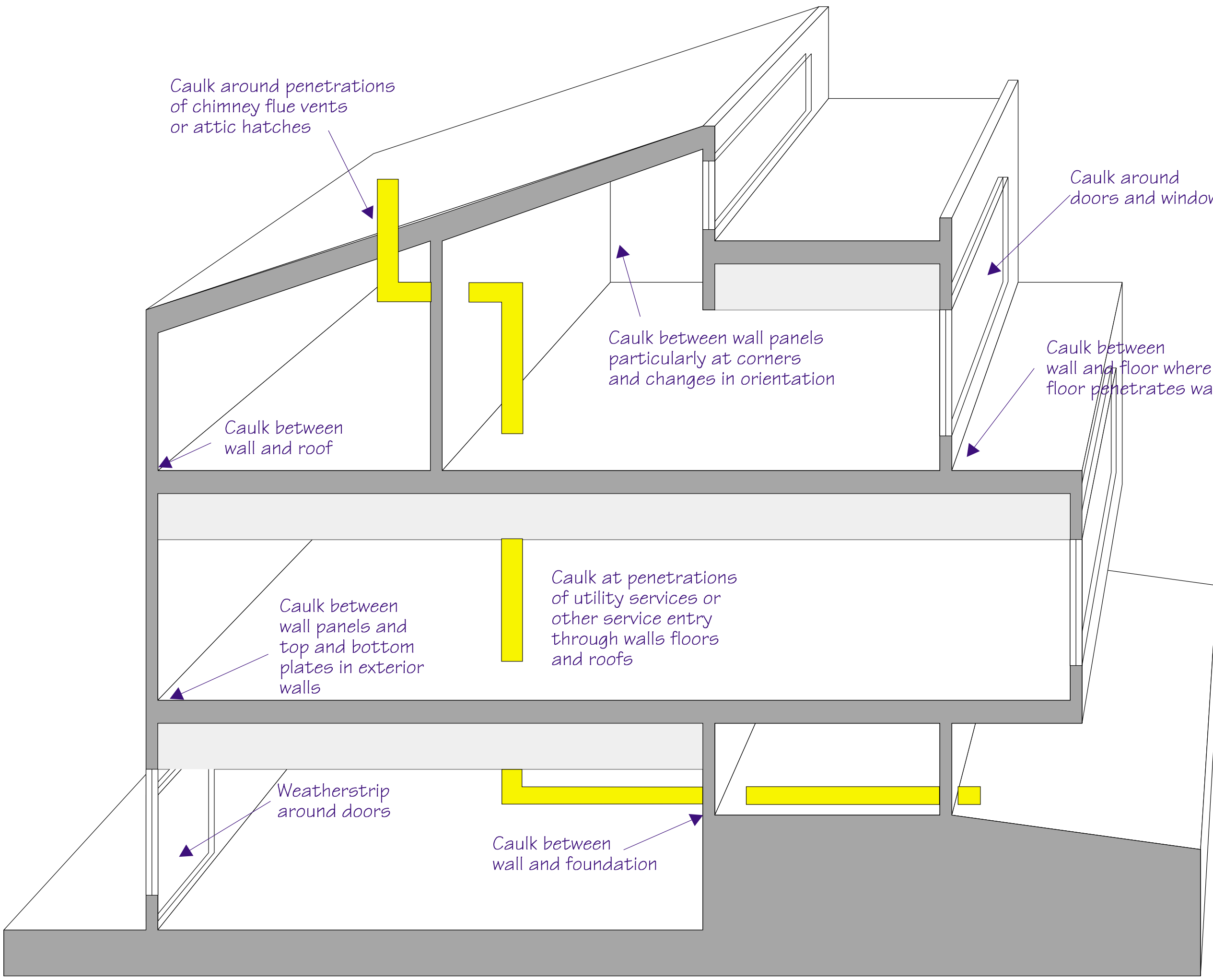
While not required by the code, designers should consider using vestibules or revolving doors on all primary entrances and exits of multistory buildings in order to reduce infiltration. Stack effects in multistory buildings can induce considerable infiltration unless precautions are taken.

Form
402.2.2

Exterior Envelope Joints and Penetrations

Exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weatherstripped, or otherwise sealed. See Figure 402D.

Figure 402D Caulking and Weatherstripping Requirements



Form
402.2.3

Moisture Migration

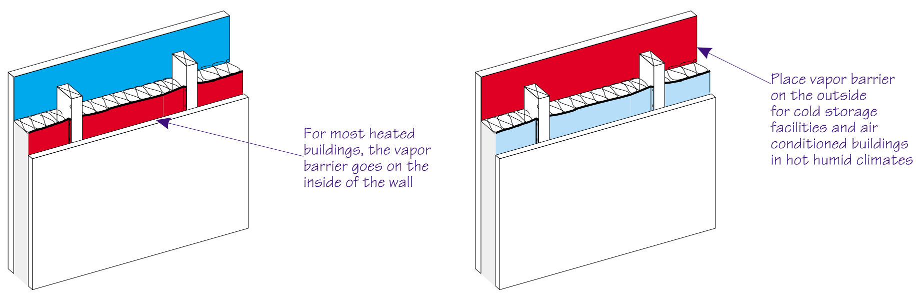
Vapor barriers may need to be installed to prevent moisture from condensing within walls, roofs, or floors. Water condensation damages the building structure and can seriously degrade the performance of building insulation. Most insulation products are available with a foil-coated or asphalt-coated paper backing that serves as a vapor barrier.

The vapor barrier should always be placed on the warm, moist side of the construction assembly. The designer should evaluate the thermal and moisture conditions when condensation might occur and make sure that vapor barriers are correctly installed to prevent condensation. Usually the risk of condensation exists when it is cold outside and warm and moist inside. For this condition, the vapor barrier is installed on the inside (see Figure 402E).

In situations where there is no ventilated air space above the insulation and no solid surface such as gypsum board immediately below the insulation, it is important that all seams be sealed with tape (stapling alone is not adequate). This applies to vinyl faced insulation installed inside warehouse roofs.

It is also important to provide adequate ventilation of spaces where moisture can build up. Most building codes require that attics and crawlspaces be ventilated, and some require a minimum 1-inch clear airspace above the insulation. Even the wall cavity may need to be ventilated in some climates.

Figure 402E Typical Vapor Barrier Installation



THERMAL PERFORMANCE CRITERIA (402.3)

Tables 402.3.1(A) through 402.4.1.2 in the code specify the thermal performance criteria for roofs, walls, floors, fenestration, and below-grade surfaces. The 90.1 Code includes criteria for 234 cities in the United States and territories (see Table 402B). Each enforcing jurisdiction will include as part of its code the tables that are appropriate for its area. When an enforcing jurisdiction includes more than one city from the table, the jurisdiction may also provide a map or other information showing how the different sets of criteria apply within the jurisdiction.

If your city is not included in Table 402B, check with your building department for advice on which criteria to use; otherwise, choose a city that is nearby and has similar climate conditions. Climate data for these 234 cities are provided in Appendix C of this manual and may be used to help choose an appropriate location.

Table 402B List of Cities with Thermal Performance Criteria

Adak, AK
Anchorage, AK
Annette Island, AK
Bethel, AK
Big Delta, AK
Fairbanks, AK
Gulkana, AK
Juneau, AK
King Salmon, AK
Kodiak, AK
McGrath, AK
Nome, AK
Summit, AK
Yakutat, AK

Birmingham, AL
Mobile, AL
Montgomery, AL

Fort Smith, AR
Little Rock, AR
Phoenix, AZ
Prescott, AZ
Tucson, AZ
Winslow, AZ
Yuma, AZ

Arcata, CA
Bakersfield, CA
China Lake, CA
Daggett, CA
El Toro, CA
Fresno, CA
Long Beach, CA
Los Angeles, CA
Mount Shasta, CA
Oakland, CA
Point Mugu, CA
Red Bluff, CA
Sacramento, CA
San Diego, CA
San Francisco, CA
Santa Maria, CA
Sunnyvale, CA

Colorado Springs, CO
Denver, CO
Eagle, CO
Grand Junction, CO
Pueblo, CO

Hartford, CT

Guantanamo Bay, CU

Washington, DC

Wilmington, DE

Apalachicola, FL
Daytona Beach, FL
Jacksonville, FL
Miami, FL
Orlando, FL
Tallahassee, FL
Tampa, FL
West Palm Beach, FL

Atlanta, GA
Augusta, GA
Macon, GA
Savannah, GA

Barbers Point, HI
Hilo, HI
Honolulu, HI
Lihue, HI

Burlington, IA
Des Moines, IA
Mason City, IA
Sioux City, IA

Boise, ID
Lewiston, ID
Pocatello, ID

Chicago, IL
Moline, IL
Springfield, IL

Evansville, IN
Fort Wayne, IN
Indianapolis, IN
South Bend, IN

Dodge City, KS
Goodland, KS
Topeka, KS

Covington, KY
Lexington, KY
Louisville, KY

Baton Rouge, LA
Lake Charles, LA
New Orleans, LA
Shreveport, LA

Boston, MA

Baltimore, MD
Patuxent, MD

Bangor, ME
Caribou, ME
Portland, ME

Alpena, MI
Detroit, MI
Flint, MI
Grand Rapids MI
Sault Sainte Marie, MI
Traverse City, MI
Duluth, MN

International Falls, MN
Minneapolis, MN
Rochester, MN

Columbia, MO
Saint Louis, MO
Springfield, MO

Jackson, MS
Meridian, MS

Billings, MT
Cutbank, MT
Dillon, MT
Glasgow, MT
Great Falls, MT
Helena, MT
Lewistown, MT
Miles City, MT
Missoula, MT

Asheville, NC
Cape Hatteras, NC
Charlotte, NC
Cherry Point, NC
Greensboro, NC
Raleigh, NC

Bismarck, ND
Fargo, ND

Table 402B List of Cities With Thermal Performance Criteria (continued)

Minot, ND	Akron, OH	Huron, SD	Bryce Canyon, UT
	Columbus, OH	Pierre, SD	Cedar City, UT
Grand Island, NE	Dayton, OH	Rapid City, SD	Salt Lake City, UT
North Platte, NE	Toledo, OH	Sioux Falls, SD	
Omaha, NE	Youngstown, OH		Norfolk, VA
Scottsbluff, NE		Chattanooga, TN	Richmond, VA
	Oklahoma City, OK	Knoxville, TN	Roanoke, VA
Concord, NH	Tulsa, OK	Memphis, TN	
		Nashville, TN	Burlington, VT
Lakehurst, NJ	Astoria, OR		
Newark, NJ	Medford, OR	Abilene, TX	Olympia, WA
	North Bend, OR	Amarillo, TX	Seattle/Tacoma, WA
Albuquerque, NM	Portland, OR	Austin, TX	Spokane, WA
Clayton, NM	Redmond, OR	Brownsville, TX	Whidbey Island, WA
Roswell, NM	Salem, OR	Corpus Christi, TX	Yakima, WA
Truth/Consequences, NM		Del Rio, TX	
Tucumcari, NM	Allentown, PA	El Paso, TX	Eau Claire, WI
	Avoca, PA	Forth Worth, TX	Green Bay, WI
Elko, NV	Erie, PA	Houston, TX	La Crosse, WI
Ely, NV	Harrisburg, PA	Kingsville, TX	Madison, WI
Las Vegas, NV	Philadelphia, PA	Laredo, TX	Milwaukee, WI
Lovelock, NV	Pittsburgh, PA	Lubbock, TX	
Reno, NV		Lufkin, TX	Charleston, WV
Tonopah, NV	Koror Island, PN	Midland, TX	
Winnemucca, NV	Kwajalein Island, PN	Port Arthur, TX	Casper, WY
Yucca Flats, NV	Wake Island, PN	San Angelo, TX	Cheyenne, WY
Albany, NY		San Antonio, TX	Rock Spring, WY
Binghamton, NY	San Juan, PR	Sherman, TX	Sheridan, WY
Buffalo, NY		Waco, TX	
Massena, NY	Providence, RI	Wichita Falls, TX	
New York (Central), NY			
New York (LAG), NY	Charleston, SC		
Rochester, NY	Columbia, SC		
Syracuse, NY	Greenville, SC		

Form
402.3.1

Roofs

The roof U-factor must be less than or equal to the value specified in the first row of Table 402.3.1(A). If your roof has more than one type of construction or if it has non-exempt skylights, then you will need to determine the U-factor for each type of construction and calculate the area-weighted average for comparison against the criteria. U-factor data for typical roof constructions are provided in the Reference section. These data may be used for compliance purposes. If your roof construction is not included in these data, then you may calculate the U-factor using the methods and procedures in the Reference section. Service openings and roof penetrations need not be considered when calculating the area-weighted average U-factor.

Figure 402F Requirement for Roofs

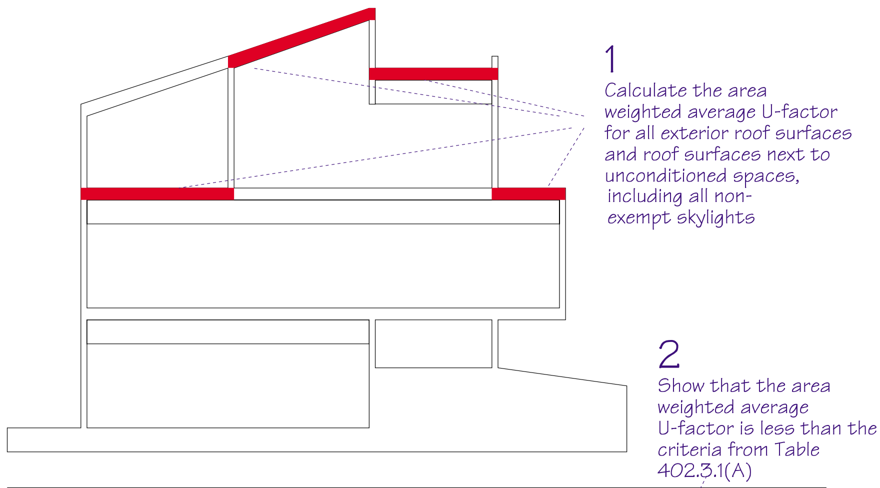


TABLE 402.3.1(A) MAX. THERMAL TRANSMITTANCE (U)	
Roof	0.061
Wall adjacent to unconditioned space	0.161
Floor over unconditioned space	0.069

Form
402.3.1
Skylight
Exception

Skylights may be excluded from the area-weighted average U-factor for the roof provided the skylights are used in conjunction with automatic daylighting controls and meet the criteria described below.

1. The opaque portion of the roof meets the thermal performance criteria (U-factor) in Table 402.3.1(A).
2. *Skylight area* is less than a specified percent of the gross roof area (as determined below). Maximum exempt skylight area is based on the visible light transmission (VLT).
3. *Daylighting controls* are installed that are capable of automatically dimming or reducing electric lighting in the daylighted zones.
4. The U-factor of the skylight is less than 0.45 Btu/(h-ft^2-°F) in locations with more than 8,000 heating degree days (base 65°F) and 0.70 Btu/(h-ft^2-°F) in other locations.
5. The U-factor of the skylight curb is less than 0.21 Btu/(h-ft^2-°F).
6. Air leakage through the skylight is less than 0.05 cfm/ft^2.

The skylight exemption was developed to result in about the same energy use as a building with no skylights. Adding skylights with automatic lighting controls reduces lighting energy but increases heating and cooling loads. As skylight area is increased, total energy use is reduced to a point (the optimum skylight area) and then increases as the thermal penalties become more significant than the lighting energy reductions. The maximum exempt area for skylights is not necessarily the optimal area. (See Figure 402G.)

Figure 402G Basis of Skylight Exemption

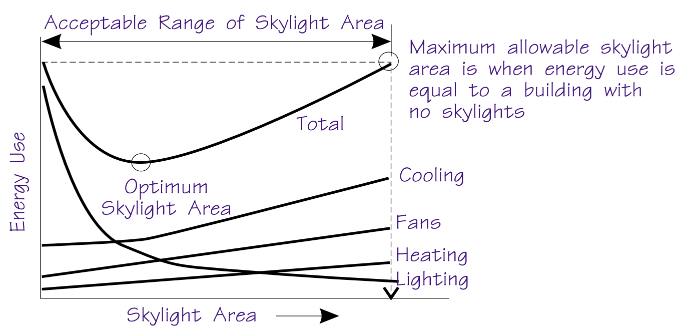
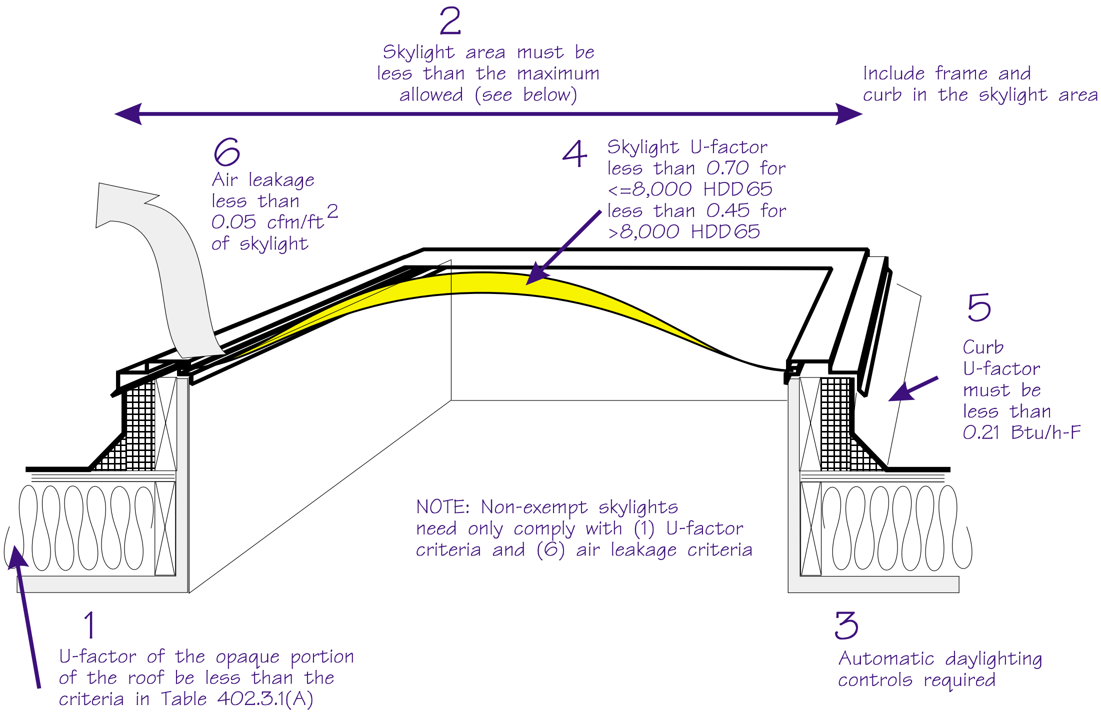


Figure 402H Summary of Requirements for Exempting Skylight Area



MAXIMUM AREA ALLOWED TO BE EXEMPT

2a Choose the appropriate design illumination

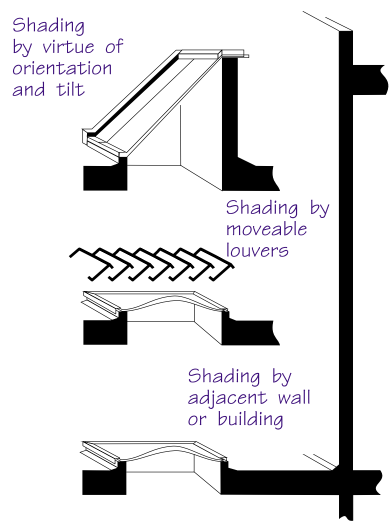
2b Select a range for the lighting power density

TABLE 402.3.1(B) MAX. EXEMPT SKYLIGHT AREA AS % OF ROOF AREA					
Visible Light Transmittance (VLT)	Light Level Ft. Candles	Range of Lighting Power Densities			
		<1.00	1.00-1.50	1.51-2.00	>2.00
0.75	30	2.3	3.4	4.5	5.6
	50	2.5	4.0	5.5	7.0
	70	2.8	4.6	6.4	8.2
0.50	30	3.6	5.1	6.6	8.1
	50	3.9	6.0	8.1	10.2
	70	4.2	6.9	9.6	12.3

2d Interpolate the results for the VLT of the skylights in the proposed building if it is between 0.50 and 0.75

2c Look up the allowed skylight area for a VLT of both 0.50 and 0.75

2e Increase the maximum exempt skylight area by 50% if skylights are shaded (see right)



Maximum Exempt Skylight Area

Table 402.3.1(B) gives the maximum skylight area that may be exempt. Values are given as a percent of the gross roof area and depend on the visible light transmission (VLT) of the skylight, the illumination level that is to be maintained in the building, and the lighting power density of the building. The maximum skylight area that may be exempt is this percentage of the gross roof area. Skylight area that exceeds the limit must be included in the area-weighted average U-factor of the roof.

Area limits are given for visible light transmissions of 0.75 and 0.50. The area limits may be interpolated for VLTs that fall within this range. The area limits for 0.75 shall be used for skylights that have a VLT of 0.75 or greater. The area limits for 0.50 shall be used for skylights that have a VLT of 0.50 or less. Extrapolation of the area limits for VLTs below 0.50 or greater than 0.75 is not permitted. The Reference section (Fenestration Performance Data) has information on the visible light transmission for various materials typically used in skylight construction. In general, most clear glazing materials such as clear glass or acrylic have a VLT greater than 0.75.

The maximum skylight area also depends on the lighting power density (LPD) in W/ft^2 and the design illumination level in footcandles. The lighting power density can be determined using the lighting power allowances in Section 401 or using the installed lighting power for the building if this is known. The design lighting level is the judgment of the designer, but should be in general agreement with the recommendations of the IESNA Lighting Handbook, Application Volume, 1987. The designer should choose the lighting level closest to the condition in the proposed building. Interpolation or extrapolation for lighting level is not permitted.

Neither the lighting level nor the LPD is known for speculative buildings or shell buildings. For shell buildings (occupancy not known), a lighting level of 30 footcandles and an LPD of 1.0 shall be used. For speculative buildings (occupancy is known but not the tenant), the LPD shall be taken from Table 401.3.2a of the 90.1 Code based on the known occupancy. The design lighting level shall be taken from IESNA Lighting Handbook based on the known occupancy.

The exempt skylight area may be increased by 50% if shading devices are installed that block more than 50% of the solar gain during the peak cooling design condition. Examples of shading devices that might qualify are external louvers, integral (between glass) shading devices or interior shading devices such as horizontal blinds, roller shades, or other similar devices. When this credit is taken, the designer must prepare calculations or data that show that solar gains are reduced by 50%. See Figure 402H for guidelines on devices that qualify.

Automatic Daylighting Controls

Automatic daylighting controls must be must be instmustinstalled for all luminaires located in the daylighted zone. The daylighted zone is defined as the area under each skylight whose horizontal dimension in each direction is equal to the skylight dimension in that direction plus either the floor to ceiling height, the dimension to an opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is least. See the topic "Daylighted Zone" in the Reference section for more information.

Any type of automatic daylighting control that is recognized in Table 401.3.3 of the 90.1 Code meets the requirement, including automatic on/off devices, multiple step systems and continuous dimming systems. Whatever type is used, it must be capable of reducing the lighting power of luminaires within the daylighted area to less than 50% of full power when adequate daylighting is available. While the type of control that is used will significantly affect the daylight savings, it has no impact on the maximum exempt skylight area.

Skylight U-factor

The U-factor of exempted skylights, including the frame, shall be no greater than 0.45 in climates with more than 8,000 HDD65 and no greater than 0.70 for other climates. Skylight U-factors shall be determined in the same manner as vertical fenestration. The Reference section of this chapter has default tables for skylight U-factors. The U-factor requirement must be satisfied, even if the skylight area is significantly less than the maximum allowed. However, some of the exempt skylights may have a higher U-factor as long as others have a lower U-factor such that the area-weighted average is less than the criteria.

Skylight Curb U-factor

The U-factor of the skylight curb must be less than or equal to 0.21. This generally requires that some type of insulation be installed: R-4 minimum with metal curbs or R-2 minimum for wood curbs (e.g. 2×6). Many manufacturers offer products with integral curbs. In these cases, manufacturer's specifications must be consulted.

Air Leakage

Air leakage through the skylight must be less than 0.05 cfm/ft^2 of skylight area.

Example 402C Exempted Skylight Area – Warehouse

Q The designer of a one-story, 50,000 ft^2 warehouse in Richmond, Virginia wants to use skylights for daylighting. The skylights have a visible light transmission (VLT) of 0.66. The electric lighting will be automatically controlled by photocells. The lighting power density for the warehouse is 0.50 W/ft^2 and the design lighting level is 30 footcandles. What is the maximum skylight area that may be exempt?

A Table 402.3.1(B) for Richmond permits 2.3% skylight area for skylight glazing materials with a visible light transmission (VLT) greater than or equal to 0.75 and 3.6% for glazing materials with a VLT less than or equal to 0.50. Interpolation is permitted between these values so the maximum exempt skylight area for this building can be calculated as shown below.

For the 50,000 ft^2 building, a total of 1,400 ft^2 (2.8 × 50000 / 100) of skylight area may be exempt, provided the other criteria are satisfied. About forty-three 4 ft × 8 ft skylights would be permitted or one for each 1,156 ft^2.

Example 402D Exempted Skylight Area – Distribution Center

Q A 100,000 ft^2 distribution center located in Boise, Idaho is designed with a total skylight area of 8,000 ft^2. The skylights have a visible light transmission (VLT) of 0.50. The electric lighting will be automatically controlled. The lighting power density for the warehouse is 1.10 W/ft^2 and the design lighting level is 45 footcandles. What is the maximum skylight area that may be exempt?

