NUMBER 7

Builder Insight

ASHRAE 90.1—Requirements for the Building Enclosure:

Understanding the Compliance Paths for Multi-Unit Residential Buildings

Homeowner Protection Office
Branch of BC Housing

Builder Insight is a series of bulletins designed to provide practical information on new technologies, research results, good building practices and emerging technical issues in residential construction to Licensed Residential Builders and others in the industry.

RDH Building Engineering Limited

This bulletin is produced by the Homeowner Protection Office (HPO), a branch of BC Housing, and was prepared by RDH Building Engineering Limited (RDH).

OVERVIEW

Approximately 30% of energy use in Canada is consumed in buildings. The largest component of this energy consumption in multi-family residential buildings is space heating.

In British Columbia, residential space heating typically accounts for 30% to 60% of a building's total energy consumption.

Reducing space-heating energy use is a primary function of the building enclosure. While heat flow through the building enclosure cannot be prevented, it can be controlled to reduce the total energy consumption and improve comfort. This is achieved by constructing a thermally insulated and airtight building enclosure.

Residential buildings that fall under Part 3 of the 2006 British Columbia Building Code (BCBC) are required to comply with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 90.1-2004. The City of Vancouver Building Bylaw (VBBL) references ASHRAE 90.1-2007. There are differences between the 2004 and 2007 versions of ASHRAE 90.1, in particular with respect to building enclosure and window requirements. In addition to the ASHRAE 90.1 requirements, the *BC Energy Efficiency Act* regulations for windows, doors and skylights also need to be considered. This bulletin describes the energy performance requirements for the building enclosure in accordance with these standards, and outlines the considerations for the alternate compliance paths for multi-unit residential buildings.

While heat flow through the building enclosure cannot be prevented, it can be controlled to reduce the total energy consumption and improve comfort.

ASHRAE 90.1 2004 & 2007 Compliance

ASHRAE 90.1 provides energy performance requirements based on climate zones. The climate zones are determined based on Heating Degree Days (HDD) resulting in four distinct zones within B.C. An HDD is a measure of how cold a location is over a period of time relative to a base temperature of 18°C.

There are three alternate compliance paths that can be followed to meet the building enclosure requirements of ASHRAE 90.1 (2004 or 2007).

Prescriptive Path

Building enclosure component thermal resistances must meet minimum requirements set out in a series of tables for different climate zones (ASHRAE 90.1 Tables 5.5-5 to 5.5-8). The tables provide two alternate columns for prescriptive compliance: either a minimum assembly R-value (maximum U-value) or a minimum insulation R-value must be met. The minimum assembly R-value considers the effects of framing thermal bridging, sheathing materials and air films, whereas the minimum insulation R-value excludes thermal bridging effects and only considers the insulation value. While thermal bridging through wood framing (15% to 20% degradation) is not as significant as steel (45% to 60% degradation) – it still must be accounted for in calculations to determine effective assembly R-value. Tables that provide typical enclosure assembly R-values are included as an appendix in ASHRAE 90.1 (Normative Appendix A).

For most assemblies, the minimum insulation requirement includes an additional requirement for continuous insulation (c.i.). Continuous insulation, typically placed as one of the outer layers within the assembly, may not be interrupted or thermally bridged except by fasteners. This can be an onerous requirement and is often the trigger for the use of a compliance path other than the prescriptive path. The tables also consider the thermal differences between wood-frame, steel-frame and mass concrete assemblies.

Typically the prescriptive path can be followed unless:

- the effective thermal resistance of an assembly cannot be met,
- there is a desire to have a window area that exceeds the maximum allowable percentage of wall area, or
- the continuous insulation requirement cannot be met.

In these instances one of the alternate compliance paths must be utilized.

ASHRAE 90.1 Climate Zones for British Columbia. Actual Heating Degree Days (HDD) for most municipalities in British Columbia can be found in Appendix C, Division B of the BC Building Code.

Air Leakage

The unintentional flow of air between the interior and exterior environment through the building enclosure is known as air leakage. Air leakage can be a significant portion of the heat loss in a building. Depending on the airtightness of the building enclosure, up to 50% of the total heat loss could occur by air leakage.

It is difficult to quantify air leakage through the building enclosure of larger multi-unit residential buildings. Therefore, ASHRAE 90.1 only provides qualitative requirements for air sealing of interfaces and joints within the building enclosure. The exception to this is for windows and doors where prescriptive performance values are referenced.