A Using Table 402.3.1(B) for Boise with the lighting power of 1.10 W/ft^2, the design lighting level is 45 footcandles (use 50 fc which is closest), and the visible light transmission (VLT) of 0.50, a maximum skylight area representing 6% of the roof may be exempt. For the 100,000 ft^2 building, a total skylight area of 6,000 ft^2 may be exempt. There is a 2,000 ft^2 difference between the skylight area in the design and what can be exempt. If the designer wants all the skylight area to be exempt, either the skylight area must be reduced or the additional 2,000 ft^2 can be included in the weighted average thermal transmission of the opaque roof. Another option would be to provide some means of shading the skylights during the peak cooling load so that the exempted skylight area can be increased by 50% (to 9,000 ft^2).

The overall roof criteria for Boise is 0.051. If the U-factor of the skylights is 0.60, then the U-factor of the opaque portion of the roof would have to be 0.039 or less, as shown below.

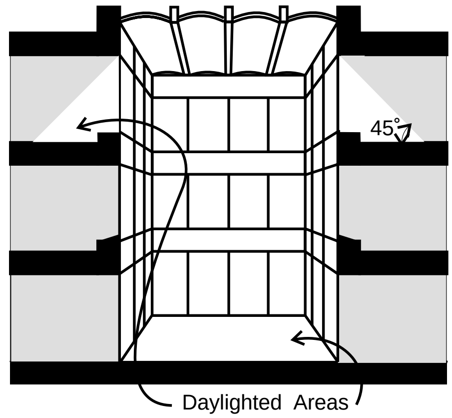
$$0.051 = \frac{0.60 \times 2{,}000 + U \times 92{,}000}{94{,}000}$$

$$U = 0.039$$

Note that the total roof area in the weighted average calculation is 94,000 ft^2 (the total of 100,000 ft^2 less the 6,000 ft^2 that can be exempt).

Example 402E Exempted Skylight Area – Atrium

Q



A central atrium space in an office is conditioned and has a floor area that measures 100 ft by 120 ft. The atrium extends through three floors with office space adjacent to the atrium. The designer wishes to use a white acrylic glazing with a visible light transmittance (VLT) of 0.64. The atrium has a lighting system that provides 100 footcandles at 2.8 W/ft^2 – the high level is needed to maintain plant growth. The adjacent offices have a lighting system designed for 50 footcandles at 1.8 W/ft^2 of connected lighting load. The gross roof area of the building is 135,000 ft^2 and there are no other skylights. The offices at the top floor of the atrium have a 10-ft ceiling height and the glazing into the atrium extends the full 10 ft. The building is located in Atlanta, Georgia. What is the maximum skylight area that can be exempt?

A

The skylight in the atrium creates daylighted areas in both the floor of the atrium and in the adjacent offices at the top floor. The daylighted area in the floor of the atrium is 12,000 ft^2. The daylighted area in the adjacent office space will extend 10 ft from the window (equal to the floor to ceiling height). This creates a donut shaped daylighted area at the top floor of 4,800 ft^2. The lighting at the atrium floor and in the entire 10-ft perimeter of adjacent office space at the top floor will have to be operated with automatic daylighting controls.

The lighting power density and the design illumination (footcandles) are calculated as an area-weighted average as follows:

$$\text{LPD} = \frac{(2.8 \times 12{,}000) + (1.8 \times 4{,}800)}{12{,}000 + 4{,}800} = 2.51 \frac{\text{W}}{\text{ft}^2}$$

$$\text{Illuminance} = \frac{(100 \times 12{,}000) + (50 \times 4{,}800)}{12{,}000 + 4{,}800} = 86\text{fc}$$

Using these values, the maximum percent skylight area is 8.2% for VLT = 0.75 and 12.3% for VLT = 0.50. By interpolation, 10.0% is permitted for a VLT of 0.64. This would enable a total skylight area of 13,500 ft^2 as shown below so the entire skylight area may be exempted.

$$\begin{aligned}\text{Percent Area} &= \text{PA}_{50} - (\text{VLT} - 0.50)\frac{\text{PA}_{50} - \text{PA}_{75}}{0.25} \\ &= 12.3 - (0.64 - 0.50)\frac{12.3 - 8.2}{0.25} \\ &= 10.0\end{aligned}$$

$$\text{Maximum Area} = \frac{10.0}{100} 135{,}000 = 13{,}500$$

Form
402.3.1

Walls Adjacent to Unconditioned Space

The U-factor for walls adjacent to unconditioned space must be less than or equal to the criteria from Table 402.3.1(A). This includes opaque doors in these walls. Separate criteria apply to exterior walls as described below. No trade-offs are allowed with other building envelope components such as roofs, exterior walls, fenestration, or floors. However the U-factor of one portion of the wall may exceed the criteria as long as the area-weighted average of the entire opaque wall is less than the criteria.

Figure 402I Requirements for Walls Adjacent to Unconditioned Space

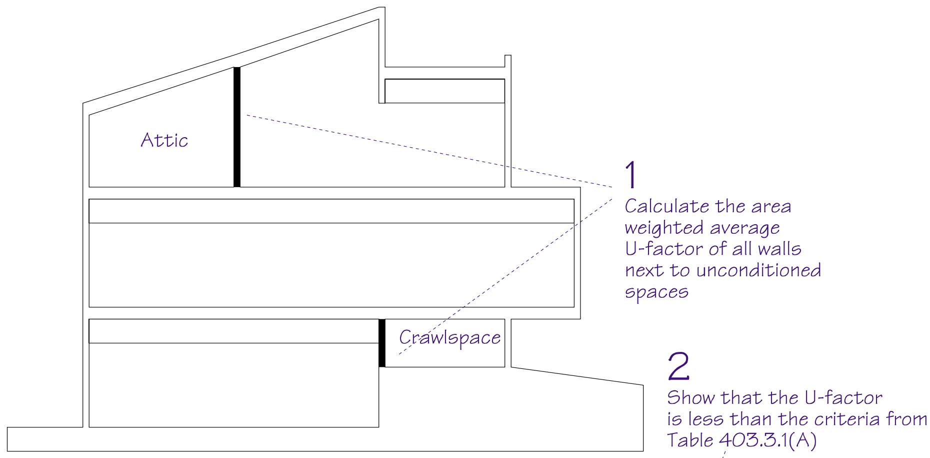


TABLE 402.3.1(A) MAX. THERMAL TRANSMITTANCE (U)	
Roof	0.061
Wall adjacent to unconditioned space	0.161
Floor over unconditioned space	0.069

Form
402.3.1

Floors Over Unconditioned Space

The U-factor for floors over exterior and unconditioned space must be less than or equal to the criteria in Table 402.3.1(A); no trade-offs are allowed with other envelope components such as roofs or walls. However, the U-factor of one floor element may be greater than the criteria if other floor elements have a lower U-factor such that the area-weighted average is less than the criteria. The criteria applies to all floors over unconditioned spaces including floors over unconditioned garages, and crawl-spaces.

Figure 402J Requirements for Floors

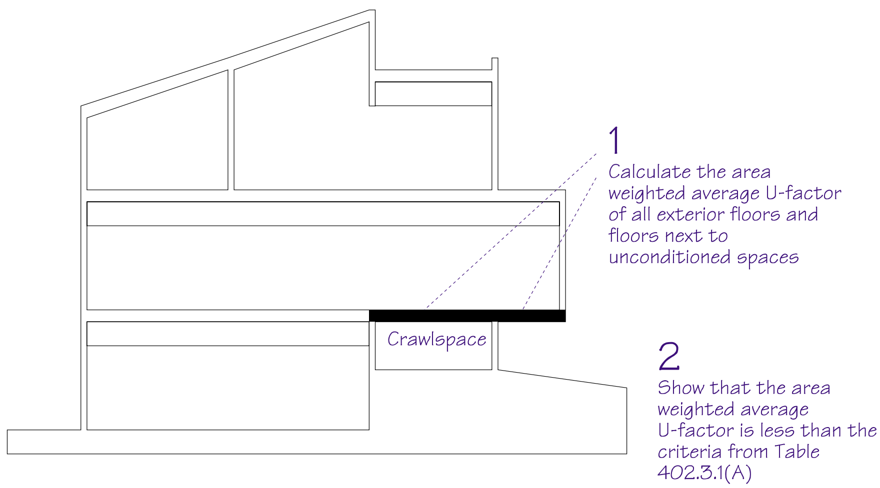


TABLE 402.3.1(A) MAX. THERMAL TRANSMITTANCE (U)	
Roof	0.061
Wall adjacent to unconditioned space	0.161
Floor over unconditioned space	0.069

Form
402.3.2

Below-Grade Walls

The R-value of below-grade wall insulation must be equal to or greater than the criteria from Table 402.3.2; no trade-offs are allowed.

Figure 402K Requirements for Below-grade Walls

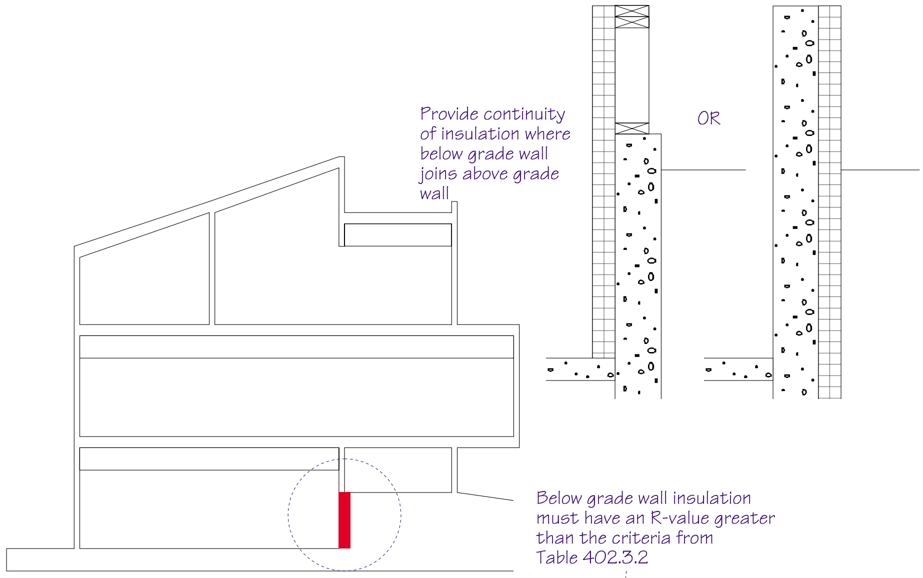


TABLE 402.3.2 MINIMUM THERMAL RESISTANCE (R-VALUE)				
Slab on grade:	Unheated / Heated:	24 inches	36 inches	48 inches
	Horizontal	R-14/R-16	R-12/R-14	R-10/R-12
	Vertical	R-7/R-9	R-6/R-8	R-4/R-6
Wall below grade:			R-8	

Form
402.3.2

Slabs-on-Grade

Table 402.3.2 gives the criteria for slabs-on-grade. The installed R-value must be equal to or greater than the criteria based on the width or the depth of the insulation (24, 36 or 48 in.) Table 402.3.2 shows two values. The first is for unheated slabs and the second is for heated slabs. If the slab is heated, the minimum R-value is increased by adding two. Figure 402L illustrates the requirements and shows acceptable installation methods. Note that insulation positioned horizontally outside the building is not an acceptable alternative. When the insulation is installed inside the wall, both horizontal and vertical dimensions may be added to achieve the necessary distance.

Figure 402L Requirement for Insulating Slabs-on-Grade

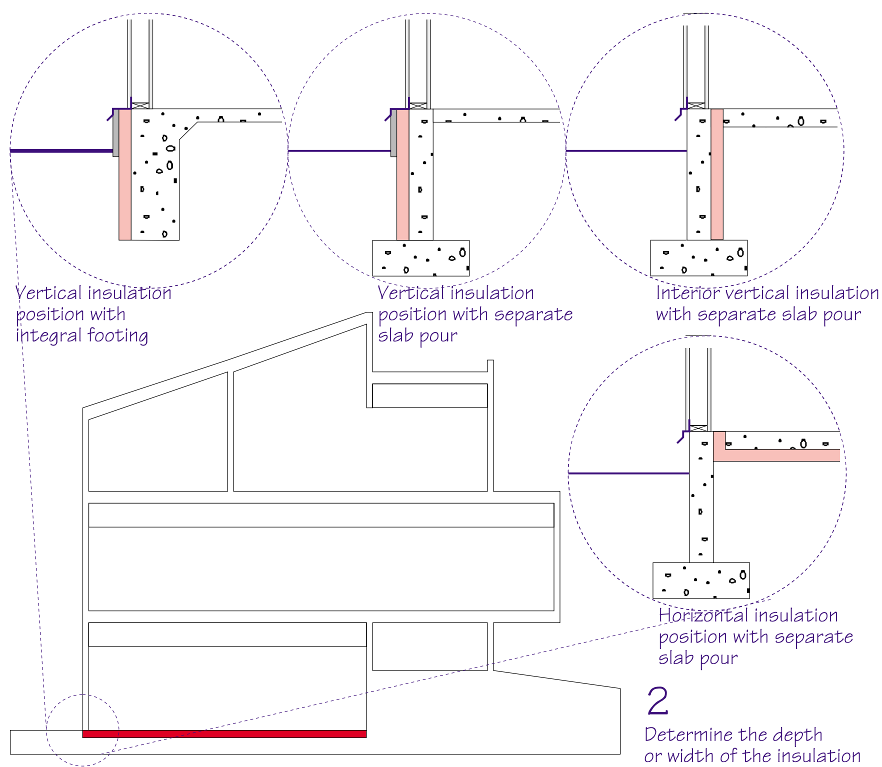


TABLE 402.3.2 MINIMUM THERMAL RESISTANCE (R-VALUE)				
Slab on grade:	Unheated / Heated:	24 inches	36 inches	48 inches
	Horizontal	R-14/R-16	R-12/R-14	R-10/R-12
	Vertical	R-7/R-9	R-6/R-8	R-4/R-6
Wall below grade:			R-8	

1 Determine the position of the insulation

3 Look up the criteria. The first value is for unheated slabs and the second value is for heated slabs.

EXTERIOR WALLS (402.4)

Exterior walls as defined here include all walls, windows, and doors exposed to the outside air. Separate criteria apply to walls that are exposed to unconditioned space (See above). There are two ways to demonstrate that exterior walls meet the code: Section 402.4.1 contains *prescriptive criteria* while Section 402.4.2 references the *systems performance method* contained in the parent, ASHRAE Standard 90.1-1989. The prescriptive criteria allow some flexibility, especially with regard to windows, but do not allow trade-offs between windows and walls. The systems performance method is a little more complicated and requires a computer, but permits tradeoffs between windows and walls, and allows more accurate consideration of solar orientation, internal gains, and other factors.

Prescriptive Criteria

Table 402.4.1.1 contains the prescriptive criteria for walls, including opaque doors. Table 402.4.1.2 contains the prescriptive criteria for windows.

The window criteria and the mass wall criteria depend on the ILD range. ILD stands for internal load density and represents the watts/ft^2 of heat produced from lights and equipment. You do not need to calculate ILD when you use the prescriptive tables. The first ILD range, up to 1.50 W/ft^2, is used for warehouses, residential spaces, and hotel/motel guest rooms. The last range, more than 3.00 W/ft^2, is used for small retail spaces less than 2,000 ft^2 and for technical and vocational schools less than 10,000 ft^2. The middle range applies to all other building types.

Opaque Walls

Form
402.4

Table 402.4.1.1 gives the criteria for exterior walls, including opaque doors. Separate criteria apply to windows (see below) and walls next to unconditioned space (see above). The procedure for using Table 402.4.1.1 is illustrated in Figure 402M and described below.

1. The first step is to calculate the area-weighted average U-factor of all exterior walls. Exterior wall area is defined on Figure 402C and in the associated text. The Reference section of this chapter contains default U-factors, and explains acceptable calculation procedures to use with your construction assembly is not contained in the default tables. Most buildings have more than one type of wall construction. In these cases, the U-factor of some walls can be greater than the requirement as long as others are less than the requirement. It is necessary, however, to calculate an area-weighted average U-factor and show that this number is less than the requirement. Example 402F illustrates how this is done.

2. Compare the area-weighted U-factor to the criteria for light-weight walls in the first row of Table 402.4.1.1. The criteria for light weight walls (HC <= 4.9) is the easiest to use since it does not depend on the ILD range, the position of the insulation, or the WWR (window-wall ratio). Separate values are provided in the two columns for insulation position, but the two numbers are the same for all locations. The lightweight wall criteria may be used for any type of wall construction, even mass walls. If the proposed U-factor is less than the criteria for light weight walls, you can stop, even if some of the walls you included in your area-weighted average were mass walls.

3. If the building does not comply with the light weight wall criteria and some of the walls in your area-weighted average are mass walls then you can determine the criteria for mass walls, which will be a little less stringent. The first step is to de-

termine the ILD range, which is based on the use of the building (see above and Figure 402M).

4. Determine the heat capacity (HC) of the wall. The HC depends mostly on the weight of the wall, but more detailed information may be required in some cases. Additional information is provided in the Reference section of this chapter on how to calculate the HC.

5. Select the insulation position for the wall. There are only two choices for the position of the insulation. If the insulation is located to the exterior of the massive elements of the wall, then you use the "Exterior" position. Otherwise you use the "Interior/Integral" choice.

6. Based on the HC and the insulation position determined in steps 4 and 5, find the wall criteria (maximum U-factor) for each window-wall ratio (WWR) value shown in the table. The WWR values represent the high and low of glass area permitted by the prescriptive requirements. Based on the WWR of the proposed building, interpolate between the two criteria values to establish the criteria for the wall. For instance, if the WWR of the proposed building were 45%, and using data from Figure 402M, the criteria would be 0.393 as calculated below. The WWR requires that you measure the total window area in the building and the gross wall area (which includes windows). You then divide the window area by the gross wall area and this is the WWR. The criteria is slightly more stringent for buildings with larger windows.

7. Repeat steps 4, 5, and 6 for each HC range and insulation position.

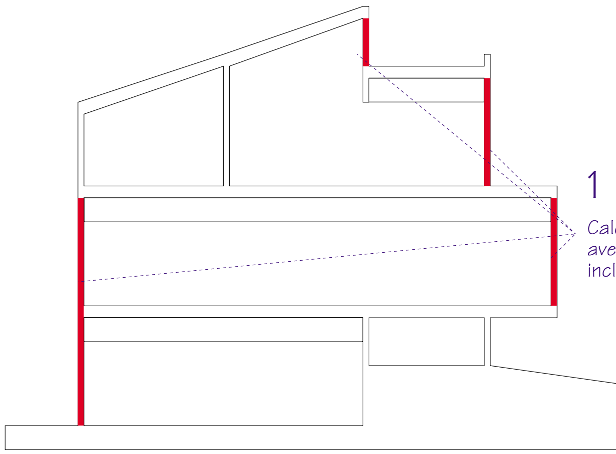
8. Calculate an area-weighted average criteria based on the results of step seven.

Example 402F Mass Wall Compliance

Q An architect is designing a small retail store in Abilene, Texas. She wishes to use a partially grouted, 12-inch concrete block wall construction. The design parameters are as follows: 19% WWR; heat capacity of the mass is 15.1 Btu/ft^2-°F; and the design features CMU with filled cores (integral insulation). What is the maximum U_{ow} allowed for a concrete block wall in this project?

A The default internal load density range for a small retail store is 3.01-3.50. At this ILD range for integral insulation in a wall with an HC of 15.1 Btu/ft^2-°F, the maximum U_{ow} varies from 0.306 Btu/h-ft^2-°F at 13% WWR to 0.284 Btu/h-ft^2-°F at 68% WWR. For the 19% WWR of this project the maximum allowable U_{ow} is 0.31 Btu/h-ft^2-°F from interpolation as follows:

Figure 402M The Prescriptive Wall Criteria



1
Calculate the area weighted average U-factor for all exterior walls, including opaque doors

5
Determine the insulation position

3
If you have mass walls, then determine the ILD range as below

3a
Use this for residential hotel/motel, and warehouse

3c
Use this ILD range for all other

3b
Use this for small retail stores < 2,000 ft² and Voc. Ed. schools < 10,000 ft²

TABLE 402.4.1.1 MAX. WALL THERMAL TRANSMITTANCE (U_{ow})				
			Insulation Position	
ILD Range	WWR	HC Range	Interior/Integral	Exterior
All	0 to 100	0.0 - 4.9	0.171	0.171
0.00 to 1.50	20	5.0 - 9.9	0.200	0.272
		10.0 - 14.9	0.284	0.382
		15.0	0.386	0.420
	73	5.0 - 9.9	0.197	0.272
		10.0 - 14.9	0.267	0.371
		15.0	0.360	0.398
1.51 to 3.00	15	5.0 - 9.9	0.204	0.272
		10.0 - 14.9	0.304	0.404
		15.0	0.408	0.447
	74	5.0 - 9.9	0.199	0.272
		10.0 - 14.9	0.281	0.381
		15.0	0.385	0.4[illegible]9
3.01 to 3.50	13	5.0 - 9.9	0.205	0.272
		10.0 - 14.9	0.306	0.406
		15.0	0.410	0.450
	71	5.0 - 9.9	0.199	0.272
		10.0 - 14.9	0.282	0.383
		15.0	0.387	0.422

2
Compare to the area weighted average U-factor to the criteria for all light weight walls (WWR, HC, and and insulation position do not matter.) If U-factor is less than the criteria, then STOP.

7
Repeat steps 4, 5, and 6 as necessary for other HC ranges and/or insulation positions

8
Calculate the area weighted average criteria

4
Calculate the wall HC and select a range, e.g. 10.0 to 14.9 in this example

6
Calculate the WWR for your building and interpolate between these values to establish the criteria

Fenestration

Form
402.4

Table 402.4.1.2 gives the maximum allowable fenestration as a percent of the gross exterior wall area. This ratio is the window-wall ratio (WWR). Both fenestration area and gross exterior wall area are defined in Figure 402C and the associated text. To determine the maximum allowable WWR, it is necessary to consider five factors: (1) internal load density, (2) projection factor, (3) shading coefficient, (4) whether or not automatic daylighting controls are installed, and (5) fenestration U-factor. (See Figure 402N).

Step 1 Determine ILD Range. Use the first ILD range, up to 1.50 W/ft^2, for warehouses, residential spaces, and hotel/motel guest rooms. Use the last range, more than 3.00 W/ ft^2, for small retail spaces less than 2,000 ft^2 and for technical and vocational schools less than 10,000 ft^2. Use the middle range for all other building types.

Step 2 Determine Overhang Projection Factor (PF). Select one of the three ranges which roughly correspond to "no" overhang, "small to medium" overhang, and "large" overhang. Figure 402N shows the overhang sizes required for projection factors of 0.25 and 0.50. Overhangs should be shown on the drawings when projection factors of 0.25 or larger are used in the calculations. Calculate a window area-weighted projection factor for the whole building when more than one overhang condition exists.

Step 3 Determine Shading Coefficient (SC_x). Select one of the up to six ranges. The SC_x can account for the shading coefficient of the glass, internal or external shading devices, and even the effect of framing and mullions. Figure 402N shows the ranges in the prescriptive tables and gives examples for each range. These are illustrative only and may not be used for compliance. The Reference section of this chapter contains typical shading coefficient values. The use of any SC_x range lower than 1.00-0.72 must be documented from other sources such as manufacturers' data. For retail storefronts, where high visibility is desired, the glass will most likely be clear and be in one of the first two ranges (1.00-0.72 or 0.71-0.61). For upper floors, and where high visibility from the outside is less of a concern, glass is likely to be tinted or reflected in most climates, and thus will fall in one of the two middle ranges (0.60-0.51 or 0.50-0.39). Shading coefficients in this range are a good compromise between reducing cooling loads and providing greater occupant comfort while still providing views and adequate daylight. The two lower SC_x ranges (0.38-0.26 or 0.25-0.00) represent reflective glass, which is most likely to be used in hot climates and/or in buildings with a high window-wall ratio. To take credit for smaller SC_x increments or variations by orientation, consider using the system performance method.

Figure 402N The Prescriptive Window Criteria

1
Determine the ILD range as below

1a
Use this for residential, hotel/motel, and warehouse

1c
Use this ILD range for all other

1b
Use this for small retail stores < 2,000 ft^2 and Voc. Ed. schools < 10,000 ft^2

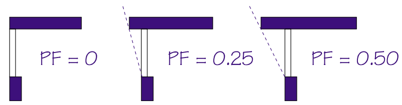
4
Use "Perimeter Daylighting" when automatic daylighting controls are installed in perimeter zones, otherwise, use "Base Case"

4a
Use "VLT >= SC" for high performance glazing

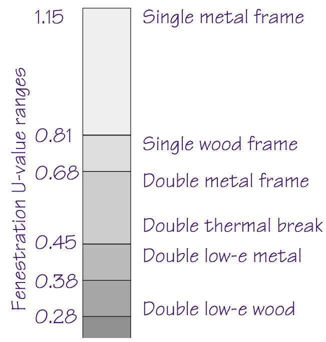
TABLE 402.4.1.2 MAXIMUM WALL RATIO (WWR)

Internal Load Density (ILD) Range	Projection Factor (PF) Range	Shading Coefficient (SCx) Range	Fenestration U-Factor (Uof) Base Case 0.81 to 0.46	Base Case 0.45 to 0.39	Base Case 0.38 to 0	Perimeter Daylighting 0.81 to 0.46	Perimeter Daylighting 0.45 to 0	Perimeter Daylighting VLT>=SC 0.38 to 0
0.00 - 1.50	0.00 - 0.25	1.00 - 0.72	17	19	19	18	21	21
		0.71 - 0.61	19	23	23	20	25	26
		0.60 - 0.51	21	26	27	23	28	30
		0.50 - 0.39	24	30	32	25	33	35
		0.38 - 0.26	28	38	40	28	40	43
		0.25 - 0.00	33	49	54	33	52	58
	0.26 - 0.50	1.00 - 0.72	22	27	28	23	29	31
		0.71 - 0.61	25	32	33	26	34	36
		0.60 - 0.51	27	36	38	28	38	42
		0.50 - 0.39	29	41	44	30	44	48
		0.38 - 0.00	33	49	54	33	51	58
	0.50 +	1.00 - 0.72	26	34	36	27	37	40
		0.71 - 0.61	29	40	42	30	42	46
		0.60 - 0.51	31	45	48	32	47	52
		0.50 - 0.00	33	50	55	34	52	59
1.51 - 3.00	0.00 - 0.25	1.00 - 0.72	14	15	16	18	21	22
		0.71 - 0.61	16	19	19	21	25	27
		0.60 - 0.51	19	22	22	23	28	31
		0.50 - 0.39	21	25	26	25	33	37
		0.38 - 0.26	25	32	33	29	40	46
		0.25 - 0.00	31	34	47	35	53	61
	0.26 - 0.50	1.00 - 0.72	19	22	22	23	29	32
		0.71 - 0.61	21	$\boxed{26}$	27	26	34	38
		0.60 - 0.51	24	30	31	28	39	43
		0.50 - 0.39	27	35	36	31	44	50
		0.38 - 0.00	31	42	45	34	52	61
	0.50 +	1.00 - 0.72	23	28	29	27	37	41
		0.71 - 0.61	26	33	35	30	42	48
		0.60 - 0.51	28	38	40	32	47	55
		0.50 - 0.00	31	43	46	35	53	62
3.01 - 3.50	0.00 - 0.25	1.00 - 0.72	12	13	13	17	19	21
		0.71 - 0.61	14	16	16	19	23	26
		0.60 - 0.51	16	19	19	22	27	30
		0.50 - 0.39	19	22	23	24	31	35
		0.38 - 0.26	22	28	29	28	38	44
		0.25 - 0.00	28	38	41	33	50	59
	0.26 - 0.50	1.00 - 0.72	16	19	19	22	27	31
		0.71 - 0.61	19	22	23	25	32	36
		0.60 - 0.51	21	26	27	27	36	42
		0.50 - 0.39	24	30	31	29	41	48
		0.38 - 0.00	28	37	39	33	49	59
	0.50 +	1.00 - 0.72	20	24	25	26	34	39
		0.71 - 0.61	23	28	30	29	40	46
		0.60 - 0.51	25	33	34	31	45	53
		0.50 - 0.00	28	38	40	33	50	60

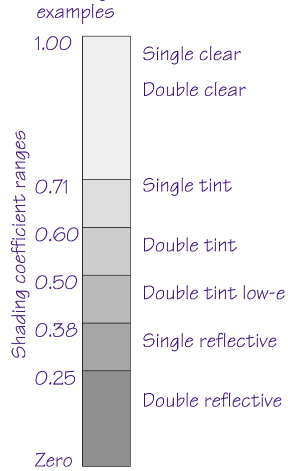
2
Determine the projection factor range based on the window area-weighted average PF for the building



5
Choose a U-factor range representing the area weighted average of all vertical fenestration in the building



3
Determine the shading coefficient range. The following are some examples



Step 4 Determine the Daylighting Option. Select one of the two options: "Base Case" or "Perimeter Daylighting". Use the default assumption "Base Case" when automatic daylighting controls are not installed (or are not needed to comply). This is a conservative choice and is always acceptable for determining compliance, even if the building has automatic daylighting controls. The "Base Case" choice is easy to use and does not require coordination between the design of the envelope and the lighting system.

If "Perimeter Daylighting" is selected, the daylighted areas in the perimeter zones of the building must have automatic daylighting controls capable of reducing electric lighting power to 50% of full power. More window area is allowed for most cities. Daylighting controls must be documented in the plans and/or specifications. If daylighting controls vary by orientation, consider using the system performance method. For some cities, the fenestration visible light transmittance must be greater than or equal to the shading coefficient before the daylighting credits may be used.

Step 5 Determine the Fenestration U-factor (U_{of}). Select an appropriate U-factor range. The ranges may vary with each city and with your choice of "Base Case" or "Perimeter Daylighting". The Reference section of this chapter has default U-factors for many common fenestration types. These defaults may be used if you do not want to do calculations or provide other documentation. The default assumptions are taken from the ASHRAE Fundamentals Handbook (1985) and include the effect of frames. Other acceptable approaches to determine U_{of} are discussed in the Reference section.

At this point, you can determine the maximum allowable window-wall ratio (WWR). In Figure 402N, the maximum allowed is 26%. If the WWR of the proposed building is less than this, then the building complies with the fenestration criteria. If not, you will need to make modifications to the design and repeat all or a part of steps 1 through 5, described above. One of the easiest adjustments to make is to change the glass type. This would affect either shading coefficient, the fenestration U-factor or both. From Figure 402N, a WWR as high as 45% could be justified by selecting a glazing product with a U-factor less than 0.38 and a shading coefficient less than 0.38.

Example 402G Use of Prescriptive Fenestration Tables – Savannah Office Building

Q An office building is planned for Savannah, Georgia near the historic district. The proposed fenestration area is 39% of the gross exterior wall area. The owner is willing to use double (1/2-inch airspace), tinted glazing, but reflective glass is not an acceptable alternative due to incompatibility with the character of nearby historic buildings.

A (a) The internal load density range for the office is 1.51-3.00. (b) The building has no overhangs, therefore the PF range is 0.000-0.249. (c) The shading coefficient for the glass from the manufacturer's specifications sheet is 0.48, therefore the SC_x range is 0.50-0.39. (d) The building has no daylighting controls so the base case is selected. (e) The default fenestration U-factor for double-glazing with a 1/2-inch airspace is 0.61, therefore the U_{of} range is 0.81 to 0.

The maximum allowable fenestration area is 26%, so modifications are necessary. Under the base case, no daylighting, assumption, either a very large PF or a very low SC_x would be necessary for the 39% fenestration area to comply. If one looks at the perimeter daylighting option, however, it would qualify provided that the visible light transmittance is greater than the SC. The automatic daylighting controls will end up reducing the electric load from both the lighting and the cooling equipment during the late afternoon summer peak demand period. The result is that the project complies and both energy consumption and energy demand are lower.

4
Choose
0.81 - 0.00
range for
U-factor

3
Choose
0.50 - 0.39
range for SCx

2
Choose 0.00 -
0.25 range for
overhang
projection
factor

1
Choose middle
internal load
range for an
office building

TABLE 402.4.1.2 MAXIMUM WALL RATIO (WWR)

Internal Load Density (ILD) Range	Projection Factor (PF) Range	Shading Coefficient (SCx) Range	Fenestration U-Factor (Uof): Base Case 1.15 to 0.82	Base Case 0.81 to 0	Base Case N/A	Perimeter Daylighting 1.15 to 0.82	Perimeter Daylighting 0.81 to 0	Perimeter Daylighting VLT>=SC 0.81 to 0
0.00 - 1.50	0.00 - 0.25	1.00 - 0.72	19	19		22	22	22
		0.71 - 0.61	24	23		26	27	27
		0.60 - 0.51	28	26		31	32	32
		0.50 - 0.39	33	30		36	38	39
		0.38 - 0.26	42	38		47	50	51
		0.25 - 0.00	61	49		67	73	75
	0.26 - 0.50	1.00 - 0.72	27	28		30	31	32
		0.71 - 0.61	33	34		37	38	39
		0.60 - 0.51	39	40		43	45	46
		0.50 - 0.39	46	48		50	54	55
		0.38 - 0.00	58	63		63	69	71
	0.50 +	1.00 - 0.72	35	37		39	41	42
		0.71 - 0.61	43	45		47	50	51
		0.60 - 0.51	50	53		55	59	60
		0.50 - 0.00	58	63		64	70	71
1.51 - 3.00	0.00 - 0.25	1.00 - 0.72	15	15		21	21	23
		0.71 - 0.61	18	18		26	26	28
		0.60 - 0.51	21	22		30	31	33
		0.50 - 0.39	[illegible]	$\boxed{26}$		36	38	40
		0.38 - 0.26	33	34		47	49	52
		0.25 - 0.00	49	52		67	72	77
	0.26 - 0.50	1.00 - 0.72	21	21		30	31	33
		0.71 - 0.61	26	26		36	39	40
		0.60 - 0.51	30	31		43	44	47
		0.50 - 0.39	36	37		50	53	56
		0.38 - 0.00	46	49		64	69	73
	0.50 +	1.00 - 0.72	27	28		39	40	43
		0.71 - 0.61	33	34		47	50	53
		0.60 - 0.51	39	41		55	59	62
		0.50 - 0.00	46	49		64	69	73
3.01 - 3.50	0.00 - 0.25	1.00 - 0.72	12	12		20	20	22
		0.71 - 0.61	15	15		24	25	27
		0.60 - 0.51	18	18		28	29	32
		0.50 - 0.39	21	22		34	35	38
		0.38 - 0.26	28	29		44	46	50
		0.25 - 0.00	42	44		63	68	74
	0.26 - 0.50	1.00 - 0.72	17	17		28	29	31
		0.71 - 0.61	21	22		34	35	38
		0.60 - 0.51	25	26		40	41	45
		0.50 - 0.39	30	31		47	50	54
		0.38 - 0.00	39	41		60	65	70
	0.50 +	1.00 - 0.72	23	23		36	38	41
		0.71 - 0.61	28	28		44	46	50
		0.60 - 0.51	33	34		51	55	60
		0.50 - 0.00	39	40		60	65	70

5
Compliance
could be
achieved with
daylighting
controls and
high performance
glazing

Form
402.4.2

System Performance Criteria (402.4.2)

Section 402.4.2 of the 90.1 Code references the system performance criteria. The system performance criteria offers more flexibility than the prescriptive criteria, especially with regard to making trade-offs between windows and walls. A full description of the method, along with the underlying equations and assumptions, is contained in the parent, ASHRAE Standard 90.1-1989. However, to use the system performance method, you only need a copy of the ENVSTD computer program. This program incorporates all the criteria and the trade-off equations in an easy-to-use package which is also a useful design tool. Only ENVSTD Version 2.1 is acceptable. While more recent versions are available, Version 2.1 is the only one that is consistent with the 90.1 Code requirements.

ENVSTD allows a designer to make trade-offs between heating and cooling requirements for the exterior wall. All components of the gross exterior wall may be considered, including fenestration, opaque walls, and opaque doors. For instance, one can trade shading coefficient for better wall U-factors, or vice-versa. ENVSTD considers the overall performance of the exterior wall and takes account of the following factors.

- Orientation
- Fenestration area
- Fenestration shading coefficient
- Projection factor (size of overhangs)
- Fenestration U-factor
- Visible light transmittance, if automatic daylighting controls are installed
- Daylighting control fraction, if automatic daylighting controls are installed
- Wall and door U-factor
- Heat capacity, e.g. credit for mass walls
- Insulation position, for mass walls only

ENVSTD separately calculates the heating and cooling performance for the exterior wall. It also separately calculates the criteria for heating and cooling. For buildings that are both heated and cooled, the total performance for both heating and cooling is compared to the criteria for both heating and cooling. If a space is only heated, then the heating performance is compared to the heating criteria (cooling does not matter). If a space is only cooled, then the cooling performance is compared to the cooling criteria (heating does not matter).

ENVSTD cannot be used to make trade-offs against the lighting or HVAC requirements. While both the lighting and equipment power densities are entered, these data are only used to improve the thermal calculations. All lighting must comply with the requirements of Section 401, regardless of the values entered in ENVSTD. The energy cost budget method (see Section 102) is the only way to make envelope trade-offs against lighting or HVAC improvements.

How to Use the ENVSTD Program

When you start the ENVSTD program, it goes through a series of opening screens containing introductory material, disclaimers and acknowledgments. After that, the exterior wall screen appears and the user can begin entering exterior wall data. Pressing the F5 function key will cause the other criteria screen to appear. Pressing F5 again will cause the exterior wall screen to appear. The other criteria screen is for roofs, floors, slabs, and below-grade walls. The criteria is identical to that previously discussed, so only the wall screen is of interest for ENVSTD trade-offs.

Wall Screen Header Information. The wall screen has header information at the top which is common to both screens. The header information which must be entered is described below.

CITY: Enter a code number for the city where the building will be located or for a nearby city with a similar climate if the desired city is not listed. Press the F6 function key and a list of all available cities will appear sorted by state. City numbers have been assigned in country-wide alphabetical order, therefore nearby cities in the same state will likely have very different numbers.

BUILDING: Enter text which identifies the building. The project name is an obvious choice. However, it is better to enter an address if a screen print of the calculations is to be submitted to a building department.

CODE: Enter B if the building is both heated and cooled. Enter C if the building is cooled only. Enter H if the building is heated only, such as a warehouse.

DATE: Enter today's date. It will help keep things straight for the building permit if revised calculations are submitted later.

Exterior Wall Information. The rest of the information on the wall screen is entered in tabular form for eight separate building orientations. If an input is out of range, the value will flash until an acceptable one is entered. The following data are entered.

WL AREA (wall area): Enter the gross exterior wall area in square feet for each orientation. This includes fenestration, doors, and opaque walls, but *not* below-grade walls or walls next to unconditioned space. Walls are portions of the building envelope which are vertical or tilted at an angle more than 60 degrees from horizontal. For each wall, use the closest of the eight orientations available. For most buildings, there typically will be four orientations. The area for each orientation must be entered separately, i.e. the F10 key cannot be used to copy across here as it can for later fields. For curved facades, subdivide and enter as best as possible.

GL AREA (glazing area): Enter the fenestration area (including the glass, sash, and frame) in square feet for each orientation. This includes all glazed doors and, if they meet the wall criteria above, clerestory windows.

SC_X (shading coefficient): Enter the SC_X for the fenestration in each orientation. For both heated and cooled or for cooled-only buildings, it is acceptable to use the shading coefficient of the glass alone, since this is the worst case. Use an area-weighted average SC_X when a building facade has multiple shading coefficients, such as clear low-e for the first floor retail shops vs. tinted low-e for the offices above. While interior shading devices, such as blinds and shades, are desirable to control solar gain and provide occupant comfort, think carefully about whether you want to take credit for these and risk basing your design on features which are easily changed by future tenants. Interior shading devices are credited only if they are part of the design (i.e. included on drawings submitted for a building permit application) and installed prior to the final inspection.

PF (projection factor): Projection factor is the ratio of the depth of the external shading projection to the height of the projection above the bottom of the window. When a building facade has more than one overhang condition, calculate the window area-weighted average projection factor and enter this value.

VLT (visible light transmittance): This information is only used when automatic daylighting controls are installed in the perimeter zones (daylight control fraction greater than zero). Enter an area-weighted average VLT if there are multiple fenestration types on a single facade. If the shading coefficient is adjusted for exterior or interior shading devices, the VLT should also be adjusted.

U_{of} (U-factor of the windows) Enter the U-factor for the windows on each orientation, including consideration of the frame. Enter an area-weighted average if there are multiple fenestration types on a single facade.

WALL U_o (wall U-factor): Enter the area-weighted average U-factor for the walls and opaque doors on each orientation. Glazed doors are included with windows.

HC (heat capacity): Enter the heat capacity of the opaque walls on each orientation. A default of 1 may be used in all cases, if you do not want to calculate the area-weighted HC for each building facade.

INS POS (insulation position): Enter a numeric code for the location of the insulation in the exterior wall for each orientation. Enter "1" for exterior insulation, "2" for integral insulation, and "3" for interior insulation. Use the most common condition if different wall constructions exist on the same facade. Press the F7 function key if you forget the meaning of the numeric codes.

EQUIP (equipment power density): Enter the equipment power density in watts per square foot for each facade. Use the default values provided in Table 402.4.2 of the 90.1 Code unless calculations are provided to justify another entry.

LIGHTS (lighting power density): Enter the lighting power density in watts per square foot for each orientation. Use the values from Table 402.4.2 of the 90.1 Code unless calculations are provided to justify another entry.

DLCF (daylight control fraction): This field is set to zero if the perimeter zone does not have automatic daylighting controls. If automatic daylighting controls are shown on the plans, then enter the decimal fraction of the lighting power within 15 feet of the exterior wall that is controlled by automatic daylighting controls.

Other Envelope Requirements Screen

When you press the F5 function key, ENVSTD will display the information contained in Tables 402.3.1 and 402.3.2. The list of ENVSTD cities is the same as the list in Table 402B.

ENVSTD will also calculate the maximum skylight area that may be exempt as a percent of the roof area. You enter the design illuminance (in footcandles) and the visible light transmission, and ENVSTD uses the average lighting power density entered for the perimeter zones in the exterior walls screen. Note that ENVSTD does not provide a way to increase the maximum exempt skylight area for shading devices.

ENVSTD calculates the R-value requirement for slabs-on-grade. Enter a "u" or an "h" in the appropriate field to indicate if the slab is unheated or heated. In the next field, enter a "v" or "h" to indicate if the insulation is positioned vertically or horizontally. Enter the depth or width of the insulation in inches in the next field, and finally, enter the installed R-value of the insulation. The program calculates the minimum R-value criteria. A value must be entered for slab R-value, even if the building does not have a slab.

Figure 402O The ENVSTD Program

WALL SCREEN

```
CITY: 198            Seattle/Tacoma WA  BUILDING: 345 Sunrise Ave BASELINE
CODE <B,C,H>: Both Heated and Cooled        DATE: 14 March 1992
             WALL ORIENTATION                             WEIGHTED
           N      NE      E     SE      S     SW      W     NW  AVERAGE CRITERIA
------- ---------------------------------------------------------  -------
WL AREA|  6750          3000          6750          3000        |  0.10 | 0.300
GL AREA|   400           0.0           400          1200        |   WWR |   WWR
   SCx |   .49           0.0           .49           .49        |  0.41 | 0.719
    PF |   0.0           0.0           0.0           0.0        |  0.00 |   0.0
   VLT |   0.0           0.0           0.0           0.0        |  0.00 |   N/A
   Uof |   .58           0.0           .58           .58        |  0.49 | 0.619
WALL Uo|   .08           .08          .089           .08        |  0.08 | 0.096
    HC |   9.6           9.6           9.6           9.6        |  9.60 |     1
INS POS|     3             3             3             3        | 3     |   N/A
EQUIP  |   .14           .14           .14           .14        |  0.14 | 0.140
LIGHTS |   .89           .89           .89           .89        |  0.89 | 0.890
DLCF   |   0.0           0.0           0.0           0.0        |  0.00 |   0.0
------- --------------------- L O A D S --------------------- -TOTAL- -------
HEATING| 5.199         2.202         4.750         2.585        | 14.736> 14.485
COOLING| 0.761         0.059         1.282         2.543        |  4.645< 15.999
TOTAL  | 5.961         2.261         6.032         5.128        | 19.381< 30.484
==============================================================================
F1 Load  | F3 Clear Input  | F5 Other Screen  | F7 Help       | F10 Copy Across
F2 Save  | F4 Directory    | F6 List Cities   | F9 Calculate  | Esc Exit to DOS
                   **********    PASSES   **********
```

Header information

Exterior wall data entered by orientation

Results section

Description of function keys

Press F5 key to toggle between screens

OTHER SCREEN

```
CITY: 198            Seattle/Tacoma WA  BUILDING: 345 Sunrise Ave BASELINE
CODE <B,C,H>: Both Heated and Cooled        DATE: 14 March 1992

MAXIMUM PERCENTAGE OF ROOF AREA IN SKYLIGHTS:            DESIGN       LIMIT
------------------------------------------------------ ------------ -----------
Visible Transmittance of Skylight                      |   .66      |   .66
  Design lighting Footcandles of Space                 |     30     |     30
    Percentage of Roof Area in Skylights:              |   2.5      <   2.8

MAXIMUM ALLOWABLE Uo:
------------------------------------------------------ ------------ -----------
Roof                                                   |  .053     <    0.067
Wall Adjacent to Unconditioned Space                   |  0        <    0.150
Floor Over Unconditioned Space                         |  0        <    0.060

MINIMUM ALLOWABLE R-VALUE:
------------------------------------------------------ ------------ -----------
Wall Below Grade                                       |  100      >    8.460
Slab on Grade (Heated or Unheated)                     |  Unheated  |  Unheated
  Insulation Position                                  | Horizontal | Horizontal
    Depth or Width (Inches)                            |  24 in.    |  24 in.
      R-Value of Concrete Slab Insulation              |  16       =    16
==============================================================================
F5 Wall Screen        |      F9 Calculate         |        Arrows  Move
F7 Help               |      Del Delete Entry     |        Esc     Wall Screen

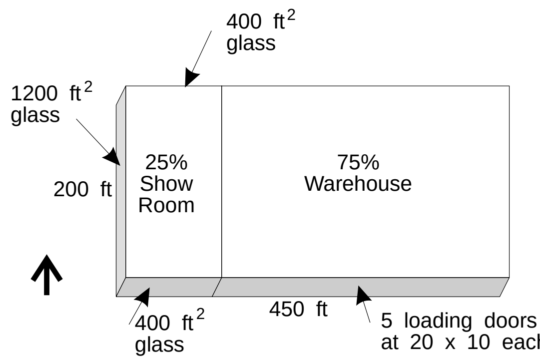
                         *********  PASSES  *********
```

Data on this screen is identical to data contained in Tables 402.3.1(A), 402.3.1(B), and 402.3.2

After entering values for all appropriate fields, press F9 to calculate. If the program says "PASSES" at the bottom of the screen, then your building meets the code. If it says "FAILS," then revise the design and try again. When you save your file, it is stored in an ASCII format which can be printed using the DOS PRINT command or with a text processor. The pass/fail message is printed at the bottom of both the exterior wall screen and the other envelope requirements screen. Make sure that both screens show "PASSES."

Example 402H ENVSTD Program – Retail Showroom/Warehouse Mixed-Use, Knoxville

Q Design is nearing completion on a 90,000 ft^2 single-story building just west of Knoxville, Tennessee which is 25% retail showroom and 75% warehouse. The building is 200 ft by 450 ft with the long axis east-west. The exterior wall height is 15 ft. The fenestration is all in the showroom on the west end of the building. It has 1,200 ft^2 of fenestration on the west end, with 400 ft^2 on the north side and 400 ft^2 on the south side. The fenestration is to be double-glazed in a metal frame. The fenestration U-factor is 0.61 from the default tables in this manual. The glass shading coefficient is 0.49 from the manufacturer's specifications. The concrete wall is 8 in. thick with minimal insulation on the interior with a U-factor of 0.37. There are five loading doors on the south side of the building. Each is 20 ft wide by 10 ft high and is insulated with a tested U-factor for the entire door (not just the insulated section) of 0.14.



A Bring up the first screen for the ENVSTD program and begin entering values. (See Screen A)

CITY For this example, the closest city is Knoxville. Press F6, enter TN for Tennessee and the city code is shown as 108. (See Screen B).

BUILDING For this example, the entry is "345 Volunteer Circle BASE". For subsequent variations, only the last code word changes.

CODE For this example, B (for both heating and cooling) is selected.

DATE Enter the date.

WL AREA First the gross exterior wall areas must be calculated.

$WA_{south} = WA_{north} = 450\text{ ft} \times 15\text{ ft} = 6{,}750\text{ ft}^2$

$WA_{east} = WA_{west} = 200\text{ ft} \times 15\text{ ft} = 3{,}000\text{ ft}^2$

Now enter 6,750 for the north, skip northeast, enter 3,000 for the east, skip southeast, enter 6,750 for the south, skip southwest, enter 3,000 for the west and skip the northwest. (For subsequent entries, the cursor will only stop at those columns where a number has been entered in WL AREA.)

GL AREA Enter 400 for the north, no entry is necessary for the east, enter 400 for the south and enter 1,200 for the west.

SC_X Use the glass SC option and simply enter 0.49. Use the F10 key to copy across to simplify entry. (This is an option when the value does not vary by orientation.)

PF Use the default assumption and assume no projection factor. No entry is necessary.

VLT Use the default assumption and assume no automatic daylighting controls. No entry is necessary.

U_{of} Enter the fenestration U-factor of 0.61 from the default tables in this chapter. Use F10 to copy across.

WALL U_{ow} First the opaque wall U-factor must be determined. It is possible to use the 0.37 value for north, east, and west walls since there are no doors on these sides. If this approach is taken, then one needs only to calculate the weighted average U-factor for the south wall.

$\text{Area}_{\text{south opaque wall}} = (450' \times 15') - 400 = 6{,}350$

$\text{Area}_{\text{loading doors}} = (20' \times 10') \times 5 = 1{,}000$

$\text{Area}_{\text{south concrete wall}} = 6{,}350 - 1{,}000 = 5{,}350$

$$U_{ow} = [(5{,}350 \times 0.37) + (1{,}000 \times 0.14)]/6{,}350$$
$$= (1{,}980 + 140)/6{,}350 = 0.33$$

Enter 0.37 for the north wall, 0.37 for the east wall, 0.33 for the south wall, and 0.37 for the west wall. (Note that U-factors this high are above the acceptable range if a light-weight wall is input. One may key them in, but when you press F9 to calculate, the program will flash these values as being out of range. Consequently, it is not possible to use the default HC of 1, a value must be determined.)