There is a trend towards more airtight building enclosures as performance issues such as water penetration control, and energy efficiency are appropriately addressed. However, improved airtightness means that it is more critical that the building ventilation system is both properly designed and is operating appropriately to ensure acceptable indoor air quality.

Minimum Thermal Resistance for Part 3 Residential Buildings (Excerpt from Table 5.5-5 to 5.5-8 from ASHRAE 90.1-2004)

	BCBC - ASHRAE Climate Zone 5 R-value (RSI) ft²•°F• h/Btu (m²•°K /W)		BCBC - ASHRAE Climate Zone 6 R-value (RSI) ft²•°F• h/Btu (m²•°K /W)		BCBC - ASHRAE Climate Zone 7 R-value (RSI) ft²•°F• h/Btu (m²•°K /W)		BCBC - ASHRAE Climate Zone 8 R-value (RSI) ft²•°F• h/Btu (m²•°K /W)	
Building Enclosure Component	**Minimum Assembly**	**Minimum Insulation**	**Minimum Assembly**	**Minimum Insulation**	**Minimum Assembly**	**Minimum Insulation**	**Minimum Assembly**	**Minimum Insulation**
Roofs								
Above Deck	R-15.8 (2.8)	R-15.0 c.i. (2.64)	R-15.8 (2.8)	R-15.0 c.i. (2.64)	R-15.8 (2.8)	R-15.0 c.i. (2.64)	R-20.8 (3.7)	R-20.0 c.i. (3.5)
Attic	R-37.0 (6.5)	R-38.0 (6.7)	R-37.0 (6.5)	R-38.0 (6.7)	R-37.0 (6.5)	R-38.0 (6.7)	R-37.0 (6.5)	R-38.0 (6.7)
Walls, Above Grade								
Mass	R-11.1 (1.95)	R-11.4 c.i. (2.0)	R-11.1 (1.95)	R-11.4 c.i. (2.0)	R-12.5 (2.2)	R-13.0 c.i. (2.3)	R-14.0 (2.47)	R-15.3 c.i. (2.7)
Wood-Frame	R-11.3 (2.0)	R-13.0 (2.29)	R-15.6 (2.75)	R-13.0+3.8 c.i. (2.3+0.7 c.i.)	R-19.6 (3.45)	R-13.0+7.5 c.i. (2.3+1.3 c.i.)	R-19.6 (3.45)	R-13.0+7.5 c.i. (2.3+1.3 c.i.)
Steel-Frame	R-15.6 (2.75)	R-13+7.5 c.i. (2.3+1.3)	R-15.6 (2.75)	R-13.0+7.5 c.i. (2.3+1.3)	R-15.6 (2.75)	R-13.0+7.5 c.i. (2.3+1.3 c.i.)	R-18.0 (3.17)	R-13.0+10.0 c.i. (2.3+1.8 c.i.)
Wall, Below Grade	-	N/R	-	R-7.5 c.i. (1.3)	-	R-7.5 c.i. (1.3)	-	R-7.5 c.i. (1.3)
Floors								
Mass	R-13.5 (2.4)	R-10.4 c.i. (1.83)	R-15.6 (2.75)	R-12.5 c.i. (2.2)	R-15.6 (2.75)	R-12.5 c.i. (2.2)	R-17.5 (3.1)	R-14.5 c.i. (2.55)
Wood-Frame	R-30.0 (5.3)	R-30.0 (5.3)	R-30.0 (5.3)	R-30.0 (5.3)	R-30.0 (5.3)	R-30.0 (5.3)	R-30.0 (3.5)	R-30.0 (5.3)
Slab on Grade Floors	**Perimeter Insulation F-factors Btu/h•ft•°F (W/m•°K) - ASHRAE Table A6.3**							
Unheated	F-0.73 (1.26)	N/R	F-0.73 (1.26)	N/R	F-0.73 (1.26)	R-10-24" (1.76)	F-0.73 (1.26)	R-15-24" (2.64)
Heated	F-0.84 (1.45)	R-10-36" (1.76)	F-0.78 (1.35)	R-10-48" (1.76)	F-0.84 (1.45)	R-10-48"(1.76)	F-0.84 (1.45)	R-10-48"(1.76)
Opaque Doors	**Window and Door Assembly U-value Btu/h•ft²•°F (W/m²•°K)**							
Swinging	U-0.70 (4.0)	n/a	U-0.50 (2.86)	n/a	U-0.50 (2.86)	n/a	U-0.50 (2.86)	n/a
Non-Swinging	U-0.50 (2.86)	n/a	U-0.50 (2.86)	n/a	U-0.50 (2.86)	n/a	U-0.50 (2.86)	n/a
Windows	*General Window Notes:* – Applies to all frame types – 50% maximum window area – Additional requirements for skylights and SHGC factor provided in AHSRAE 90.1			*Window Area*	0–40%	40.1–50%	0–40%	40.1–50%
				Fixed	U-0.57 (3.25)	U-0.46 (2.63)	U-0.57 (3.25)	U-0.46 (2.63)
				Operable	U-0.67 (3.82)	U-0.47 (2.68)	U-0.67 (3.82)	U-0.47 (2.68)