HC The HC for this wall is 9.6. Enter 9.6 in the first column and use F10 to copy across.

INS POS The insulation is located on the inside, so enter 3.

Screen A -- ENVSTD Sign On Screen

```
                      ASHRAE/IES STANDARD 90.1-1989
  ENERGY EFFICIENT DESIGN OF NEW BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS


        +------+ +----+ +-+ +-+  +-+ +-------+ +-------+ +------+
        | +----+ |    | | | | |  | | | +-----+ +--+ +--+ | +---+++
        | +----+ | ++ ++| | | |  | | | +-----+    | |    | |   | |
        | +----+ | |++ || | | ++++ | +-----+ |    | |    | |   | |
        | |      | | | || | ++ || ++       | |    | |    | |   | |
        | +----+ | | | ++ |  | ++ |  +-----+ |    | |    | +---+++
        +------+ +-+ +----+  +----+  +-------+    +-+    +------+

        ENVELOPE SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM


                           COPYRIGHT (c) 1989
                              OCTOBER 1989
                         VERSION 2.1 (90.1-1989)


                        < Press Any Key To Continue >
```

EQUIP Calculate the area-weighted average for both the retail and the warehouse. A value of 0.15 W/ft^2 is calculated based on information on the plans.

LIGHTS Calculate the area-weighted average for both the retail and the warehouse. A value of 0.90 W/ft^2 is calculated based on information on the plans.

DLCF Use the default assumption and assume no automatic daylighting controls. No entry is necessary.

Now press F9 to calculate whether or not the design complies. Screen C shows all the data that you have entered and the information that the building passes.

Screen B -- ENVSTD Screen With City List

```
CITY:                                         BU+---------------------------------+
CODE <B,C,H>:                                   |         City list for TN        |
        ------------------- WALL ORIENTATION|     Enter State Abbreviation    |
           N      NE     E      SE     S        |  44  Chattanooga                |
-------------------------------------------|  108  Knoxville                 |
WL AREA|                                    |  134  Memphis                   |
GL AREA|                                    |  147  Nashville                 |
   SCx |                                    |                                 |
   PF  |                                    |                                 |
   VLT |                                    |                                 |
   Uof |                                    |                                 |
WALL Uo|                                    |                                 |
   HC  |                                    |                                 |
INS POS|                                    |                                 |
EQUIP  |                                    |                                 |
LIGHTS |                                    |                                 |
DLCF   |                                    |                                 |
-------+--------------------- L O A D S ---|                                 |
HEATING|                                    |                                 |
COOLING|                                    |                                 |
TOTAL  |                                    |                                 |
-------------------------------------------|                                 |
F1 Load  |  F3 Clear Input |  F5 Other Scree|                                 |
F2 Save  |  F4 Directory   |  F6 List Cities+---------------------------------+
```

Screen C -- ENVSTD Screen After Calculation

```
CITY:   108   Knoxville TN                BUILDING: 345 Volunteer Circle BASE
CODE <B,C,H>: Both Heated and Cooled          DATE: 15 September 1994
        ------------------- WALL ORIENTATION ------------------ WEIGHTED
           N      NE     E      SE     S      SW     W      NW  AVERAGE CRITERIA
--------------------------------------------------------------------------------
WL AREA|  6750          3000          6750          3000        | 0.103 |  0.305
GL AREA|   400                         400          1200        |   WWR |    WWR
   SCx |   .49                         .49           .49        | 0.415 |  0.426
   PF  |   0.0                                                  | 0.000 |    0.0
   VLT |   0.0                                                  | 0.000 |    N/A
   Uof |   .58                         .58           .58        | 0.491 |  0.745
WALL Uo|   .37           .37           .33           .37        | 0.356 |  0.121
   HC  |   9.6           9.6           9.6           9.6        | 9.600 |      1
INS POS|     3             3             3             3        |   3   |    N/A
EQUIP  |   .15           .15           .15           .15        | 0.150 |  0.150
LIGHTS |    .9            .9            .9            .9        | 0.900 |  0.900
DLCF   |   0.0                                                  | 0.000 |    0.0
-------+--------------------- L O A D S -----------------------+-TOTAL---------
HEATING| 9.465         4.211         7.971         3.192        | 24.840> 16.622
COOLING| 5.320         2.242         6.898         6.715        | 21.174< 31.772
TOTAL  |14.785         6.453        14.869         9.907        | 46.014< 48.393
--------------------------------------------------------------------------------
F1 Load  |  F3 Clear Input |  F5 Other Screen |  F7 Help      |  F10 Copy Across
F2 Save  |  F4 Directory   |  F6 List Cities  |  F9 Calculate |  Esc Exit to DOS
                         *********   PASSES   *********
```

SUMMARY FORMS AND WORKSHEETS

One summary form and two worksheets are provided to assist with the calculations and documentation necessary in showing compliance with the envelope requirements of the 90.1 Code. Blank copies of these forms are included in Appendix D of this manual. The Case Study section of this chapter provides examples of completed forms. A general description of the forms is provided below.

Summary Form and Checklist

The front page of this form contains basic project information; the back lists information to be put on the drawings submitted for a building permit. The applicant completes the top and left hand side of the front page, and refers to the appropriate plan page on the drawings for the items on the checklist.

For any project with multiple construction assemblies, two additional worksheets are likely to be needed unless included on the plans:

- The Roof/Floor Worksheet - if there are skylights or multiple roof or floor types.
- The Exterior Wall Worksheet - if there are opaque doors or multiple fenestration or opaque exterior wall types.

Inputs are generally straightforward, though in some cases it is necessary to do calculations on one of the worksheets in order to determine the value to enter. For the exterior wall (Section 402.4), there are two compliance options, so the values entered may vary based on the approach selected. Internal load density will be a range for the prescriptive option, and two values (equipment and lighting) for the system performance option. Opaque wall U-factors are subdivided into light and heavy weight for the prescriptive option, but combined for the performance option (ENVSTD). Heat capacity calculations are not necessary if a heat capacity of 1 (worst case) has been used. Similarly, projection factor calculations are not necessary if a value of 0 is used and no credit is being claimed. Visible light transmittance need not be specified if the prescriptive option is being used and this is not included in the particular path chosen. ENVSTD output must be submitted for the performance option.

The plans examiner then compares this information with the drawings to verify that R-values, U-factors, shading coefficient, etc. match those on the plans and that the area takeoffs are correct. After all corrections have been responded to, the plans examiner notes any features which merit special attention by the inspector, and forwards the form to the inspector.

The inspector verifies all categories where there is an inspection check box, unless the applicant has written in “NA” and the plans examiner has concurred. After the inspections have been completed, the final version of the form can be filed with the building permit drawings as a record of construction.

Roof/Floor Worksheet

This worksheet is used to calculate the area-weighted average U-factor for: the proposed gross roof area (including non-exempt skylights); gross wall adjacent to unconditioned space area (including doors in this wall); and, gross floor over unconditioned space area to show compliance with Section 402.3.1. It is also used to calculate the area-weighted average U-factor, shading coefficient, and visible light transmittance for proposed exempt skylights to show compliance with the exception to Section 402.3.1. This is necessary if there is more than one roof, wall or floor type; if there are non-exempt skylights; or if there is more than one exempt skylight type. (The shaded areas of the form indicate information that is to be taken from the plans.) The front of the worksheet contains the calculations for the roof, wall, and floor, and the back contains the calculations for the exempt skylights and the instructions.

For the roof, the calculations must include all non-exempt skylights. The wall category here is only for walls adjacent to unconditioned space, and is likely to be used infrequently since most walls are exterior walls. The floor category includes floors over outside air or unconditioned space.

For the exempt skylights, only the maximum area allowed can be included here. Any additional area must be included with the roof on the front of the worksheet.

Exterior Wall Worksheet

This worksheet is used to calculate the area-weighted average U-factor, shading coefficient, visible light transmittance, and projection factor for the fenestration (windows, swinging and sliding glass doors) to show compliance with Section 402.4. It is also used to calculate the area-weighted average U-factor for light weight walls (including opaque doors) and to list the U-factor and heat capacity for heavy weight walls to show compliance with Section 402.4. This is necessary if there is more than one fenestration or exterior wall type. (The shaded areas of the form indicate information that is to be taken from the plans.) The front of the worksheet contains the calculations for the fenestration; the back contains the calculations for the exterior wall and the instructions.

For the fenestration calculations, all windows as well as sliding and swinging glass doors are to be included. (Skylights are included in the Roof/Floor Worksheet.)

For the opaque exterior wall calculations, light weight and heavy weight walls are subdivided but opaque doors (both swinging and roll-up) must be included in either case.

Note that calculations must be done separately for each orientation if ENVSTD is used to demonstrate compliance. This is because the impact of the fenestration shading coefficient and exterior wall heat capacity will vary based on the solar load which they are exposed to.

PERMIT APPLICANT'S RESPONSIBILITIES

At permit application, the goal of the applicant is to provide all the necessary information to show compliance with the 90.1 Code. If the plans examiner is able to verify compliance with one review, then the permit can be issued and construction started without delay. To assist in submitting the permit application, the applicant should review not only the following information specific to the applicant but also the subsequent two sections that review responsibilities of the plans examiner and the inspector. The following section addresses the two common problems with permit applications: (1) missing information, or (2) incorrect information.

Information may be missing because the applicant is not aware of all of the code requirements or because the required information is located on the specifications but not on the plans. Note that building departments generally approve plans, but not specifications. The Checklist on the back of the Envelope Summary Form provides a detailed list of the type of information that needs to be on the plans. This information can then be provided in a number of ways.

- *On the drawings.* Provide elevations which indicate window, door and skylight areas, and sections that show insulation position and thickness.
- *On sections and in schedules.* For instance, list R-values of insulation on sections and include U-factors, shading coefficient, visible light transmittance, and air infiltration on fenestration and opaque door schedules.
- *Through notes and call outs.* Note that all exterior joints are to be caulked, gasketed, weatherstripped or otherwise sealed.
- *Through supplementary worksheets or calculations.* Provide area-weighted calculations where required, such as for U-factors, heat capacity, shading coefficient, visible light transmittance, and projection factor. You may include these calculations on the drawings or incorporate as additional columns in the schedule or submit completed worksheets provided with this manual.

Incorrect information may be due to a lack of understanding of the code. More likely, it indicates that the code has changed since the last project. The applicant can use a correction list as a reminder to update the office specifications to avoid receiving this same correction again in the future. Some features to note are:

- Roofs with skylights cannot generally comply with the roof U-factor requirements unless the skylights meet the exemption criteria. This exemption requires skylights to be at least double-glazed (triple in colder climates), with R-5 curbs, automatic daylighting controls for lighting, and limits the skylight area to less than 5% of the roof in most cases.
- Walls adjacent to unconditioned space require batt insulation in metal or wood frame walls, or at least insulation filled cores for mass walls in virtually all climates.
- Floors adjacent to unconditioned space cover floors over basements, but also include floors over parking garages and building overhangs.
- Below-grade wall insulation is more effective on the outside since the thermal mass is then within the insulated shell, but it needs to be protected from sunlight and future landscaping work when it extends above grade.
- For heated basements, the below-grade walls must be insulated, or if the basement is unconditioned, the floor above must be insulated.
- For slab-on-grade floors, unheated/heated refers to whether there are pipes, ducts, or other heating elements in the slab, not to whether the space is heated or unheated. Vertical insulation must extend all the way to the top of the slab. (See Figure 402L)
- Exterior walls include opaque doors, both fire exit doors and roll-up loading doors. Uninsulated roll-up doors perform comparable to single glazing and thus wall insulation will need to be increased to compensate if these doors are uninsulated. The insulation in door cavities is often short-circuited by the metal at the edge of the door slab and the metal frame. Choose a door with a thermal break in the door slab and the door frame to get the best insulating value.
- Exterior frame walls usually fall within the 0-4.9 heat capacity range.

- Exterior walls with wood framing can usually meet the prescriptive U-factor requirements with batt insulation filling the cavity.
- Exterior walls with metal framing in climates over 4,000 heating degree days will generally require continuous insulation on either the inside or outside of the metal stud, in addition to filling the cavity with batt insulation. (Tip: if an alternative is desired, consider using the ENVSTD tradeoff procedure and improving the glazing.) Exterior mass walls (5.0+ heat capacity) in all but the mildest climates require some insulation to be added to either the exterior or interior of the wall. Insulation filled cores are usually not enough and do not work in climates subject to earthquakes where cores must be filled with concrete for seismic safety. (Tip: if an alternative is desired, consider using the ENVSTD tradeoff procedure and improving the glazing.)
- Fenestration in the exterior wall includes windows, glass sliding doors, glass swinging doors, and clerestory windows, provided that they are in the plane of the wall (i.e. sloped at an angle of 60 degrees from the horizontal or greater). Fenestration with a shallower slope is considered skylights and must be included in the roof criteria.
- Fenestration in climates over 3,000 HDD65 must be at least double-glazed to meet the prescriptive criteria. Large window-wall ratios will necessitate overhangs, low shading coefficients, high visible light transmittance, and/or automatic daylighting controls for the lighting.
- The perimeter daylighting options cannot be used unless the lighting drawings are submitted with the building permit application.
- Complying with the visible light transmittance criteria (VLT>= SC) usually means a green or high-performance tint, not bronze or gray.
- If more flexibility is desired for the fenestration, consider using the ENVSTD tradeoff procedure, but be aware that more calculations will be necessary to justify the inputs.
- ENVSTD can only be used for tradeoffs in the exterior wall (i.e. between exterior walls, doors, and fenestration). ENVSTD does not perform tradeoffs that include the roof, skylights, floor, below-grade wall or slab-on-grade floor.

PLANS EXAMINER'S RESPONSIBILITIES

The plans examiner must review each permit application for 90.1 Code compliance before a permit is issued. By letting the designer and contractor know what's expected of them early in the process, the building department can help assure that the approved drawings comply with the code. This helps the inspector to avoid the headache of correcting a contractor who is following drawings that do not meet the code requirements.

The biggest challenge for the plans examiner is often determining where the necessary information is and whether the drawings are complete. The plans examiner should make sure that the applicant includes the Envelope Summary and Checklist forms in this manual as part of the submittal package. The information provided on these forms makes the job easier and reduces plan review time.

A complete building envelope plan review covers all of the requirements in Section 402, but the electrical drawings may also need to be included and reviewed if the applicant seeks credit for automatic daylighting control for skylights or fenestration. For Section 402, first review the comments for the applicant above for a general sense of key requirements, then:

- Check that fenestration and opaque door air leakage are included on the fenestration and opaque door schedules and that they do not exceed the maximum allowed. This could also be a note referencing the appropriate industry standard.
- Look for notes indicating that all exterior joints, cracks, and holes in the building envelope are to be caulked, gasketed, weatherstripped, or otherwise sealed.
- Check that moisture migration is addressed, either through vapor retarders being shown on roof, wall, and floor sections or other acceptable means. The appropriate vapor retarder location will vary by climate. It is generally on the inside, but is on the outside for air conditioned buildings in hot-humid climates such as in the southeastern United States.
- Check that the proposed area-weighted average roof U-factor from the Roof/Floor Worksheet complies with the code and matches the drawings. Verify that both opaque roof and non-exempt skylights have been included.
- Verify that insulation R-value is on the opaque roof sections, that the areas are correct, and that the U-factors have been taken from the reference material in this manual or are calculated correctly to include framing effects and thermal short-circuiting due to metal framing members.
- Verify that the proposed U-factor for non-exempt skylights is on the skylight schedule, that the numbers and areas are correct, and that the U-factors are NFRC-certified, taken from the reference material in this manual, or calculated correctly to include the effects of framing.
- Check that the proposed exempt skylights: (1) do not exceed the area allowed; (2) do not exceed the U-factor allowed; (3) are not less than the visible light transmittance required; (4) have curb U-factors that do not exceed 0.21 (equivalent to R-5); (5) have an infiltration rate that does not exceed 0.05 cfm/ft^2. Also check that the electrical drawings have been included in the permit and indicate that all electric lighting fixtures within daylighted zones under skylights are con-

trolled by automatic daylighting controls. All non-exempt skylights must be included in the roof U-factor calculations.

- Check that the proposed area-weighted average exempt skylight U-factors, shading coefficients, and visible light transmittances (VLT) from the Roof/Floor Worksheet match the drawings.
- Verify that: (1) the proposed U-factors, shading coefficients, and VLTs are on the skylight schedule; (2) the numbers of skylights and areas of each are correct; (3) the U-factors are NFRC-certified, taken from the reference material in this manual, or calculated correctly to include the effects of framing; (4) the shading coefficients are NFRC-certified solar heat gain coefficients (includes the effects of the frame) or taken from manufacturer's specifications; and (5) the VLTs are NFRC-certified (as part of the solar heat gain coefficient procedure) or taken from the manufacturer's specifications.
- Check that the proposed area-weighted average wall adjacent to unconditioned space U-factor from the Roof/Floor Worksheet complies with the code and matches the drawings.
- Verify that insulation R-value is on the drawings, that the areas are correct, and that the U-factors have been taken from the reference material in this manual or are calculated correctly to include framing effects and thermal short-circuiting due to metal framing members.
- Check that the proposed area-weighted average floor over unconditioned space U-factor from the Roof/Floor Worksheet complies with the code and matches the drawings.
- Check that all below-grade walls have an insulation R-value no less than that required.
- Verify that the insulation R-value is on the wall or foundation sections, and that it is protected if it is installed on the outside and extends above grade.
- Check that all slab-on-grade floors have a perimeter insulation R-value no less than that required.
- Verify that: (1) the insulation R-value is on the wall or foundation sections; (2) the value is correct based on horizontal or vertical installation; (3) the insulation extends no less than 24, 36 or 48 inches as required; and, (4) it is protected if it is installed on the outside and extends above grade.
- Check that the window-wall ratio calculation (values in table are expressed as a percent) is correct. Window area should include the entire rough opening area of all windows, sliding and swinging glass doors, and clerestories.
- Check that the proposed area-weighted average opaque exterior wall U-factors from the Exterior Wall Worksheet comply with the code (interpolate as necessary for heavyweight walls) and match the drawings.
- Verify that lightweight walls, heavyweight walls, and opaque doors have been included.
- For lightweight walls, verify that: (1) insulation R-value is on the wall sections: (2) the wall areas are correct; and, (3) the U-factors have been taken from the

reference material in this manual or are calculated correctly to include framing effects and thermal short-circuiting due to metal framing members.

- For opaque doors located in these walls, verify that the door U-factor is listed in the door schedule and that the U-factors are NFRC-certified or taken from the reference material in this manual or calculated correctly and include the effects of thermal short-circuits in the door slab and door frame (i.e. are not just based on cut through the center of the insulated section).
- For heavyweight walls, verify that: (1) insulation R-value is on the wall sections, (2) the areas are correct, (3) the U-factors have been taken from the reference material in this manual, or are calculated correctly to include framing effects and thermal short-circuiting due to metal framing members, and (4) the heat capacities have been taken from the reference material in this manual or are calculated correctly.
- For opaque doors located in these walls, verify that the door U-factor is listed in the door schedule and that the U-factors are NFRC-certified or taken from the reference material in this manual or calculated correctly and include the effects of thermal short-circuits in the door slab and door frame (i.e. are not just based on cut through the center of the insulated section).
- Check that the proposed area-weighted average fenestration U-factors, shading coefficients, visible light transmittances (if applicable), and projection factors (if applicable) from the Exterior Wall Worksheet comply with the code and match the drawings.
- Verify that: (1) the proposed U-factors, shading coefficients, and visible light transmittances are on the fenestration schedule, (2) the numbers and areas of each are correct, (3) the U-factors are NFRC-certified, or taken from the reference material in this manual or calculated correctly and include the effects of framing, (4) the shading coefficients are NFRC-certified solar heat gain coefficients (includes the effects of the frame) or taken from manufacturer's specifications, and (5) the visible light transmittances are NFRC-certified (as part of the solar heat gain coefficient procedure) or taken from the manufacturer's specifications.
- Verify that the overhang projection and height used in the projection factor calculation are correct.
- Verify that the electrical drawings are included with the building permit application and that automatic daylighting controls are installed to control electric lighting power in perimeter daylighted zones (if applicable). Make note to the electrical inspector to verify that automatic daylighting controls are installed.
- Check that the inputs to the ENVSTD program match those on the Exterior Wall Worksheet and the drawings. Check calculations for equipment and lighting unless code values have been used. Note that ENVSTD cannot be used to increase the allowed lighting wattage regardless of the values input here. (Tips on reviewing ENVSTD: projection factor (PF)and daylight control credit factor (DLCF) may be left blank if credit is not being taken; no justifying calculations are necessary if heat capacity is input as 1 and insulation position is input as 3 (interior) since these are worst case assumptions.)

Remember that good plan review is important. It's much easier to change a number on a drawing than to remove equipment after it's already been installed.

FIELD INSPECTOR'S RESPONSIBILITIES

The inspector’s task is to make sure that the project is constructed in accordance with the approved plans. Be aware that a number of requirements will vary from project to project. Consequently, while some requirements may be learned once, others will necessitate on-site checking of the approved plans.

The primary challenge for the inspector may be educating the contractors about any changes in the code requirements so that installations are performed correctly, not simply the way they may have been routinely done in the past.

For this code, some of the important items are listed below. Keep in mind that the performance of the fenestration is largely based on the quality control of the manufacturer, while the performance of the insulation is largely based on the quality of the installer. As a start, review the comments above for the applicant and for the plans examiner for a general sense of key requirements.

For the foundation inspection:

- Verify that the perimeter slab insulation has the R-value shown on the drawings and that it covers the areas shown on the drawings. If the insulation is vertical, check to see that the insulation goes all the way to the top of the slab (See Figure 402M) or is protected from sunlight and landscaping if installed on the exterior.
- Verify that the below-grade wall insulation has the R-value shown on the plans. If insulation is to be installed later on the exterior, verify that the correct R-value is installed before the wall is backfilled.
- Inform contractor of any missing items or corrections to be made.For the framing inspection:
- Verify that problems noted at the foundation inspection have been addressed.
- Verify fenestration requirements as soon as products begin arriving on the construction site as it is much more difficult to make changes after all the fenestration has been installed. If there is a problem, it can be fixed more easily early in the process. For large buildings, most of the windows may not have even been fabricated yet.
- Verify that windows, skylights, sliding glass doors, swinging glass doors, opaque swinging doors, and roll-up doors do not exceed infiltration rate specified.
- Verify that exterior joints, cracks, and holes are caulked, gasketed, weatherstripped, or otherwise sealed. Key areas to check for caulking and sealing are where the framing abuts the foundation wall or slab floor, around window and door frames, around wall panels, where the wall meets the roof, and at all utility penetrations. Site-built windows with fixed lites should be caulked and operating sash should be weatherstripped. Doors should be weatherstripped.
- Verify non-exempt skylight U-factors, or the frame type, the number of glazing layers, gap width, low-emissivity coatings, gas fillings and spacer types per the drawings. (Tip: to attempt to verify gas fills in sealed glass units, look for two little plugs in the spacer separating the panes–one for pumping the gas in and the other for letting the air out. Note that these plugs suggest that there is a gas fill other than air, but do not guarantee it. However, if there are no plugs, then gas fill is unlikely.) (Tip: to verify insulating/non-metallic spacer, look for a dark color material separating the panes of glass, rather than aluminum. Be aware that there are some insulating aluminum spacers that look similar to the eye but which have a different profile beneath that improves their performance.)

- Verify exempt skylight overall product U-factor, visible light transmittance, curb U-factors that do not exceed 0.21 (equivalent to R-5), infiltration rates that do not exceed 0.05 cfm/ft^2. Be aware that the electrical inspector must also verify that all electric lighting fixtures within daylighted zones under skylights are controlled by automatic daylighting controls. (See notes and tips above for non-exempt skylights.)
- Verify opaque door U-factors.
- Verify that exterior wall has mass required and that cores are filled with insulation (if applicable).
- Verify fenestration overall product U-factor, shading coefficient, visible light transmittance (if applicable). Verify that windows are recessed or overhangs installed to provide projection factor indicated to shade windows (if applicable). Be aware that the electrical inspector must also verify that all electric lighting fixtures within daylighted zones under skylights are controlled by automatic daylighting controls (if applicable). (See notes and tips above for non-exempt skylights.)
- Inform contractor of any missing items or corrections to be made.

For the insulation inspection:

- Verify that problems noted at the framing inspection have been addressed.
- Verify moisture migration features such as vapor retarders (if appropriate at this stage).
- Verify insulation R-value for roofs. Verify that insulation is in substantial contact with the surface being insulated to avoid air paths which bypass the insulation. If eave vents are installed, verify baffling of vent openings to deflect incoming air above the insulation.
- Verify that type IC (insulation contact) luminaires are installed, if shown on the plans or if insulation contacts the fixtures.
- Verify insulation R-value for walls adjacent to unconditioned space. Verify that insulation is in substantial contact with the surface being insulated to avoid air paths which bypass the insulation.
- Verify insulation R-value for floors over unconditioned space. Verify that insulation is in substantial contact with the surface being insulated to avoid air paths which bypass the insulation. For frame floors, this may mean installing supports to keep the insulation tight against the floor.
- Verify insulation R-value of below-grade walls (if not done previously).
- Verify that below-grade wall insulation is protected as it extends above grade. If the below-grade wall is furred out and insulation installed on the interior protection is usually not a problem. If the below-grade wall insulation is installed on the exterior (generally preferable from an energy point of view), it must extend above the ground and consequently be protected.
- If below-grade walls are partially below-grade and partially above grade, make sure that a continuous thermal barrier is provided.

- Verify insulation R-value for exterior walls. Verify that insulation is in substantial contact with the surface being insulated to avoid air paths which bypass the insulation. Verify that insulation is not compressed by inset stapling of batt insulation or other means. Verify that insulation fills all cavities completely by cutting insulation around electrical outlets and switches, and by slicing insulation to fit behind and in front of electrical wiring in the cavity. Verify that band joists and other between floor elements of the wall are insulated.
- Inform contractor of any missing items or corrections to be made.

For the final inspection:

- Verify that problems noted at the insulation inspection have been addressed.

An inspector's ongoing challenge is responding to change orders during construction. In any construction project, there will be field changes. The call is easy if a more efficient piece of equipment is being substituted for a less efficient one. For the opaque elements, more insulation is generally better. For fenestration, a lower U-factor and shading coefficient is generally better, as is a higher visible light transmittance. Unfortunately, however, changing the glass almost always changes more than one characteristic and it is not always clear if energy efficiency is being improved. Often what reduces the shading coefficient (good), also reduces the visible light transmittance (bad). If there is any doubt as to the impact, the inspector should confer with the plans examiner for the project.

A more difficult change order is one that reduces efficiency. For example, if the proposed substitute fenestration has a higher U-factor and shading coefficient, or if the window area is proposed to be increased, the inspector must definitely check with the plans examiner. In these cases, compliance is based on a combination of the fenestration area, U-factor, shading coefficient, and, perhaps the visible light transmittance, projection factor, and (if ENVSTD has been used) even the opaque wall characteristics. While there may be enough slack to decrease the efficiency somewhat, it's not possible to make a determination without reviewing all of the elements and how compliance was initially demonstrated. Whenever there are significant changes, the inspector is expected to request that the applicant submit revised plans, so that the plans examiner can verify compliance and assure that there is a correct record on file in the building department.

An even tougher case is when the contractor has already installed noncomplying equipment without checking with the inspector. For instance, ordinary double-glazing may have been installed instead of double-glazing with a low-emissivity coating. The inspector should be quite strict for several reasons. First, since most contracts are awarded on a cost-competitive basis, the low bid company might win the job and then make its profit by installing non-complying equipment. This would be unfair to the higher-bid contractors. Second, a lenient inspector's job will be more difficult in the future. If a non-complying contractor skates by this time, that contractor will most likely have additional requests for future projects. In addition, other contractors will also begin to ask for special treatment. Self-policing, which works well if everyone is being treated fairly, will begin to decline.

Finally, there is the situation when the approved plans do not contain all of the code requirements. If information or notes are missing from the plans, the inspector can, for instance, simply direct the contractor to make the necessary changes in the field; i.e. caulk and seal joints. The inspector's job is more difficult, however, if the drawings contain information that is wrong. Perhaps the inspector in a cold climate notices that the metal stud wall is not covered with insulated sheathing as is required in that climate and informs the contractor. The contractor responds that they are following the approved plans and indeed they are. The inspector, as the representative of the building official, is clearly authorized to require that the contractor build the project to code. (If necessary the inspector can show the contractor the building department note which says "approved subject to errors and omissions.) In this case, it seems appropriate for the inspector to inform the plans examiner of the problem and ask the plans examiner to help solve the problem. The plans examiner may be able to suggest improvements in other areas that would compensate for this shortfall. It is important that the plans examiner and inspector appreciate the challenges of each others' work and the benefits of a team effort.

Case Study – Office Building

The following case study demonstrates the recommended procedure for documenting compliance with the envelope requirements (Section 402 of the 90.1 Code). Requirements that must be documented include: air leakage and moisture migration, the thermal performance of all opaque surfaces, and fenestration (including skylights).

This case study includes a completed summary form, a roof/floor worksheet, and an exterior wall worksheet. Two compliance paths are demonstrated for the case study: the prescriptive method and the system performance method. In practice only one of these paths needs to be followed to show compliance with the 90.1 Code.

The following drawings for the case study are included in Appendix B.

- Floor plan (page B-1): Shows the general layout of the building. Used to determine wall, roof, skylight, and window areas. This drawing is referred to as "A2" on the summary form.
- Building elevations (Page B-2): Show each facade of the building. Used to determine wall and window area, and projection factor. These drawings are referred to as "A5" on the summary form.
- Building sections (Page B-3): Show cross sections of the building at various locations. Used to determine projection factor, roof area, and wall area. These drawings are referred to as "A6" on the summary form.

The following drawings are not included in the appendix; however, they are referred to on the completed summary form. These drawings would be included in a complete set of building plans submitted to a building department for approval.

- Wall/floor/roof sections: Show the construction assembly of walls and roofs. Used to determine projection factor, wall and roof area, and U-factor. Also indicates slab edge insulation and vapor barriers to prevent moisture migration. These drawings are referred to as "A7" on the summary form.
- Wall/floor/roof details. Show the construction assembly of the connections between the walls and floor and the walls and roof, as well as the wall construction at doors and windows in detail. Used to supplement the information contained in the wall/floor/roof section diagrams. These drawings are referred to as "A9" on the summary form.
- Fenestration details. Show the assembly of all windows and doors in detail. Used to determine the area of all fenestration. These drawings are referred to as "P3" and "P3A" on the summary form.
- Lighting plan. Shows the layout of all lighting and describes the lighting controls. Used in conjunction with the lighting fixture schedule to determine the lighting power density and to verify the existence of daylighting controls. This drawing is referred to as "E2" on the summary form.

The following information is included with the text of this section, but would ordinarily be included with the plans and/or specifications.

- Window, Door, and Skylight Schedules: Show window, door, and skylight types and dimensions. Also includes manufacturer specified U-factors, shading coefficients, visible light transmittance, and infiltration. Used to determine window, door, and skylight area and thermal performance.

- General Notes: Show compliance with air leakage requirements.

References are made on the summary form and checklist to wall and window detail drawings and to lighting control specifications. These have not been included in the case study; however, they would be included in the complete set of plans submitted to a building department for approval.

BUILDING DESCRIPTION

The case study building is a new office to be constructed in Chattanooga, Tennessee. The building is single story with an insulated slab-on-grade floor. All walls are light construction. High performance windows and skylights have been specified. The skylights include light louvers that are connected to a photosensor and to the building's daylighting control system. The design lighting level of this building is 50 footcandles, and the lighting designer has determined that the lighting power density is less than 1.0 W/ ft^2.

Window/Door/Skylight Schedules

To facilitate the determination of window, door, and skylight areas and performance characteristics, the designer of this building has included a window/door schedule and a skylight schedule. Although such schedules are not required by the 90.1 Code, they are highly recommended, and greatly facilitate not only the completion of the compliance forms, but also the verification of building envelope compliance. A well constructed window, door, or skylight schedule should include the following:

- ID: An identification number or letter used to identify the window, door, or skylight on the drawings.
- Quantity: The number of windows, doors, or skylights of a given type.
- Dimensions: The frame or rough opening dimensions for each window type. This allows the total window, door, or skylight area to be easily calculated.
- Physical Description: A brief description of the physical characteristics of each window, door, or skylight. For windows and skylights, this should include the frame type, the number of panes, the existence of any coatings, tints, or films, the presence of any gas fills (such as argon or krypton), and the gap width. For doors, this would include the type of door, its thickness, what the door is made of, and whether or not it is insulated.
- Performance characteristics: The U-factor, shading coefficient (SC), and visible light transmittance (VLT) of skylights and windows, and the U-factor of opaque doors. These values can be taken from manufacturer's data or from the default tables in the Reference section of this chapter. When manufacturer's literature is used, copies should be provided to the building department, so that they can verify the performance characteristics.
- Maximum Infiltration: Shows the appropriate ASTM or AAMA test procedure which applies.

Note that the skylight schedule includes a curb description and a separate field for the curb U-factor. This information, although helpful, is typically not given in a skylight schedule, but rather, is included in a roof section showing a typical skylight.

General Notes

Construction notes and call-outs are typically included on the plans which indicate that the appropriate envelope infiltration requirements will be met. The following are notes taken from the case study plan set.

- All exterior joints and openings in the building envelope that are observable sources of air leakage shall be caulked, gasketed, weatherstripped, or otherwise sealed.
- Site constructed doors, windows, and skylights shall be caulked between the unit and the building, and shall be weatherstripped (except for unframed glass doors and fire doors).
- Manufactured doors and windows installed shall have air infiltration rates certified by the manufacturer. This is also shown on the schedule.
- All insulating material shall be installed in compliance with the flame spread rating and smoke density requirements of the applicable building code.

COMPLIANCE DOCUMENTATION

The compliance forms that address the building envelope are not difficult to complete, provided that an organized methodology is used to collect and document the required information. This text discusses the procedure that was used to fill out the envelope compliance forms for the case study building.

The Envelope Summary, Roof/Floor Worksheet, and the Exterior Wall Worksheet are the three forms that must be completed to demonstrate compliance with the requirements of Section 402. For buildings with only one type of wall, roof, or floor construction, the Roof/Floor and Exterior Wall Worksheets may be omitted. For more complex buildings, the two worksheets are used to determine area-weighted average U-factors and other performance parameters.

Table 402C Office Case Study Window/Door Schedule

ID	Number	Dimensions	Frame	Outer Lite	Film	Inner Lite	Gap	U-factor	SC	VLT	Infiltration Requirement
A	2	7'2.75" x 6'11.5"	Fixed Al-TB	1/4 in. green	HM-44	1/4 in. clear	1/2 in. air filled	0.32	0.25	0.32	ASTM E283-89
B	1	6'5" x 6'11.5"	Fixed Al-TB	1/4 in. green	HM-44	1/4 in. clear	1/2 in. air filled	0.32	0.25	0.32	ASTM E283-89
C	2	4'1.5" x 8' 5.75"	Fixed Al-TB	1/4 in. green	HM-44	1/4 in. clear	1/2 in. air filled	0.32	0.25	0.32	ASTM E283-89
D	1	6' x 8'5.75"	Al-TB door	1/4 in. green	HM-44	1/4 in. clear	1/2 in. air filled	0.32	0.25	0.32	ASTM E283-89
E	1	5'10" x 6'11.5"	Fixed Al-TB	1/4 in. green	HM-44	1/4 in. clear	1/2 in. air filled	0.32	0.25	0.32	ASTM E283-89
D	19	7'6" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
E	2	7'8.75" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
F	1	6'7.75" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
G	1	6'6" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
H	2	6'1.5" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
I	1	5'10.5" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
J	1	6'11.5" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
K	1	8'1.5" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
L	2	9'10" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
M	1	5'4.75" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
N	1	6'6.75" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
O	1	4'6" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
P	2	3' x 8'5.75"	Al-TB door	1/4 in. green	HM-55	1/4 in. clear	1/2 in. air filled	0.32	0.29	0.4	ASTM E283-89
Q	6	7'6" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-88	1/4 in. clear	1/2 in. air filled	0.33	0.43	0.6	ASTM E283-89
R	1	4'11.5" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-88	1/4 in. clear	1/2 in. air filled	0.33	0.43	0.6	ASTM E283-89
S	1	7'8.75" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-88	1/4 in. clear	1/2 in. air filled	0.33	0.43	0.6	ASTM E283-89
T	1	4'6" x 5'11.5"	Fixed Al-TB	1/4 in. green	HM-88	1/4 in. clear	1/2 in. air filled	0.33	0.43	0.6	ASTM E283-89
U	1	3' x 8'5.75"	Al-TB door	1/4 in. green	HM-88	1/4 in. clear	1/2 in. air filled	0.33	0.43	0.6	ASTM E283-89

Table 402D Office Case Study Skylight Schedule

ID	Number	Dimensions	Frame	Outer Lite	Inner Lite	Gap	Other	Curb	U-factor	SC	VLT	Curb U-factor	Infiltration Requirement
A	21	4'9" x 3'9"	Al-TB	1/4 in. clear	1/4 in. clear	1/2 in. air	Louvers	1X12 wood w/R-5	0.62	0.81	0.78	0.17	<0.05 cfm/ft^2
B	6	3'9" x 4'9"	Al-TB	1/4 in. clear	1/4 in. clear	1/2 in. air	Louvers	1X12 wood w/R-5	0.62	0.81	0.78	0.17	<0.05 cfm/ft^2
C	2	2'3" x 8'3"	Al-TB	1/4 in. clear	1/4 in. clear	1/2 in. air	Louvers	1X12 wood w/R-5	0.62	0.81	0.78	0.17	<0.05 cfm/ft^2
D	2	4'9" x 2'	Al-TB	1/4 in. clear	1/4 in. clear	1/2 in. air	Louvers	1X12 wood w/R-5	0.62	0.81	0.78	0.17	<0.05 cfm/ft^2

Envelope Summary Form

The Envelope Summary form is organized to follow the sequence of the requirements. It is used by the permit applicant to demonstrate compliance, by the building department plan checker to verify compliance, and by the building inspector as a more detailed checklist for building inspection. The Compliance and Enforcement section of this chapter provides a checklist of the responsibilities of each of these parties. The summary form includes a checklist for the applicant on the back that describes the information that should be included on the plans and specifications.

402.2.1 Air Leakage

The first item on the summary form pertains to air leakage. The permit applicant must show that the doors and fenestration meet the infiltration requirements. This information should be provided in the window, door, and skylight schedules. The applicant indicates the place in the plans where the window schedule is included. For the case study building, all windows have fixed aluminum frames. The 90.1 Code requires that these windows comply with ASTM E283-89.

402.2.2 Exterior Envelope Joints

The permit applicant indicates a page number on the plans where the plans examiner can find comments regarding caulking and sealing of exterior envelope joints. This information is usually provided in a “General Notes” sidebar on one of the plan pages. For this case study, the information is contained in this text, so the reference is given as "See Notes."

402.2.3 Moisture Migration

The next item on the summary form pertains to moisture migration. The permit applicant shows that vapor barriers will be installed and correctly oriented. This information is typically given in the wall and roof section diagrams (ref. A7). For this case study building, all insulation is either foil or Kraft-paper faced. The "faced" side of the insulation in this building is the inside surface, since in Chattanooga, Tennessee, as in most cities, this is where there is the greatest risk of condensation. The page number for the roof and wall sections is listed on the summary form, so that the plans examiner can quickly verify that vapor barriers have been included and are correctly positioned.

402.3.1 Roof Requirements

The area-weighted average roof U-factor, including skylights that do not meet the exemption criteria, is listed on the summary form. Default U-factors for different roof assemblies are given in Table 402K of this manual. If the U-factor for a given roof assembly cannot be found in this table, one of the approved U-factor calculation methods described in the Reference section of this chapter may be used. All roof assemblies in this case study building are 9.25 in. deep, single rafter wood joist constructions with R-30C insulation. The U-factor shown in the table for this roof type is 0.034 Btu/(hr ft^2 F). Since all skylights are exempt, area-weighted average calculations are not needed. This value is entered on the summary form, along with the page number on which the roof section diagrams (ref. A7) can be found. If more than one roof type existed, or if some or all of the skylights in the building were non-exempt, it would be necessary to determine the area-weighted average U-factor for all roof constructions. This calculation is documented on the Roof/Floor worksheet. In order to comply with the 90.1 Code, the area-weighted average roof U-factor must be less than the value listed in Table 402.3.1(A). Since the U-factor determined for this building is less than the value of 0.068 Btu/(hr ft^2 F) given in the table for Chattanooga, TN, the building is in compliance with the Code.

402.3.1 Skylight Exemption

If the permit applicant has exempted some or all of the skylights, compliance with the skylights exemption criteria must be documented on the summary form. The area-weighted average U-factor and the proposed area of exempted skylights are entered on the summary form. The page number of the plans where daylighting controls are shown is entered, as well as the skylight curb U-factor and the skylight infiltration rate. For this case study building, the U-factor is the same for all skylights and is equal to 0.62 Btu/(h ft^2 F). This value, along with a reference to the skylight schedule is listed on the summary form. In Chattanooga, TN, the skylight U-factor must be lower than 0.70 Btu/(h ft^2 F) to qualify for exemption. If there was more than one type of skylight installed in this building, it would have been necessary to calculate the area-weighted average skylight U-factor using the Roof/Floor Worksheet.

The total skylight area in the case study building is 537 ft^2. The maximum exempt skylight area, expressed as a percentage of the gross roof area, is given in Table 402.3.1(B) of the 90.1 Code. In order to find the appropriate value using this table, the area-weighted VLT of the skylights must be known, as well as the design light level and the lighting power density (LPD). The VLT of all of the skylights in this building is the same, and is equal to 0.78. Since the 90.1 Code does not allow extrapolation beyond 0.75, the VLT=0.75 section of Table 402.3.1(B) must be used. For an office building, the design light level is 50 footcandles and for this building the LPD is less than 1.0. The maximum exempt skylight area is given in the table as 2.5% of the gross roof area for these conditions; however, since the skylights in this building are equipped with louvers that can block over 50% of solar gains, the value given in the table can be increased by 50%. Thus, the maximum exempt skylight area for this building is 3.75% of the gross roof area. The gross roof area of this building is 16,290 ft^2, when measured as shown in Figure 402C of this chapter, so a total skylight area of 611 ft^2 can be exempt. The actual exempt skylight area of 537 ft^2, and a reference to the page of the plans which shows the skylight layout, is entered on the summary form.

Electric lighting in daylighted areas must be connected to automatic daylighting controls. These controls are documented on the lighting plan (ref. E2).

Exempt skylight curbs must have a U-factor that is less than 0.21 Btu/(h- ft^2 F). The skylight curbs in this case study building are wood, with R-5 foam insulation. As mentioned above, this information is included in the skylight schedule; however, it could also be provided in a skylight detail. Both the curb U-factor and a reference to the above schedule are shown on the summary form.

Exempt skylights must also have an infiltration rate less than 0.05 cfm/ ft^2. This information is typically shown in the skylight schedule.

402.3.1 Floors Over Unconditioned Space

The next section on the summary form pertains to floors over unconditioned space. This case study building is a single story slab-on-grade building, and therefore has no floors over unconditioned space. As a result, this section of the summary form has been marked N/A for not applicable. If more than one floor type existed, it would be necessary to calculate their area-weighted average U-factor using the Roof/Floor Worksheet. The value obtained would then be compared to the maximum permissible value given in Table 402.3.1(A) of the 90.1 Code to verify compliance.

402.3.1 Walls Adjacent to Uncondtioned Space

The proposed area-weighted average U-factor for walls (including opaque doors) adjacent to unconditioned space must also be entered on the summary form. In this building, there is only one type of wall adjacent to unconditioned space, so the area-weighted average U-factor is equal to the U-factor for this one wall type. Default U-factors for opaque walls are given in Table 402P of this manual. The wall in question is a wood framed wall, with 2x4's spaced at 16 inches, and R-11 insulation. The U-factor given for such a construction is 0.088 Btu/(h ft^2 F). This value, along with a reference which refers to the location of the appropriate wall section or detail diagram (ref. A9) is given on the summary form. Table 402.3.1(A) of the code lists the maximum permissible U-factor for walls adjacent to unconditioned space. In Chattanooga, TN, this value is 0.198 Btu/(h ft^2 F), so the wall construction in this building complies. If more than one wall type adjacent to unconditioned space exists, the Roof/Floor Worksheet can be used to calculate the area-weighted U-factor.

402.3.2 Below-Grade Walls

If there were below-grade walls in the case study building, the R-value of the insulation on these walls would be listed on the summary form, along with a page number which references the location of the section diagrams for these walls in the plans. The minimum permissible R-value for such walls is given in Table 402.3.2 of the 90.1 Code. In this case study building, there are no below-grade walls, so this section of the summary form has been marked N/A.

402.3.2 Slabs-on-Grade

The next section of the summary form pertains to slab-on-grade floors. These floors can be either heated or unheated, and there is a different line on the summary form for each. The floor of the case study building is an unheated slab floor with vertical, 24 inch deep, R-14 rigid insulation. This data is entered on the form, along with the plan page number that contains the appropriate wall/floor section diagram. The minimum R-value requirements for slab insulation are given in Table 402.3.2 of the 90.1 Code. The minimum R-value in Chattanooga, TN for unheated slab floors with 24 in. deep vertical insulation is R-6; therefore, the case study building complies with the Code.

There are no heated slab floors in the case study building, so this line of the summary form is marked N/A.

402.4 Exterior Walls

The next section of the summary form pertains to exterior wall surfaces. The first entry is for the gross wall area. The gross wall area includes all doors and fenestration, and is measured as shown in Figure 402C of this chapter. For this case study building, the gross wall area is 7,149 ft^2. This value is listed on the summary form, along with references to the plan page numbers containing the drawings that were used to determine this value. The next entry is the total fenestration area. The fenestration area for this building is 1,983 ft^2. Again, this value and the appropriate page numbers are listed on the summary form. The fenestration area divided by the gross wall area is the window-wall ratio (WWR). For this building, the WWR is 0.28. This value is entered on the summary form.

It is also necessary to enter the internal load density (ILD) on the summary form. There are three default ILD ranges that apply to different occupancy types. For warehouses, residential spaces, and hotel/motel guest rooms, the ILD range is 0.00 to 1.50. For retail spaces smaller than 2000 ft^2 and technical/vocational schools smaller than 10,000 ft^2, the ILD range is 3.01 or greater. For all other occupancy types, the ILD range is 1.51 to 3.00. Thus, for this case study building, the appropriate ILD range is 1.51 to 3.00.

402.4.1.1 Opaque Wall Data

The area-weighted average U-factor of all opaque walls is entered on the summary form. This is compared to the criteria for light weight walls (HC < 5). If the building does not comply, then the heat capacity (HC) of mass walls can be considered. The walls in the case study building are all the same: 2 x 6 in. walls with 24 in. spacing and R-19 batt insulation. A default U-factor is given for this and several other wall types in Table 402P of this chapter. The U-factor is 0.057 Btu/(hr ft^2 F). Since there is only one type of wall construction in this building, area-weighted average U-factor calculations are not required. The maximum permissible U-factor for opaque walls is given in Table 402.4.1.1 of the 90.1 Code. For light walls, the value given is independent of the WWR. In Chattanooga, TN, the maximum permissible U-factor is 0.125 Btu/(hr ft^2 F), so this building complies with the code.

402.4.1.2 Fenestration Data

Next, the area-weighted average U-factor, shading coefficient, projection factor, and visible light transmittance of all vertical fenestration in the given building is entered on the summary form. These values are used to determine the maximum permissible window-wall ratio. For this building, the area-weighted fenestration U-factor is 0.32 Btu/(hr ft^2 F), the SC is 0.31, the projection factor is 0.85, and the VLT is 0.42. These values are calculated using the worksheets, and the appropriate page references are shown on the summary form. It is also necessary to show whether or not the given building has perimeter daylighting. The perimeter zones of this case study building are daylighted, so the “yes” on the form is circled, and a reference to the page on which the daylighting controls can be found is given.

Knowledge of the area-weighted average fenestration performance characteristics allows the maximum permissible WWR to be determined using Table 402.4.1.2 of the 90.1 Code. For this building, the ILD is in the range 1.51 to 3.00, so this section of the table is entered. Furthermore, the area-weighted projection factor is greater than 0.50, so this section is entered. The area-weighted shading coefficient of the fenestration in this building is less than 0.50, so this row of the table is entered. In order to qualify for perimeter daylighting in Chattanooga, TN, the area-weighted VLT of the fenestration must be greater than the SC. For this building, the VLT is equal to 0.42 and the SC is equal to 0.31, so the perimeter daylighting section of the table is entered. Since the area-weighted U-factor is less than 0.38 Btu/(hr ft^2 F), the last column of the table is entered, and the maximum WWR is found to be 69%. Since the WWR of this building was determined above to be 28%, the building complies with the 90.1 Code.

Supplementary Worksheets and ENVSTD Results

The last step in completing the Envelope Summary form is to indicate which worksheets were used to calculate the values listed on the form, and whether or not an ENVSTD output was generated. If they were used, the worksheets and the ENVSTD output must be submitted to the building department, along with the Envelope Summary form. This allows the plans inspector to quickly verify the calculations made to determine compliance. A description of the two worksheets and of the ENVSTD program is given in the following sections.

SYSTEM PERFORMANCE METHOD

The ENVSTD program can also be used to demonstrate compliance with the 90.1 Code. This method of compliance is useful if the designer wishes to make trade offs between wall performance and fenestration performance. For instance, if a designer has used fenestration with relatively poor thermal characteristics, he can "make up" for it by specifying wall constructions with relatively low U-factors. The ENVSTD program calculates exterior wall compliance and "other envelope" compliance. The "other" category includes roofs, skylights, floors over unconditioned space, walls adjacent to unconditioned space, and slab insulation. The ENVSTD output for exterior wall compliance has been included in this case study. The "other envelope" output has not been included since the requirements are identical to the prescriptive criteria.

In order to the use of ENVSTD, it is helpful to first complete a separate Roof/Floor Worksheet and Exterior Wall Worksheet for each building orientation. A typical building will have four orientations; however, ENVSTD can accept as many as eight orientations. Curved walls should be divided as accurately as possible into the appropriate orientations.

Upon entering the ENVSTD program, it is necessary to enter a code for the city in which the building is located. A list of all available cities is displayed by pressing the <F6> key. The case study building is located in Chattanooga, TN, which is code #44. The next step is to name the building or project. The building in this case study has simply been named office; however, it is more suitable to use a project name, or, preferably, an address. Next, the type of space conditioning needs to be specified (heating, cooling, or both). The case study building is both heated and cooled. A date is then entered.

The gross wall area is entered in the first row of the data table for each orientation. This area includes doors and fenestration. Next, the vertical fenestration area is entered for each orientation. The area-weighted shading coefficient, projection factor, visible light transmittance, and U-factor are then entered for each orientation. These values are taken from the Exterior Wall Worksheets. Again, when using ENVSTD, it is necessary to complete a separate worksheet for each building orientation. Note that the PF given for the west facade is 0.50, whereas it was previously calculated to be 1.36. ENVSTD does not accept PF's greater than 1.0. Furthermore, credit is not given for PF's greater than 0.50: these projection factors are simply treated as being equal to 0.50. After entering the fenestration data, the area-weighted opaque exterior wall U-factor is entered for each orientation. In this case study, all wall constructions are the same; however, in most buildings, there will be more than one type of wall construction. Similarly, all walls in this building are lightweight walls, so an HC equal to "1" is entered for each orientation. As mentioned previously, it is recommended that calculations first be performed under the assumption that all walls are lightweight (HC=1). If the building fails to comply, then mass walls can be taken into account. The next row is for insulation position. For lightweight walls, as in this case study, this value is equal to “2” for all orientations, which means that the insulation is integral to the wall. Exterior insulation is equal to “1” and interior insulation is equal to “3”.

The next field is the equipment power density. This value is taken from Table 402.4.2 of the 90.1 Code. According to the table, the default adjusted equipment power density for an office space is 0.40. This is the same for each orientation in this building; however, if different areas of the building were used for different purposes, then this value could change with orientation. The next entry is the lighting power density. This value is provided by the lighting designer. Again, for this building, the lighting power density is less than one for each orientation; however, a conservative value of one has been used for each. The final entry on the ENVSTD exterior wall form is the daylight control fraction. If the perimeter zones are not daylighted, this value is equal to zero. Otherwise, the DLCF is equal to the percentage of lights that are within 15 feet of a given facade that are controlled by automatic daylighting controls. The DLCF for this building is 0.80 for each facade.

By pressing the <F9> key, ENVSTD will calculate whether a given design complies with the 90.1 Code. The results of the ENVSTD exterior wall calculation are as shown on the included sheet. Note that this building “passes” the envelope performance requirements.

ENVSTD also calculates compliance with the other envelope requirements. By pressing the <F5> key, the “other envelope requirements” screen appears. The data from the Roof/Floor Worksheet is entered on this screen. The first entry is the area-weighted VLT of all skylights in the building. This value is equal to 0.78 for the case study building. The next entry is the design illuminance of the building. For an office space, this is equal to 50 footcandles. If the <F9> key is pressed at this point, ENVSTD will return the maximum exempt skylight area as a percentage of gross roof area. The actual area of exempt skylights as a percentage of gross roof area can then be entered, provided that this value is equal to or less than the limiting value. Note that ENVSTD does not allow the designer to take credit for shading devices on skylights, thus, the maximum allowable skylight area is the same as that listed in Table 402.3.1(B).

The next entry is the roof U-factor. This value includes opaque surfaces and any non-exempt skylights, and is taken from the Roof/Floor Worksheet. The roof U-factor for this building is equal to 0.034 Btu/(hr ft^2 F). The area-weighted U-factors for walls adjacent to unconditioned space and floors over unconditioned space are also entered. Again, these values are taken from the Roof/Floor Worksheet. This building has no floors over unconditioned space. The U-factor for walls adjacent to unconditioned space is equal to 0.088 Btu/(hr ft^2 F).

The last section of the “other envelope requirements” screen pertains to below-grade walls and slab insulation. The R-value of below-grade walls must first be entered. This value is taken directly from the wall section diagrams on the plans. There are no below-grade walls on this case study building. It must be specified whether slab floors are heated or unheated. The floors in this building are unheated. The position of the slab insulation must also be entered (vertical or horizontal). The slab insulation for this building is vertical. Next, the depth of vertical insulation, or the width of horizontal insulation is entered. For this case study building, the slab edge insulation is 24 in. deep. The last entry is for the R-value of the slab insulation. The slab in this case study building is insulated with two in. of polyisocyanurate, which has an R-value of about 7 (hr ft^2 F)/Btu per in., so the total R-value for this building is 14.

After all of the data has been entered, pressing the <F9> key will determine whether the design complies with the other envelope requirements. If the building passes both the exterior wall requirements and the other requirements, then it complies with the performance method as specified by the 90.1 Code. The output from the ENVSTD program should be submitted to the building department, along with the Envelope Summary form, the Roof/Floor Worksheet, and all Exterior Wall Worksheets.

Figure 402P Office Case Study Envelope Summary Form

Figure 402Q Office Case Study Roof/Floor Worksheet

Figure 402Q Office Case Study Roof/Floor Worksheet (continued)

Figure 402R Office Case Study Exterior Wall Worksheet

Figure 402R Office Case Study Exterior Wall Worksheet (continued)

Figure 402S Summary Compliance Screen

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           ENVELOPE SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
                                  VERSION 2.1
                           U.S. DEPARTMENT OF ENERGY
       VOLUNTARY PERFORMANCE STANDARDS FOR NEW COMMERCIAL AND MULTI-FAMILY
         HIGH RISE RESIDENTIAL BUILDINGS; MANDATORY FOR FEDERAL BUILDINGS

CITY: 44                 Chattanooga TN  BUILDING: Office
CODE <B,C,H>: Both Heated and Cooled         DATE: 11/29/94
             WALL ORIENTATION                                  WEIGHTED
           N      NE      E      SE      S      SW      W     NW  AVERAGE CRITERIA
------- ------------------------------------------------------------- ------- -------
WL AREA|  1641          1738          1458          2312        |  0.28 | 0.310
GL AREA|   336           673           391           593        |   WWR |   WWR
   SCx | 0.43          0.29          0.29          0.27         |  0.32 | 0.421
    PF | 0.53          0.63          0.68          0.50         |  0.58 |   0.0
   VLT | 0.60          0.40          0.40          0.36         |  0.43 |   N/A
   Uof | 0.33          0.32          0.32          0.32         |  0.32 | 0.762
WALL Uo| 0.057         0.057         0.057         0.057        |  0.06 | 0.126
    HC |    1             1             1             1         |  1.00 |     1
INS POS|    2             2             2             2         | 2     |   N/A
EQUIP  | 0.40          0.40          0.40          0.40         |  0.40 | 0.400
LIGHTS |    1             1             1             1         |  1.00 | 1.000
DLCF   | 0.80          0.80          0.80          0.80         |  0.80 |   0.0
------- ---------------------- L O A D S ---------------------- -TOTAL- -------
HEATING| 2.193         2.767         2.148         3.503        | 10.611< 15.724
COOLING| 5.017         5.806         4.956         6.752        | 22.531< 36.187
TOTAL  | 7.210         8.574         7.104        10.255        | 33.143< 51.911
================================================================================
                    **********    PASSES   **********
```

Case Study – Restaurant

The following information is provided as an exercise. The envelope details are given for a new building to be constructed in the midwestern United States. Enough information is provided to complete the required envelope compliance forms.

BUILDING DESCRIPTION

The building used in this example is a new, single story restaurant that will be built in Columbus, Ohio in the immediate future. The restaurant is to be constructed on an unheated slab floor, with 2 inch thick, 24 inch deep (vertical), polyisocyanurate foam insulation. All of the walls in the building are light construction. The exterior walls consist of 2x6 fir studs spaced at 16 inches, with R-19 fiberglass batt insulation. Walls adjacent to unconditioned space consist of 2x4 fir studs spaced at 16 inches, with R-11 fiberglass batt insulation. There are two roof constructions: the first is used over the perimeter of the building, and consists of a 9.25 inch deep single rafter wood joist assembly with R-30C insulation. The second roof type is used over the center of the building, and has the same assembly as the first roof type, with the addition of one inch of extruded polystyrene foam. The interior load density (ILD) of this building is between 1.51 and 3.00 W/ft^2.

The following area take-offs can be used to determine 90.1 Code compliance:

- Roof Area: The gross roof area, including skylights, is 9,680 ft^2. Of this total, 5,480 ft^2 is the first roof type described above, and 4,200 ft^2 is the second roof type. There are two skylights (see skylight schedule) in this second roof type.
- Exterior wall area: The gross exterior wall area, including doors and fenestration, is 4300 ft^2. All walls have the same construction assembly.
- Wall adjacent to unconditioned space area: The gross wall area adjacent to unconditioned space is 400 ft^2. There are no doors located in this wall area.
- Floors over unconditioned space area: There are no floors over unconditioned space.
- Below grade wall area: There are no below grade walls.
- The area weighted average projection factor for all vertical fenestration in the building is between 0.26 and 0.50.

Window/Door/Skylight Schedules

In addition to the above information, the following schedules were taken from the plans for this building. These schedules can be used to determine the area and performance characteristics of the windows, doors, and skylights in the building.

Table 402E Window Schedule (incl. glass doors)

ID	Number	Dimensions	Frame	Outer Lite	Film	Inner Lite	Gap	U-factor	SC	VLT	Infiltration
A	4	1’4.75”x5’5”	Fixed AL-TB	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
B	2	3’4”x7’4.5”	Fixed AL-TB	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
C	43	3’6”x7’4.5”	Fixed AL-TB	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
D	4	3’5”x7’4.5”	Fixed AL-TB	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
E	2	2’1.25”x36”	Fixed AL-TB	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
F	1	3’1.5”x7’	AL-TB Door	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89
G	1	3’1.5”x7’	AL-TB Door	1/4in. bronze	None	1/4in. clear	1/2in. air filled	0.51	0.57	0.47	ASTM E283-89

Table 402F Door Schedule

ID	Number	Dimensions	Thickness	Description	Insulation	U-factor	Infiltration
A	1	5’x6’8”	1’3/4”	Steel Door. No thermal break.	Paper honeycomb	0.56	ASTM E283-89
B	1	3’6”x7’	1’3/4”	Steel Door. No thermal break.	Paper honeycomb	0.56	ASTM E283-89

Table 402G Skylight Schedule

ID	Number	Dimensions	Frame	Glazing	Curb	U-factor	SC	VLT	Curb U-factor	Infiltration
A	2	4’x4’	Al-TB	Single, medium white acrylic	1x12 fir w/R-5 Foam	1.21	0.68	0.53	0.17	<0.05 cfm/ft^2

General Notes

The plans for this restaurant also included the following general comments:

- All exterior joints and openings in the building envelope that are observable sources of air leakage shall be caulked, gasketed, weatherstripped, or otherwise sealed.
- Site constructed doors, windows, and skylights shall be caulked between the unit and the building, and shall be weatherstripped (except for unframed glass doors and fire doors).
- Manufactured doors and windows installed shall have air infiltration rates certified by the manufacturer. This may also be shown on the schedule.

Reference

AREA-WEIGHTED AVERAGES

The 90.1 Code requires that you know the U-factor, shading coefficient, visible light transmission, projection factor, etc. for envelope components. Buildings are usually complex designs and include many different types of wall, roof, and floor construction assemblies. Often more than one type of window or overhang will exist in a building. In these cases, it is necessary to calculate an area-weighted average.

The area-weighted average is like a simple average, except that larger surfaces are weighted more heavily than smaller surfaces. Suppose that a building has two roof constructions. The first construction represents an area of 9,000 ft^2 and has a U-factor of 0.030. The second construction represents an area of just 1,000 ft^2 and a U-factor of 0.100. A simple average is 0.065 is calculated as shown below.

$$\textit{Simple}\ \text{Average} = \frac{0.030 + 0.100}{2} = 0.065$$

Since the higher U-factor represents only 10% of the roof area, the simple average is inaccurate. The area-weighted average is 0.037, almost half the simple average. The area-weighted average is calculated by multiplying each U-factor by its area, adding these products, and dividing the sum by the total area. The area-weighted average calculation is shown below.

$$\textit{Area}\ \text{Weighted Average} = \frac{9000 \times 0.030 + 1000 \times 0.100}{10000} = 0.037$$

Area-weighted averages are used for U-factors, shading coefficients, visible light transmissions, heat capacity, and overhang projection factors. However, you may not use area-weighted averages with R-values.

Example 402I Area-weighted Average U-factor Calculation - Warehouse Distribution Center

Q A single-story warehouse distribution center has 15,000 ft^2 of gross exterior wall. The fenestration area is only 200 ft^2, but there are 20 truck loading doors, each 20 ft wide and 10 ft high. The U-factor is 0.12 for the insulated concrete wall, but only 1.15 for the uninsulated metal roll-up doors (not much different from a single-glazed window). What is the opaque wall U-factor for the entire building?

A A weighted average U-factor must be calculated that takes account of both the U-factor of the roll-up doors and the exterior wall. This is done as follows:

Opaque wall area = 15,000 – 200 = 14,800 ft^2
Opaque door area = 20 ft × 10 ft × 20 doors = 4,000 ft^2
Insulated concrete wall area = 14,800 – 4,000 = 10,800 ft^2

$$\begin{aligned} U_{ow} &= [(10{,}800 \times 0.12) + (4{,}000 \times 1.15)]/14{,}800 \\ &= (1296 + 4600)/14{,}800 \\ &= 0.40 \end{aligned}$$

DAYLIGHTED ZONE

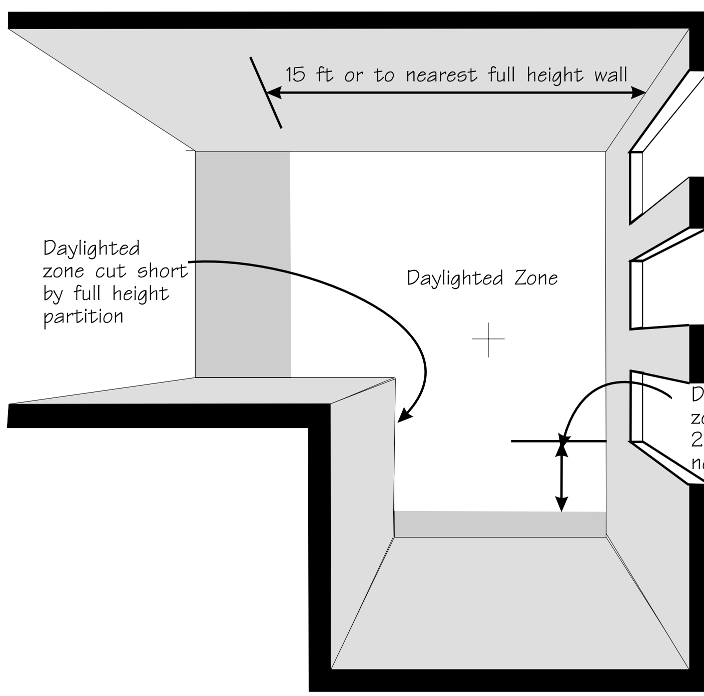
Daylighted zone is an important concept in the 90.1 Code for several reasons.

- Skylights may be exempt from the area-weighted average roof U-factor when automatic daylighting controls are installed for lighting fixtures that serve the daylighted area created by the skylight.
- When the daylighting columns are selected from the prescriptive tables, automatic daylighting controls must be installed in the daylighted areas that are capable of reducing electric lighting to at least 50% of full lighting power.
- With the ENVSTD computer program, daylighting controls must be installed in the perimeter zones when the daylighting control factor (DLCF) is greater than zero.
- In Section 401 of the code, a lighting power credit is offered when automatic daylighting controls are installed in daylighted areas.

Any type of fenestration can create a daylighted zone including skylights, windows (vertical fenestration), clerestories, roof monitors, and doors with glazing.

- For windows, the code defines the daylighted zone as the area adjacent to the windows that receives daylighting from the glazing. Unless more detailed daylighting analysis is provided, the daylighting zone depth may be assumed to extend into the space a distance of 15 ft or to the nearest opaque partition, whichever is less. The daylighting zone width is assumed to be the width of the window plus either 2 ft on each side, the distance to an opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is less.

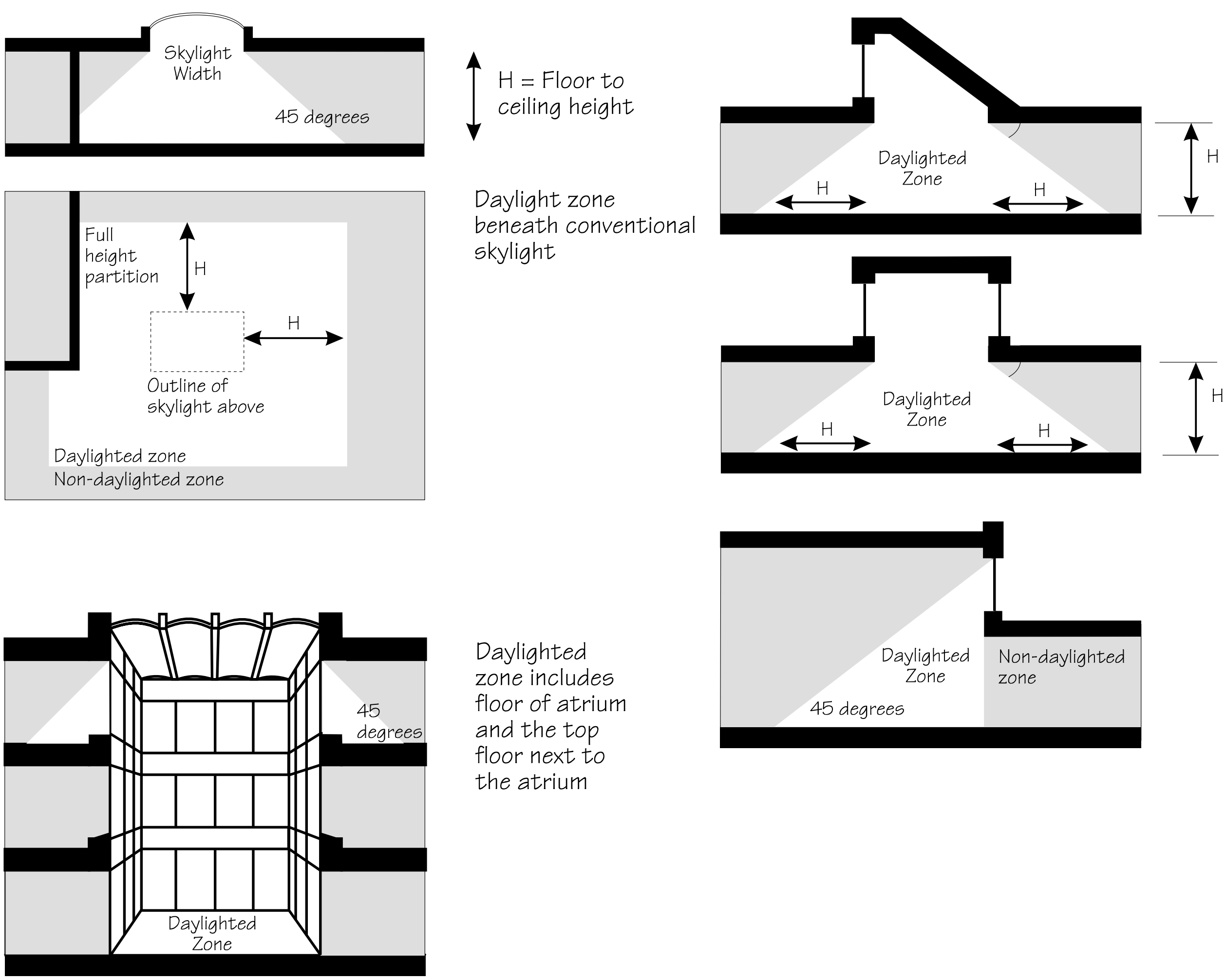
Figure 402T Daylighted Zone at Vertical Fenestration



- For skylights, the code defines daylighted zones as the area under each skylight where the horizontal dimension in each direction is equal to the skylight dimension in that direction plus either the floor to ceiling height, the dimension to an opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is less.

For clerestories and roof monitors, the daylighted zone is limited by the requirements on vertical glazing. In some cases, the daylighted zone that they create can be more similar to that created by skylights.

Figure 402U Daylighted Zone Beneath Skylights



EQUIPMENT POWER DENSITY (EPD)

Table 402.4.2 gives adjusted equipment power densities for the most common occupancies. These values include adjustments for occupant loads through a procedure defined in ASHRAE Standard 90.1-1989. With the ENVSTD program, you must either use these values or the equipment power for your building, if it is known. When estimating the equipment power for your building, be sure to consider diversity. This means that the percent operation should be considered for each piece of equipment. For instance, a paper shredder or binding machine that is used only intermittently should be assigned a percent power of something less than 100%. This option may be used only when the equipment in the space can be identified.

The occupant load adjustment is the difference between the occupant load estimated for the building and the default value for ENVSTD calculations. The ENVSTD computer program assumes that the occupant load is equivalent to 0.6 W/ft^2. This is roughly equivalent to one person for each 112 ft^2 of floor area. Buildings with more occupant load than 0.6 W/ft^2 will have a positive adjustment and buildings with fewer occupants will have a negative adjustment. The occupant load adjustment is calculated for common occupancies and included in Table 402.4.2 of the code. These values may be used to adjust your estimates of equipment power density. Many of the occupant load adjustments are negative numbers, meaning that the building category has less loads from people than 0.6 W/ft^2. In these cases, the negative occupant load adjustment reduces the equipment power density. You may not, however, enter an equipment power density less than zero.

FENESTRATION PERFORMANCE

The term "fenestration" refers to the light-transmitting areas of a wall or roof, mainly windows and skylights. The 90.1 Code sets performance requirements for fenestration by limiting fenestration area. The fenestration area allowed depends on the shading coefficient, the size of overhangs, the thermal performance (U-factor), and whether or not daylighting controls are installed. These terms are defined below and default values are given which may be used in compliance calculations.

Controlling solar gains and maximizing daylighting can significantly affect energy use in buildings. Solar gains through windows add to cooling loads in the summer and during other times when the building is air conditioned. On cold days, solar gains can also offset heating loads, although this is generally not a significant benefit in commercial buildings, because high internal heat gains typically reduce the hours heating is needed when the building is occupied. The more significant benefit of sunlight is daylighting. Light is solar radiation in the visible spectrum – with a wave length between about 380 and 770 nanometers. With the right type of electric lighting system and controls, daylight can be a significant benefit. The ideal fenestration would allow light to enter the building, but block solar radiation outside the visible spectrum – that in the ultraviolet and near infrared part of the solar spectrum.

Solar gain can be limited through the use of tinted or reflective glazing or through the use of overhangs. The code also offers credits for glazing that does a good job of bringing in daylight while limiting solar gains.

Fenestration U-factor

Fenestration U-factor (U_{of}) is the rate of heat flow through the fenestration when there is a one degree temperature difference between the air on one side and the air on the other side. In the United States, the units are Btu per hour per degree Fahrenheit or

Btu/h-°F. U-factor does not consider solar gains through the fenestration; this is addressed by the shading coefficient (see below). The fenestration U-factor must include the effect of the framing, using methods and procedures included in the ASHRAE Fundamentals Handbook (1985). Typical fenestration U-factors are given in Table 402H which may be used for compliance calculations.

Table 402H Fenestration U-factors

Product	Gap Width (in.)	Emissivity	Center of Glass	Wood Frame	Metal Frame	Thermal Break Frame
Framing Adjustment Factor				**0.95**	**1.25**	**1.05**
Windows						
Single	n.a.	n.a.	1.10	1.05	1.38	1.16
	n.a.	e = 0.6	1.02	0.97	1.28	1.07
	n.a.	e = 0.4	0.91	0.86	1.14	0.96
	n.a.	e = 0.2	0.79	0.75	0.99	0.83
Double	3/16	n.a.	0.62	0.59	0.78	0.65
	1/4	n.a.	0.58	0.55	0.73	0.61
	1/2	n.a.	0.49	0.47	0.61	0.51
	1/2	e = 0.6	0.43	0.41	0.54	0.45
	1/2	e = 0.4	0.38	0.36	0.48	0.40
	1/2	e = 0.2	0.32	0.30	0.40	0.34
Triple	1/4	n.a.	0.39	0.37	0.49	0.41
	1/2	n.a.	0.31	0.29	0.39	0.33
Glass Skylights						
Single	n.a.	n.a.	1.23	1.17	1.54	1.29
Double	3/16	n.a.	0.7	0.67	0.88	0.74
	1/4	n.a.	0.65	0.62	0.81	0.68
	1/2	n.a.	0.59	0.56	0.74	0.62
	1/2	e = 0.6	0.56	0.53	0.70	0.59
	1/2	e = 0.4	0.52	0.49	0.65	0.55
	1/2	e = 0.2	0.48	0.46	0.60	0.50
Plastic Skylights						
Single	n.a.	n.a.	1.15	1.09	1.44	1.21
Double	n.a.	n.a.	0.7	0.67	0.88	0.74

Data from the ASHRAE Fundamentals Handbook (1985)

Data for the center of the glass U-factor from manufacturers and other sources may also be used for compliance calculations, but the data must be adjusted to account for the effect of window frames. Based on the procedures in the ASHRAE Fundamentals Handbook (1985), this is a straightforward procedure. Manufacturers generally publish a U-factor for the center of the glass. The center-of-glass U-factor multiplied times the framing adjustment factor from the first row of Table 402H.

The National Fenestration Rating Council (NFRC) is another source of fenestration U-factors that may be used for compliance calculations. NFRC has developed detailed procedures for testing and calculating the U-factor of manufactured products. Many manufacturers follow these procedures, and NFRC publishes a directory of products with certified U-factors. NFRC data includes consideration of the frame as well as edge effects and no further adjustments are required. U-factors published by NFRC are more accurate than the U-factors that result from the ASHRAE methods referenced by the 90.1 Code and reflected in Table 402H. They are also generally higher, so it will be more difficult for buildings to comply if they use NFRC U-factors.

Many buildings have more than one type of window. In these cases, an area-weighted average U-factor must be calculated. When using the prescriptive tables, an area-weighted U-factor is calculated for the whole building. When using the system performance method (the ENVSTD computer program), the area-weighted average U-factor must be calculated for each orientation or building facade.

Shading Coefficient (SC_x)

The shading coefficient is a number between zero and one that indicates the amount of solar heat gain that will pass through fenestration. By definition, the shading coefficient of 1/8 in. thick, clear, double strength window glass is 1.0. All other fenestration is rated relative to this. If a window has a shading coefficient of 0.5, it means that it will allow into the building only half the solar heat gain as the same size window with 1/8 in. clear glass. The shading coefficient of glass and other materials depends on the thickness of the material, the number of panes, any tinting that is mixed with the glass when it is manufactured, and any special coatings that are applied to the surface of the glass. Shading coefficient, or SC_X, is a required input for both the prescriptive tables and the ENVSTD computer program. This section gives default values for SC_X and shows how to consider the shading effects of internal and exterior shading devices.

Shading coefficient is usually considered to be a property of the glazing material by itself, but the 90.1 Code defines shading coefficient, or more specifically SC_X, much more broadly. SC_X can include the shading effect of venetian blinds, draperies, roller shades, or other interior shading devices that are shown on the building plans and are in place at the time of the final inspection. It can also include the effect of permanently installed exterior louvers or sunscreens. Shading devices such as overhangs or side fins cannot be factored into the calculations of the SC_X. Neither can shading by other structures, terrain, or vegetation. A separate credit is offered for overhangs, however, based on the projection factor of the overhang.

When a building has more than one type of glass or interior shading condition, an area-weighted average SC_X must be calculated. For the prescriptive tables, an area-weighted average SCx is calculated for the building as a whole. For the ENVSTD program, a separate area-weighted average SCx is calculated for each orientation.

Table 402I Typical Shading Coefficients and Visible Light Transmissions

	Uncoated Glass		Low-E Glass		Medium Reflective		High Reflective	
	SC	VLT	SC	VLT	SC	VLT	SC	VLT
Single Glazing (1/4 in.)								
Clear	0.95	0.88	n.a.	n.a.	0.65	0.43	0.23	0.08
Bronze	0.71	0.53	n.a.	n.a.	0.52	0.25	0.26	0.05
Gray	0.71	0.45	n.a.	n.a.	0.40	0.13	0.26	0.04
Green	0.71	0.75	n.a.	n.a.	0.50	0.33	0.25	0.07
High Performance Tint	0.58	0.66	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Double Glazing (1 in.)								
Clear	0.81	0.78	0.72	0.73	0.56	0.41	0.16	0.06
Bronze Outer Lite	0.57	0.47	0.48	0.44	0.40	0.23	0.16	0.05
Gray Outer Lite	0.57	0.41	0.46	0.36	0.40	0.18	0.16	0.04
Green Outer Lite	0.57	0.66	0.49	0.62	0.38	0.30	0.15	0.06
High Performance Tint	0.47	0.64	0.39	0.59	n.a.	n.a.	n.a.	n.a.
Single Acrylic								
Clear	0.97	0.92	-	-	-	-	-	-
Bronze	0.53	0.27	-	-	-	-	-	-
High White	0.76	0.82	-	-	-	-	-	-
Medium White	0.68	0.53	-	-	-	-	-	-
Low White	0.45	0.32	-	-	-	-	-	-
Double Acrylic								
Clear	0.89	0.89	-	-	-	-	-	-
Bronze	0.43	0.25	-	-	-	-	-	-
High White	0.72	0.75	-	-	-	-	-	-
Medium White	0.63	0.49	-	-	-	-	-	-
Low White	0.40	0.29	-	-	-	-	-	-
Triple Acrylic								
Clear	0.82	0.85	-	-	-	-	-	-
Bronze	0.36	0.27	-	-	-	-	-	-
High White	0.68	0.69	-	-	-	-	-	-
Medium White	0.58	0.45	-	-	-	-	-	-
Low White	0.35	0.23	-	-	-	-	-	-

Notes:
1. All glass is assumed to be 1/4-in. thick.
2. Double glass is assumed to consist of two 1/4-in. panes separated by a 1/2-in. air space.
3. The medium performance reflective coating is typical of pyrolytic coatings. These are coatings that are applied when the glass is in a hot, semi-molten state.
4. The high performance reflective coating is typical of "SS08" coatings. SS08 is a generic name used by many manufacturers to indicate a stainless steel (SS) coating with a visible light transmission of 8% when applied to clear glass.
5. Reflective coatings are assumed to be placed on the second surface.
6. The low-e coating is typical of many products on the market, having an emissivity of about 0.15. This coating is assumed to be placed on the third surface.

Shading Coefficient of the Glazing Material

The first step in calculating SC_x is to look up the shading coefficient for the glass or glazing material by itself. This data may be taken from manufacturer's literature or from Table 402I of this manual. This table has data for glass and for acrylic commonly used in skylights. Values from these tables may be used for compliance cal- shading devices.

Adjustment for Interior Shading

The shading benefit of interior shading devices may be calculated using the methods in the ASHRAE Fundamentals Handbook (1985). Data from this and other sources are presented in Table 402J. Adjustment factors in this table are multiplied times the shading coefficient of the glass to yield the shading coefficient of the glass in combination with the interior shading device. For instance, if double bronze glass (SC = 0.57) were used with a light colored blind, the adjustment would be 0.80. The combined shading coefficient would then be 0.57×0.80 or 0.46.

The benefit of interior shading devices depends on the glazing material. A white roller shade, for instance, is more effective with clear glass than with low transmission reflective glass. This is because its effectiveness depends on the ability of the shading device to reflect solar radiation back out the window and this ability is increased with high transmission glass.

Adjustments for Exterior Shading

The most effective way to control solar heat gains through windows is to intercept the sun before it strikes the window. Exterior shading devices can be an effective means of achieving this. Exterior shading devices include horizontal or vertical fixed position louvers, moveable louvers, and sunscreens. Sunscreens are often decorative in nature and range in style from large pattern aluminum or metal screens to miniature louvers that enable less obstructed views. The methods contained in the ASHRAE Fundamentals Handbook (1985) may be used to assess the benefits of exterior shading devices. Sunscreen manufacturers may also have data that may be used in quantifying the benefits of these devices.

Table 402J Shading Coefficient Adjustment for Interior Shading Devices

Shading Coefficient of Glass	Light Colored Blind	Medium Colored Blind	Light Colored Drapery	Medium Colored Drapery	Dark Colored Drapery
0.90 - 1.00	0.57	0.67	0.57	0.64	0.73
0.80 - 0.89	0.68	0.75	0.61	0.65	0.76
0.70 - 0.79	0.76	0.81	0.65	0.68	0.77
0.60 - 0.69	0.77	0.82	0.69	0.74	0.81
0.50 - 0.59	0.80	0.84	0.76	0.78	0.85
0.40 - 0.49	0.83	0.85	0.80	0.85	0.93
< 0.40	0.86	0.89	0.83	0.86	0.92

Visible Light Transmission (VLT)

Visible light transmission (VLT) is the fraction of solar radiation in the visible spectrum that passes through fenestration. When the perimeter zones in buildings have automatic daylighting controls, it is necessary to know the VLT of the fenestration. With the prescriptive requirements, one of the columns in the prescriptive tables is based on the ratio of VLT to shading coefficient – sometimes referred to as the efficacy of the fenestration – being greater than one. With the ENVSTD computer program, the VLT is a specific input to the program which must be entered when daylighting controls are installed in the perimeter zones. Typical VLT values are published in Table 402I. The VLT is also published by glazing product manufacturers with their technical literature.

There is a strong relationship between the visible light transmission and the shading coefficient. The lower the shading coefficient, generally the lower the visible light transmission. Some glazing products, however, have a VLT higher than other products with the same shading coefficient. For instance, bronze, gray, and green tinted glass all have about the same shading coefficient for a given glass thickness, but green glass has a significantly higher visible light transmission. Likewise, some coatings applied to the surface of glazing reduce the shading coefficient more than they do the VLT. For these reasons, manufacturer's literature should be carefully consulted in the selection of glazing products.

HEAT CAPACITY (HC)

HC is the heat capacity per square foot of wall area (Btu/ft^2-°F) and is used in the 90.1 Code to quantify the amount of thermal mass in exterior walls. It is used with both the prescriptive and system performance methods. With both methods, a benefit is assigned to exterior wall mass that can be traded off against less insulation, and with the system performance method, increased glass area. It is not necessary to calculate HC for light weight walls; a default of 1.0 Btu/(ft^2-°F) may be assumed.

HC is calculated by using the following equation. The term "i" is an index of each layer in the wall and "n" is the total number of layers that have significant mass.

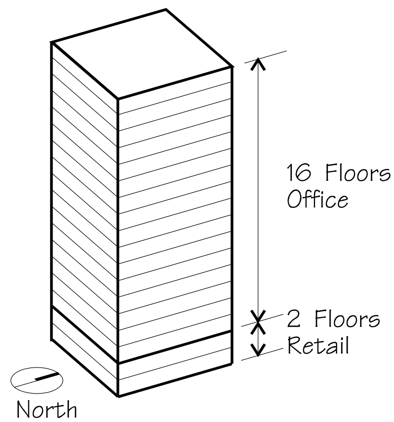
$$\mathrm{HC} = \sum_{i=1}^{n} \mathrm{Density}_i \times \mathrm{Specific\ Heat}_i \times \mathrm{Thickness}_i$$

$$\mathrm{lbm/ft^3} \times \mathrm{Btu/lbm^{-F}} \times \mathrm{ft} = \mathrm{Btu/F} - \mathrm{ft}^2$$

Example 402J Shading Coefficient Calculation - Office Tower with Ground Floor Retail

Q What is the area-weighted average SC_x to use for an 18-story rectangular building that has two floors of retail at the ground level and 16 stories of office above? Each retail story has 500 ft^2 of fenestration on the south side, 850 ft^2 on the east side and none on the other two sides. Each office floor has 400 ft^2 on both the north and south sides and 480 ft^2 on the east and west sides. All the fenestration is double-glazing with a low-e coating. The clear low-e on the retail stories has an SC_x of 0.71, while the SC_x is 0.48 for the tinted low-e on the office floors.

A For prescriptive table use, calculate an area-weighted average SC_x for all fenestration.



$SC_{x\ overall}$ = {[(500 + 850) × 0.71 × 2 stories]

+ [(400 + 480 + 4 00 + 480) × 0.48 × 16 stories]}/{[(500 + 850) × 2 stories]

+ [(400 + 480 + 400 + 480) × 16 stories]} = (1,917 + 13,517)/(2,700 + 28,160)

= 0.50

Use the 0.50-0.39 range.

For the ENVSTD program, calculate an area-weighted average SC_x *for each orientation*.

$SC_{x\ north}$ = 0.48 (only office fenestration)

$SC_{x\ east}$ = [(850 × 0.71 × 2 stories) + (480 × 0.48 × 16 stories)]

/[(850 × 2 stories) + (480) × 16 stories)] = (1,207 + 3,686)/(1,700 + 7,680)

= 0.52

$SC_{x\ south}$ = [(500 × 0.71 × 2 stories) + (400 × 0.48 × 16 stories)]

/[(500 × 2 stories) + (400) × 16 stories)] = (710 + 3,072)/(1,000 + 6,400)

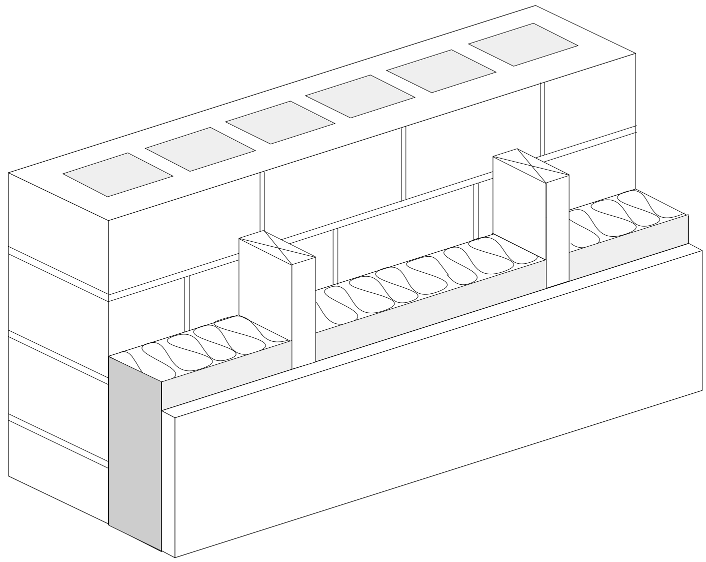
= 0.51

$SC_{x\ west}$ = 0.48 (only office fenestration)

Enter 0.48 for the north wall orientation, 0.52 for the east, 0.51 for the south and 0.48 for the west.

Example 402K Wall Heat Capacity Calculation

Q What is the heat capacity (HC) for the wall construction depicted below? The exterior wall consists of 8 in. partially grouted Concrete Masonry Unit (CMU), and the interior has R-11 batt insulation between 2×4 studs (16 in. o.c.) with an interior layer of 5/8 in. gypsum board.



A The HC is the sum of the density times the specific heat times the thickness for each layer of the wall. The calculation can be structured in tabular form as shown below.

Item	Weight (lb/ft^2)	Fraction of Wall	Specific Heat (Btu/lb-°F)	HC (Btu/ft^2-°F)
8" Partially Grouted CMU (105 lb/ft^3)	47.00	1.00	0.20	9.40
2 × 4 Wood Studs	9.30	0.15	0.33	0.46
R-11 Batt	0.25	0.85	0.30	0.06
5/8" Gypsum Board	2.60	1.00	0.26	0.68
Total				10.60

LIGHTING POWER DENSITY (LPD)

When you use the ENVSTD computer program, you must enter the lighting power density for each building orientation. There are three ways to determine the lighting power density.

1. *Prescriptive*. Use the prescriptive unit lighting power allowance (ULPA) from Table 401.3.2a. This is the easiest method, but it is limited to just a few building types.
2. *Systems Performance*. Use the system performance unit lighting power allowance (ULPA) from Table 401.3.2b. This method must be used for buildings not listed in Table 401.3.2a.
3. *Installed Power*. Use the installed lighting power adjusted for automatic lighting controls. This option is available only when the design of the lighting system is known. It may not be used for speculative buildings or whenever the permit to construct the building envelope is filed before the lighting design is complete.

In many instances, it is necessary to calculate a weighted average LPD. This is the case with all mixed use buildings and when either the system performance or installed power methods are used. The weighted average LPD used with the ENVSTD computer program must be based on just the perimeter zone. For the purposes of the perimeter area-weighted average calculations, the perimeter zones of the building may be assumed to be within 15 ft. of the exterior walls.

OVERHANG PROJECTION FACTOR (PF)

Overhangs can control solar gains by blocking direct sun during the summer when the sun is high in the sky. During the winter when there may be a heating load, a properly designed south overhang can allow the sun to penetrate into the building, providing some heating benefit. The benefit of overhangs depends on the orientation of the window, the latitude of the building site, and the balance point of the building. The most accurate way to assess the benefits of overhangs is through computer simulations that calculate thermal loads for each hour of the year, taking the position of the sun into account for each hour.

The figure of merit used to characterize the performance of overhangs with the prescriptive and system performance methods is the projection factor which is the ratio of the projection (A) of the overhang from the glazing surface to the height (B) distance from the window sill to the bottom of the overhang (see Figure 402V). Neither the prescriptive method nor the system performance method offers additional benefits for overhangs with projection factors greater than 0.50. This size overhang has a projection half as great as the distance from the window sill to the bottom of the overhang. Projections greater than 0.50 can be entered in the ENVSTD program and can be used with the prescriptive tables, but the benefit assigned is the same as if a projection factor of 0.50 were entered.

Example 402L Projection Factor Calculation - Office Building with Light Shelves

Q

What is the area-weighted average projection factor for a 10-story office building with light shelves on the south side, but none on the north side? The long axis of the 60 ft by 200 ft building runs east-west and there are no windows on the east or west ends. Each floor on both the north and south sides has two continuous bands of windows – the lower band is 4 ft of tinted low-e double-glazing which starts 3 ft above the floor and the upper band is 1 ft 6 in. of clear low-e double-glazing which starts 8 ft above the floor. (All glass is recessed so that the exterior surface of the glass is 6 in. from the exterior surfaces of the wall.) On the south side only a horizontal light shelf begins 6 in. above the top of the lower window and extends 1 ft 8 in. out from the exterior wall surface.

A

The projection factor of the lower band of glass on the south side is 0.37 (20 in./4 ft + 6 in.) The area-weighted average PF for all glazing is:

$$\begin{aligned} PF_{overall} &= [(1'6'' \times 200' \times 10 \text{ stories} \times 0.00) \\ &\quad + (4' \times 200' \times 10 \text{ stories} \times 0.00) \\ &\quad + (1'6'' \times 200' \times 10 \text{ stories} \times 0.00) \\ &\quad + (4' \times 200' \times 10 \text{ stories} \times 0.37)] \\ &\quad / [(1'6''+4') \times 200' \times 10 \text{ stories} \times 2 \text{ facades}] \\ &= (0 + 0 + 0 + 2960) / 22{,}000 = 0.13 \end{aligned}$$

Use the 0.000 - 0.249 range. (There has been no benefit from doing the calculations.)

For the ENVSTD program, calculate an area-weighted average PF *for each orientation*.

$$\begin{aligned} PF_{north} &= \text{no light shelves, so assume } 0.00 \\ PF_{south} &= [(1'6'' \times 200' \times 10 \text{ stories} \times 0.00) \\ &\quad + (4' \times 200' \times 10 \text{ stories} \times 0.37)] \\ &\quad / [(1'6''+4') \times 200' \times 10 \text{ stories}] \\ &= (0 + 2960) / 11{,}000 = 0.27 \end{aligned}$$

For the ENVSTD program, enter 0.00 for PF for the north wall orientation and 0.27 for the south.

U-FACTORS AND R-VALUES

When it is colder on one side of an envelope element, such as a wall, roof, floor, or window, heat will conduct from the warmer side to the cooler side. Heat conduction is driven by temperature differences and is a major component of heating and cooling loads in buildings. The building envelope requirements of the 90.1 Code address heat conduction by specifying minimum R-values (thermal resistance to heat flow) for insulation or maximum U-factors (the rate of steady-state heat flow) for building envelope construction assemblies.

Basic Concepts

U-factor

The U-factor is the rate of steady-state heat flow. It is the amount of heat in Btu (British thermal units) that flows each hour through one square foot, when there is a one degree temperature difference between the inside air and outside air. The heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. Steady-state heat flow assumes that temperatures on both sides of a building envelope element (while different) are held constant for a sufficient period of time so that heat flow on both sides of the assembly is steady. The steady-state heat flow method is a simplification, because in the real world, temperatures change constantly. It can, however, predict average heat flow rates over time, and is used by the 90.1 Code to limit conductive heat losses and gains. Because they are easy to understand and use, the terms for steady-state heat flow are part of the basic vocabulary of building energy performance.

Each layer of a building assembly, such as the sheathing and the insulation, has its own *conductance*, or rate of heat transfer. The conductance for an individual layer is like the U-factor, and it has the same units. The difference is that it is only for a single element or layer. The U-factor includes the conductance of every element of the building assembly, including the air films on the interior and exterior surfaces of the construction assembly. The surface conductances quantify the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment.

For light frame walls, the steady-state U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant or average temperature conditions. The dynamic heat storage properties of the concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow rates.

R-value

R-values are also used to describe steady-state heat flow, but in a slightly different way. The R-value is the *thermal resistance* to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R- value. The big advantage of R-values is that they can be added together. For homogeneous assemblies, the total R-value of a construction assembly is the sum of the R-values of each of the layers. The layers should include the sheathing and finishes, the insulation and weatherproofing elements, and the surface air films. The U-factor is the inverse of the total R-value.

$$\text{U - Value} = \frac{1}{\text{Total R - Value}}$$

The R-value is widely recognized in the building industry and is used to describe insulation effectiveness. The insulation R-value is not the total R-value of the wall, however. It only describes the thermal resistance of the insulation material. The R-value of the entire wall assembly can be significantly lower when metal framing penetrates the insulation.

Framing Effects

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value, and conduct heat more readily than the insulated areas. It is incorrect to neglect framing members when calculating the U-factor for the wall, roof, or floor assembly. The correct U-factor includes the insulation portion of the wall and the U-factors through the solid (or framed) portion of the wall. The 90.1 Code requires that the U-factor of each envelope assembly be calculated taking into account framing and other thermal bridges within the construction assembly.

Default U-factors

Precalculated U-factors are provided in this section for typical construction assemblies, including roofs, floors, and doors. These values are calculated using acceptable methods, and may be used for compliance with the code.

Table 402K Default U-factors for Roofs and Attics (Btu/h-ft²-°F)

Nominal R-value	U-factor	Exterior Insulation [1] Expanded Polystyrene 1.0" R3.8	1.5" R5.7	2.0" R7.6	Extruded Polystyrene 0.75" R3.7	1.0" R5.0	1.5" R7.5	2.0" R10.0	Polyisocyanurate 0.5" R3.6	0.75" R5.4	1.0" R7.2	1.5" R10.8	2.0" R14.4
Standard Wood Framed Attic (3.5" bottom chord) [2]													
None	0.606												
R-11	0.085												
R-19	0.051												
R-30	0.033												
R-38	0.026												
R-49	0.021												
R-60	0.017												
Raised Heel Attic (3.5" joist depth) [2]													
None	0.479												
R-11	0.083												
R-19	0.050												
R-30	0.032												
R-38	0.026												
R-49	0.020												
R-60	0.016												
Single Rafter Wood Joists (5.5" depth) [3,4]													
None	0.407	0.160	0.123	0.099	0.162	0.134	0.100	0.080	0.165	0.127	0.104	0.075	0.059
R-11	0.083	0.063	0.057	0.051	0.064	0.059	0.051	0.045	0.064	0.058	0.052	0.044	0.038
R-13	0.073	0.057	0.051	0.047	0.057	0.053	0.047	0.042	0.058	0.052	0.048	0.041	0.035
R-15	0.064	0.052	0.047	0.043	0.052	0.049	0.043	0.039	0.052	0.048	0.044	0.038	0.033
Single Rafter Wood Joists (7.25" depth) [3,4]													
R-19	0.051	0.043	0.040	0.037	0.043	0.041	0.037	0.034	0.043	0.040	0.038	0.033	0.030
R-21	0.047	0.040	0.037	0.035	0.040	0.038	0.035	0.032	0.040	0.038	0.035	0.031	0.028
Single Rafter Wood Joists (9.25" depth) [3,4]													
R-25	0.040	0.035	0.033	0.031	0.035	0.033	0.031	0.029	0.035	0.033	0.031	0.028	0.025
R-30C	0.034	0.030	0.028	0.027	0.030	0.029	0.027	0.025	0.030	0.029	0.027	0.025	0.023
Single Rafter Wood Joists (11.25" depth) [3,4]													
R-30	0.034	0.030	0.028	0.027	0.030	0.029	0.027	0.025	0.030	0.028	0.027	0.025	0.023
Single Rafter Wood Joists (13.25" depth) [3,4]													
R-38	0.027	0.024	0.023	0.022	0.024	0.024	0.022	0.021	0.024	0.023	0.022	0.021	0.019

1. Exterior Insulation is the case where insulation is installed above the roof structure in a continuous manner. Typically, it is rigid insulation applied to the top of roof decking with roofing materials attached directly on top of the insulation. Framing members are often left exposed on the interior side. The framing material, metal or wood, does not matter since it does not penetrate the insulation and provide thermal short-circuits.
2. Attics represents the case where insulation is installed within the attic space. Standard framing assumes that the insulation is tapered at the roof edge. Raised heel assumes full depth insulation all the way to the exterior walls. Both types of framing assume the attic is ventilated above the insulation and so no credit is given for any roofing materials.
3. For all wood framed roofs, insulation is assumed to be installed above the ceiling but on the interior of the roof.
4. The single rafter wood joists category represents the case where insulation is installed between wood rafters just below the roof. The rafters may be tilted or flat, but in all cases there is full depth insulation. It is assumed that the rafter space above the insulation is ventilated and so no credit is given for any roofing materials. The key difference between the two interior insulation wood frame cases is that the attic case is assumed to have an unlimited space to add insulation and the insulation will cover the ceiling joists when insulation exceeds R-11, whereas for the vaulted case the depth of insulation is limited by the depth of the rafter and the desire to maintain a 1-in. ventilated airspace between the insulation and the roof structure.

Table 402L Default U-factors for Wood and Steel Swinging Doors Btu/(h-ft²-°F)

Nominal Thickness (Inches)	**Description**	**No Storm Door**	**Wood Storm Door[3,6]**	**Metal Storm Door[3,7]**
Wood Doors[1,2,3,4,5]				
1-3/8	Panel door with 7/16-in panels	0.57	0.33	0.37
1-3/8	Hollow-core flush door	0.47	0.30	0.32
1-3/8	Solid-core flush door	0.39	0.26	0.28
1-3/4	Panel door with 7/16-in panels	0.54	0.32	0.36
1-3/4	Hollow-core flush door	0.46	0.29	0.32
1-3/4	Panel door with 1-1/8-in panels	0.39	0.26	0.28
1-3/4	Solid-core flush door	0.33	0.25	0.28
2-1/4	Solid-core flush door	0.27	0.20	0.21
Steel Doors[1,2,3,4,5]				
1-3/4	Fiberglass or mineral wool core with steel stiffeners, no thermal break	0.60	n.a.	n.a.
1-3/4	Paper honeycomb core without thermal break	0.56	n.a.	n.a.
1-3/4	Solid urethane foam core without thermal break	0.40	n.a.	n.a.
1-3/4	Solid fire-rated mineral fiberboard core without thermal break	0.38	n.a.	n.a.
1-3/4	Polystyrene core without thermal break (18 gage commercial steel)	0.35	n.a.	n.a.
1-3/4	Polyurethane core without thermal break (18 gage commercial steel)	0.29	n.a.	n.a.
1-3/4	Polyurethane core without thermal break (24 gage commercial steel)	0.29	n.a.	n.a.
1-3/4	Polyurethane core with thermal break and wood perimeter (24 gage commercial steel)	0.20	n.a.	n.a.
1-3/4	Solid urethane foam core with thermal break	0.19	0.16	0.17

1. Opaque doors are to be included with the opaque wall when calculating compliance with the 90.1 Code. Opaque door U-factors should be taken from the National Fenestration Rating Council (NFRC) certification program whenever available. If NFRC values are not available, then the U-factors from this table may be used. Opaque door U-factors must include the effects of the door edge and the frame. It is not acceptable to calculate U-factors based on a cross-section through the insulated portion.
2. Note that to take credit for a thermal break, the door must have a thermal break in both the door slab and in the frame.
3. All U-factors for exterior doors in this table are for doors with no glazing, except for the storm doors which are in addition to the main exterior door. Interpolation and moderate extrapolation are permitted for door thicknesses other than those specified.
4. Values are based on a nominal 32 by 80 in. door size with no glazing.
5. Outside air conditions: 15 mph wind speed, 0°F air temperature; inside air conditions: natural convection, 70°F air temperature.
6. Values for wood storm door are for approximately 50% glass area.
7. Values for metal storm door are for any percent glass area.

Table 402M Default U-factors for Sliding and Roll-Up Doors Btu/(h-ft^2-°F)

Door Description	**Overall U-factor**
Uninsulated, single-layer	1.15
Nominal 2" thick with 1-3/4" polyurethane foam core and vinyl thermal breaks and section joint seals	0.14
Nominal 3" thick with 2-7/8" expanded polystyrene core and continuous vinyl extrusion to form a thermal break and weather-tight seal along section joint	0.12
Other doors	Use value from most similar swinging door above

* The thermal performance of sliding and roll-up doors, typically installed in warehouses, is comparable to single-glazing unless the doors are insulated. Even when insulated, the effective R-value may be only 40%-50% of the nominal R-value of the insulation used because of thermal bridging around the edges of each section and the door frame. For compliance with the code the U-factor used must be for the entire door including the frame and not be based simply on a cut through the insulated section.

Table 402N Default U-factors for Floors over Unconditioned Space or over Outside Air (Btu/h-ft^2-°F)

		Continuous Insulated Sheathing											
Nominal	**U-factor**	**Expanded Polystyrene**			**Extruded Polystyrene**				**Polyisocyanurate**				
R-value		**1.0" R3.8**	**1.5" R5.7**	**2.0" R7.6**	**0.75 R3.7**	**1.0" R5.0**	**1.5" R7.5**	**2.0" R10.0**	**0.5" R3.6**	**0.75 R5.4**	**1.0" R7.2**	**1.5" R10.8**	**2.0" R14.4**
6 in. Concrete Floor With Rigid Foam [1]													
None	0.379	0.155	0.12_0	0.098	0.158	0.131	0.099	0.079	0.160	0.124	0.102	0.074	0.059
Concrete Floor With Pinned Batts [2]													
R-11	0.073												
R-13	0.064												
R-15	0.057												
R-19	0.046												
R-21	0.042												
Concrete Floor w/ Spray-On Insulation [3]													
R- 4 (1")	0.151												
R- 8 (2")	0.094												
R-12 (3")	0.068												
2 x 6 Wood Joists (5.5 " depth) [2]													
None	0.307	0.142	0.112	0.092	0.144	0.121	0.093	0.075	0.146	0.115	0.096	0.071	0.057
R-11	0.073	0.057	0.052	0.047	0.058	0.054	0.047	0.042	0.058	0.052	0.048	0.041	0.036
R-13	0.065	0.052	0.047	0.043	0.052	0.049	0.044	0.039	0.052	0.048	0.044	0.038	0.033
R-15	0.058	0.047	0.043	0.040	0.048	0.045	0.040	0.037	0.048	0.044	0.041	0.036	0.032
R-19	0.049	0.041	0.038	0.036	0.042	0.040	0.036	0.033	0.042	0.039	0.036	0.032	0.029
R-21	0.043	0.037	0.035	0.033	0.037	0.036	0.033	0.030	0.038	0.035	0.033	0.030	0.027
2 x 8 Wood Joists (7.25 " depth) [4]													
R-25	0.037	0.033	0.031	0.029	0.033	0.031	0.029	0.027	0.033	0.031	0.029	0.027	0.024
R-30C	0.032	0.028	0.027	0.026	0.029	0.027	0.026	0.024	0.029	0.027	0.026	0.024	0.022
2 x 10 Wood Joists (9.25 " depth) [4]													
R-30	0.032	0.028	0.027	0.026	0.028	0.027	0.026	0.024	0.028	0.027	0.026	0.024	0.022
2 x 12 Wood Joists (11.25 " depth) [4]													
R-38	0.026	0.023	0.022	0.021	0.023	0.023	0.021	0.020	0.023	0.022	0.022	0.020	0.019

Notes: Insulation position descriptions:

1. Concrete floors with rigid foam board insulation: This may be installed either below the concrete slab or between the slab and a topping slab or subfloor. (The values are somewhat optimistic since, if installed below the concrete, no derating has been applied for the short-circuiting of the metal pins and, the assumption is that the insulation is continuous with no framing penetrations.)
2. Concrete floors with pinned batt insulation: Here fiberglass batts are pinned beneath the concrete and installed in a continuous manner with no framing. (Again, the values are somewhat optimistic since no derating has been applied for the short-circuiting of the metal pins.) If rigid foam were added here, it would typically be above the floor slab.
3. Concrete floors with spray-on insulation: The insulation, typically cellulose, is sprayed on in a continuous manner below the concrete. Again, if rigid foam were added here, it would typically be above the floor slab.
4. Wood joist floors: The insulation is installed between the floor joists. The calculations have been done for joists at 16 inches on center, but the values are reasonable for 24 inches on center since the framing area is so small. (This is not true for walls.)

Table 402O Engineered Metal Buildings (Based on 5 Foot Purlin Spacing)

Nominal R-value	Standard Installation - Insulation Laid Over Purlins and Compressed (U-factors)	Insulation Laid out Parallel to and between Purlins and not Compressed, Plus R-Thermal Block Separating Purlins from Roof Deck (U-factors)
R-6	0.20	0.12
R-10	0.14	0.09
R-13	0.12	0.08
R-19	0.09	0.07

Data in this table apply when both the framing and the building surface are metal. It is the situation most vulnerable to thermal short-circuits.

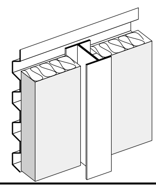
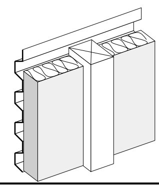
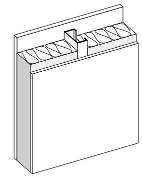
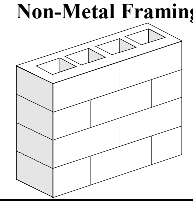
Table 402P U-factors for Opaque Walls (Btu/h-ft^2-°F)

			Continuous Insulated Sheathing											
Nominal R-value	Effective R-value	U-factor	Expanded Polystyrene			Extruded Polystyrene				Polyisocyanurate				
			1.0" R3.8	1.5" R5.7	2.0" R7.6	0.75 R3.7	1.0" R5.0	1.5" R7.5	2.0" R10.0	0.5" R3.6	0.75 R5.4	1.0" R7.2	1.5" R10.8	2.0" R14.4
2x4 Metal Framing at 16 in on center (3.5 in cavity depth)														
None	(0.0)	0.403	0.159	0.122	0.099	0.162	0.134	0.100	0.080	0.164	0.127	0.103	0.075	0.059
R-11	(5.5)	0.133	0.088	0.076	0.066	0.089	0.080	0.067	0.057	0.090	0.077	0.068	0.055	0.046
R-13	(6.0)	0.125	0.085	0.073	0.064	0.085	0.077	0.064	0.055	0.086	0.074	0.066	0.053	0.045
R-15	(6.4)	0.119	0.082	0.071	0.062	0.082	0.074	0.063	0.054	0.083	0.072	0.064	0.052	0.044
2x4 Metal Framing at 24 in on center (3.5 in cavity depth)														
R-11	(6.6)	0.116	0.080	0.070	0.062	0.081	0.073	0.062	0.054	0.082	0.071	0.063	0.051	0.043
R-13	(7.2)	0.108	0.077	0.067	0.059	0.077	0.070	0.060	0.052	0.078	0.068	0.061	0.050	0.042
R-15	(7.8)	0.102	0.073	0.064	0.057	0.074	0.067	0.058	0.050	0.074	0.066	0.059	0.048	0.041
2x6 Metal Framing at 16 in on center (6.0 in cavity depth)														
R-19	(7.1)	0.110	0.077	0.067	0.060	0.078	0.071	0.060	0.052	0.079	0.069	0.061	0.050	0.042
R-21	(7.4)	0.106	0.076	0.066	0.059	0.076	0.069	0.059	0.051	0.077	0.067	0.060	0.049	0.042
2x6 Metal Framing at 24 in on center (6.0 in cavity depth)														
R-19	(8.6)	0.094	0.069	0.061	0.055	0.070	0.064	0.055	0.048	0.070	0.062	0.056	0.047	0.040
R-21	(9.0)	0.091	0.067	0.060	0.054	0.068	0.062	0.054	0.048	0.068	0.061	0.055	0.046	0.039
2x4 Wood Framing at 16 in on center (3.5 in cavity depth)														
None	(0.0)	0.263	0.132	0.105	0.088	0.133	0.114	0.088	0.072	0.135	0.109	0.091	0.068	0.055
R-11	(11.0)	0.088	0.066	0.059	0.053	0.066	0.061	0.053	0.047	0.067	0.060	0.054	0.045	0.039
R-13	(12.7)	0.079	0.061	0.054	0.049	0.061	0.057	0.050	0.044	0.062	0.055	0.050	0.043	0.037
R-15	(15.0)	0.070	0.055	0.050	0.046	0.055	0.052	0.046	0.041	0.056	0.051	0.046	0.040	0.035
2x4 Wood Framing at 24 in on center (3.5 in cavity depth)														
R-11	(11.0)	0.086	0.065	0.058	0.052	0.065	0.060	0.052	0.046	0.066	0.059	0.053	0.045	0.039
R-13	(12.7)	0.078	0.060	0.054	0.049	0.060	0.056	0.049	0.044	0.061	0.055	0.050	0.042	0.037
R-15	(15.0)	0.068	0.054	0.049	0.045	0.054	0.051	0.045	0.040	0.055	0.050	0.046	0.039	0.034
2x6 Wood Framing at 16 in on center (5.5 in cavity depth)														
R-19	(18.0)	0.058	0.048	0.044	0.040	0.048	0.045	0.041	0.037	0.048	0.044	0.041	0.036	0.032
R-21	(21.0)	0.052	0.043	0.040	0.037	0.043	0.041	0.037	0.034	0.043	0.040	0.038	0.033	0.030
2x6 Wood Framing at 16 in on center (5.5 in cavity depth) plus R-10 headers														
R-19	(18.0)	0.057	0.047	0.043	0.040	0.047	0.044	0.040	0.036	0.047	0.044	0.040	0.035	0.031
R-21	(21.0)	0.051	0.042	0.039	0.037	0.043	0.040	0.037	0.034	0.043	0.040	0.037	0.033	0.029
2x6 Wood Framing at 24 in on center (5.5 in cavity depth)														
R-19	(18.0)	0.057	0.047	0.043	0.040	0.047	0.044	0.040	0.036	0.047	0.044	0.040	0.035	0.031
R-21	(21.0)	0.050	0.042	0.039	0.036	0.042	0.040	0.037	0.034	0.043	0.040	0.037	0.033	0.029
2x6 Wood Framing at 24 in on center (5.5 in cavity depth) plus R-10 headers														
R-19	(18.0)	0.056	0.046	0.042	0.039	0.046	0.044	0.039	0.036	0.047	0.043	0.040	0.035	0.031
R-21	(21.0)	0.050	0.042	0.039	0.036	0.042	0.040	0.036	0.033	0.042	0.039	0.036	0.032	0.029

Acceptable Calculation Methods

The 90.1 Code specifies acceptable calculation methods for determining U-factors, and makes a distinction between construction assemblies with metal framing members, and assemblies with non-metal framing such as wood or concrete. It also distinguishes between metal sheathing and non-metal sheathing. Heat flow through construction assemblies with metal framing and/or sheathing is more complex and requires special consideration. Table 402Q shows the calculation methods that can be used with each general type of construction.

Table 402Q Applicability of U-factor Calculation Methods

	Metal Sheathing Metal Framing 	**Metal Sheathing Non-Metal Framing** 	**Non-Metal Sheathing Metal Framing** 	**Non-Metal Sheathing Non-Metal Framing** 
Laboratory Tests	x	x	x	x
Series-Parallel Path (Isothermal Planes)		x		x
Parallel Path Correction Factors			x	
Two-Dimensional Models	x	x	x	x
Zone Method			x	

Laboratory Tests

Laboratory tests are the most accurate way to determine the U-factor of a construction assembly, and are acceptable for all types of construction. An 8 ft by 8 ft sample of the construction assembly is placed in a test unit. For steady-state measurements, the temperatures on either side of the wall are held constant until temperatures within the construction have stabilized; then the rate of heat flow is measured. The biggest advantage of laboratory testing is that it gives equally good data for any type of construction assembly. The major disadvantage is that it is costly and time consuming. There is a large variety of possible construction assemblies, and it is impractical to test them all. For this reason, it is usually more cost effective to use calculation methods. Laboratory measurements must use one of the following test procedures: Guarded Hot Plate (ASTM C-177-85), Heat Flow Meter (ASTM C-518-85), Guarded Hot Box (ASTM C-236-87), or Calibrated Hot Box (ASTM C-976-82).

Series-Parallel Path (Isothermal Planes) Method

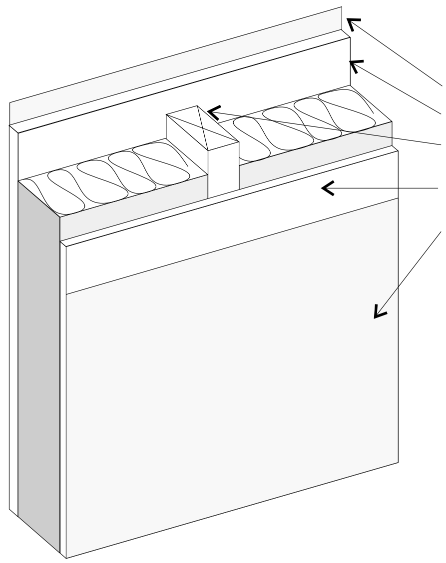
The *series-parallel method* is a reasonably accurate procedure for calculating the U-factor when one or more elements in a construction are relatively conductive. It may be used for wood framed walls and for concrete and masonry walls. Hollow masonry units are a good example of when this calculation method is appropriate. The solid webs connecting the faceshells are quite conductive compared to the air spaces in the hollow cores, and the faceshells conduct heat laterally. The heat, in effect, flows around the hollow cores. The series-parallel method divides the construction assembly into a series of layers. For a masonry unit, the layer containing the webs and cores is treated with a parallel path calculation to arrive at an average

R-value for the layer. This is then added to the R-values of the two faceshells, as in a series method calculation. Finally, the total R-value is inverted to the U-factor. This method is also referred to as the isothermal planes method, because it assumes uniform temperature across the planes separating the layers.

Example 402M U-factor Calculation – Series - Parallel Path

Q

What is the thermal transmittance of the wood framed wall shown in the following drawing?



A

The series and parallel path method may be used for this type of construction. The U-factor is calculated separately for the cavity and framing portions of the wall based on the thermal resistance of each element of the wall. These calculations are made in the following table:

	Cavity	Framing
Outside air film	0.17	0.17
7/8 in. stucco	0.18	0.18
Building paper	0.06	0.06
Cavity insulation	13.00	
Framing		4.375
1/2 in. gypsum board	0.45	0.45
Inside air film	0.68	0.68
Sum of thermal resistance	14.54	5.01

The estimated framing is 15% of the wall area and the U-factor may be calculated as shown below.

$$U = \frac{0.15}{5.01} + \frac{1-0.15}{14.54} = 0.088$$

Parallel Path Correction Factors

The 90.1 Code provides a simple way to calculate the thermal resistance (R-value) of certain types of roofs and walls with metal framing. Tables 402.1.2.1a and 402.1.2.1b in the code contain two sets of parallel path correction factors: one for metal trusses surrounded by insulation and one for metal wall studs. The correction factor is essentially a multiplier times the insulation R-value. It provides a very easy way of accounting for the effect of metal framing in wall and roof construction assemblies. These tables are repeated below as Tables 402R and 402S.

Two Dimensional Heat Flow

Two-dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. While the series-parallel path calculation method assumes that heat flows in a straight line from the warm side of the construction to the cooler side, with two dimensional models, heat can also flow laterally in the construction, following the path of least resistance. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer. A model is set up by dividing the construction into a large number of small pieces, and defining the thermal resistance between each piece. The result is analyzed with electric circuit theory. The network consists of a rectangular array of nodes connected by resistances. As in the real material, the energy flow will take the path of least resistance. The computer can perform the complicated calculations necessary to solve the network, yielding the U-factor for the unit at steady state. It can also solve the network for dynamic energy conditions. Short of performing laboratory tests, this is the most accurate method available for determining the U-factors of concrete and masonry walls.

Zone Method

For conditions for which there are no parallel path correction factors, the zone method may be used. It may be used for construction assemblies with metal framing and non-metallic sheathing, such as concrete or masonry. The use of this method is documented in the ASHRAE Fundamentals Handbook (1985) and involves dividing the construction assembly into zones. Heat flow in the zone near the metal framing is assumed to be conducted toward the framing and the thermal resistance is smaller.

Compressed Insulation

Insulation that is compressed must be derated in accordance with Table 402T. or the reduction may be calculated in accordance with the procedures in the ASHRAE Fundamentals Handbook (1985).

Table 402R Parallel Path Correction Factors for Metal Roof Trusses

Size of Members	Spacing of Framing (inches o.c.)	Insulation R-value	Correction Factor	Effective R-value
All	48	R-0	1.00	R-0
		R-5	0.96	R-4.8
		R-10	0.92	R-9.2
		R-15	0.88	R-13.2
		R-20	0.85	R-17.0
		R-25	0.81	R-20.3
		R-30	0.79	R-23.7
		R-35	0.76	R-26.6
		R-40	0.73	R-29.2
		R-45	0.71	R-32.0
		R-50	0.69	R-34.5
		R-55	0.67	R-36.0

Table 402S Effective R-values for Wall Insulation Installed Between Metal Framing

Nominal Framing Depth	Nominal Insulation R-value	Correction Factor	Effective R-value
4"@16"o.c.	R-11	0.50	R-5.5
	R-13	0.46	R-6.0
	R-15	0.43	R-6.4
4"@24"o.c.	R-11	0.60	R-6.6
	R-13	0.55	R-7.2
	R-15	0.52	R-7.8
6"@16"o.c.	R-19	0.37	R-7.1
	R-21	0.35	R-7.4
6"@24"o.c.	R-19	0.45	R-8.6
	R-21	0.43	R-9.0
8"@16"o.c.	R-25	0.31	R-7.8
8"@24"o.c.	R-25	0.38	R-9.6

The correction factors for metal framed walls may be used with metal studs of 16 ga. or lighter.

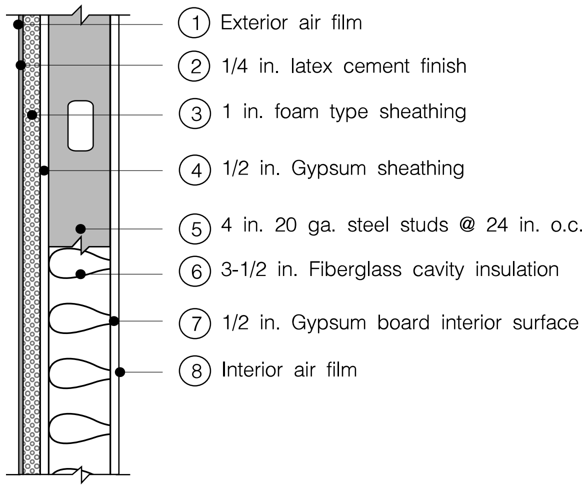
Table 402T Effective R-value of Fiberglass Batts Compressed in Various Depth Cavities (h-ft^2-°F/Btu)

Nominal Lumber Size	Actual Depth of Cavity	Insulation R-values at Standard Thickness													
		38C	38	30C	30	25	22	21	19	15	13	11	8	5	3
2" × 12"	11-1/4"	38	37												
2" × 10"	9-1/4"		32	30											
2" × 8"	7-1/4"		27		26	24									
2" × 6"	5-1/2"				21		20	21	18						
2" × 4"	3-1/2"						14		13	15	13	11			
2" × 3"	2-1/2"										10				
2" × 2"	1-1/2"										6.5	6.0	5.7		
2" × 1"	1/2"													3.2	3.0

The standard thicknesses are as follows: 10-1/4" for R-38C, 12" for R-38, 8-1/4" for R-30C, 9-1/2" for R-30, 8" for R-25, 6-3/4" for R-22, 5-1/2" for R-21, 6-1/4" for R-19, 3-1/2" for R-15, 3-1/2" for R-13, 3-1/2" for R-11, 2-1/2" for R-8, 1-1/2" for R-5 and 3/4" for R-3.

Example 402N U-factor Calculation – Parallel Path Correction Factors

Q What is the thermal transmittance of the metal framed wall shown in the following drawing?



Component	R-value
(1) Exterior air film	0.17
(2) Latex cement finish	0.21
(3) Foam sheathing	4.00
(4) Gypsum sheathing	0.45
(5) 2×4 steel studs 24 in. o.c.	N.A.
(6) Fiberglass insulation	11.00
(7) Gypsum board interior	0.45
(8) Interior air film	0.68

A The parallel path correction factors may be used for this type of construction. This calculation method is available for wall sections with non-metal skin attached to metal stud framing. It is a modified form of the equivalent circuit method. It uses the parallel path correction factors listed in Table 402.1.2.1b. The correction factor for a 2×4 metal stud framing at 24 in. o.c. with R-11 fiberglass cavity insulation is 0.60. The thermal transmittance of this assembly is given by the following equations:

$$R_e = R_{insulation} \times F_c = 11.0 \times 0.60 = 6.6$$

The thermal resistance of the framing and insulation with thermal bridging accounted for. The parallel path correction factor of 0.60 is taken from Table 402.1.2.1b of the code.

$$\sum_i R_i = 0.17 + 0.21 + 4.00 + 0.45 + 6.60 + 0.45 + 0.68 = 12.56$$

The thermal resistance of the materials in "series"

$$U_t = \frac{1}{R_t} = \frac{1}{12.56} = 0.0796$$

The overall thermal transmittance of the assembly

Two Dimensional Heat Flow

Two-dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. While the series-parallel path calculation method assumes that heat flows in a straight line from the warm side of the construction to the cooler side, with two dimensional models, heat can also flow laterally in the construction, following the path of least resistance. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer. A model is set up by dividing the construction into a large number of small pieces, and defining the thermal resistance between each piece. The result is analyzed with electric circuit theory. The network consists of a rectangular array of nodes connected by resistances. As in the real material, the energy flow will take the path of least resistance. The computer can perform the complicated calculations necessary to solve the network, yielding the U-factor for the unit at steady state. It can also solve the network for dynamic energy conditions. Short of performing laboratory tests, this is the most accurate method available for determining the U-factors of concrete and masonry walls.

Zone Method

For conditions for which there are no parallel path correction factors, the zone method may be used. It may be used for construction assemblies with metal framing and non-metallic sheathing, such as concrete or masonry. The use of this method is documented in the ASHRAE Fundamentals Handbook (1985) and involves dividing the construction assembly into zones. Heat flow in the zone near the metal framing is assumed to be conducted toward the framing and the thermal resistance is smaller.

Compressed Insulation

Insulation that is compressed must be derated in accordance with Table 402T or the reduction may be calculated in accordance with the procedures in the ASHRAE Fundamentals Handbook (1985).

Table 402U Effective R-value of Fiberglass Batts Compressed in Various Depth Cavities (h-ft^2-°F/Btu)

Nominal Lumber Size	Actual Depth of Cavity	Insulation R-values at Standard Thickness													
		38C	38	30C	30	25	22	21	19	15	13	11	8	5	3
2" × 12"	11-1/4"	38	37												
2" × 10"	9-1/4"		32	30											
2" × 8"	7-1/4"		27		26	24									
2" × 6"	5-1/2"				21		20	21	18						
2" × 4"	3-1/2"						14		13	15	13	11			
2" × 3"	2-1/2"										10				
2" × 2"	1-1/2"										6.5	6.0	5.7		
2" × 1"	1/2"													3.2	3.0

The standard thicknesses are as follows: 10-1/4" for R-38C, 12" for R-38, 8-1/4" for R-30C, 9-1/2" for R-30, 8" for R-25, 6-3/4" for R-22, 5-1/2" for R-21, 6-1/4" for R-19, 3-1/2" for R-15, 3-1/2" for R-13, 3-1/2" for R-11, 2-1/2" for R-8, 1-1/2" for R-5 and 3/4" for R-3.