c.i. - denotes continuous insulation *N/R - denotes no insulation requirement*

Window Performance Certification

ASHRAE 90.1 requires that window U-values must be determined in accordance with National Fenestration Rating Council (NFRC) Standard 100. Windows that do not have NFRC certification (not listed in the NFRC Product Directory) are required to reference tables of typical product types provided in the 90.1 Standard Appendices (which provide unfavorable results for typical assemblies).

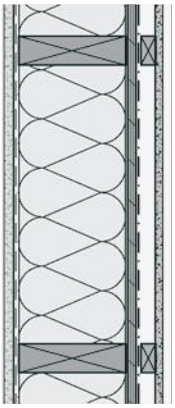
NFRC U-values are based on modeled standard window sizes (validated through laboratory testing), and may not be representative of actual window sizes and configurations installed in the actual building. It is also important to consider the effective U-values for all window types including the fixed, operable and sliding doors in the calculations. Additional simulations will be required to determine actual U-values for particular configurations. This information is necessary in order to undertake any of the trade-off analysis associated with the Building Enclosure Trade-Off or Energy Cost Budget compliance paths.

The *BC Energy Efficiency Act* contains new mandatory requirements for labeling of window products with respect to energy performance and NFRC product certification. For more details visit www.nfrc.org or www.empr.gov.bc.ca.

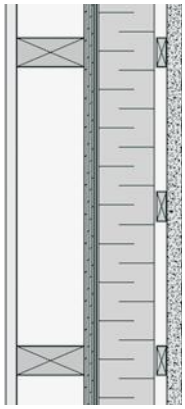
Minimum Thermal Resistance for Part 3 Residential Buildings in the City of Vancouver, Climate Zone 5 (Excerpt from Table 5.5-5 from ASHRAE 90.1-2007)

	City of Vancouver ASHRAE Climate Zone 5 – Residential Buildings R-value (RSI) ft²•°F• h/Btu (m²•°K /W)	
Building Enclosure Component	**Minimum Assembly**	**Minimum Insulation**
Roof – Insulation Above Deck	R-20.8 (3.7)	R-20 (3.5) c.i.
Roof – Attic	R-37.0 (6.5)	R-38 (6.7)
Wall – Above Grade Wood-Frame	R-19.6 (3.5)	R-13 + 7.5 c.i. (2.3 +1.3)
Wall – Above Grade Steel-Frame	R-15.6 (2.75)	R-13 + 7.5 c.i. (2.3 +1.3)
Wall – Above Grade Mass	R-12.5 (2.2)	R-13.3 (2.3) c.i.
Wall – Below Grade Concrete	R-8.4 (1.5)	R-7.5 (1.3) c.i.
Floors – Mass	R-15.6 (2.75)	R-12.5 (2.2) c.i.
Floors – Wood-Frame	R-30.2 (5.3)	R-30 (5.3)
Slab on Grade Floors	**Perimeter Insulation F-factors – ASHRAE Table A6.3 Btu/h•ft•°F (W/m •°K)**	
Unheated	F-0.54 (0.94)	R-10 (1.8) for 24"
Radiant Heated	F-0.86 (1.49)	R-15 (2.6) for 24"
Windows and Doors	**Assembly U-value Btu/h•ft² •°F (W/m²•°K)**	*General Window Notes:* – The U-factor, solar heat gain coefficient (SHGC) and air leakage rates for windows and doors must be accredited by the NFRC – Additional requirements for skylights and SHGC factor provided in AHSRAE 90.1-2007
Opaque Doors – Swinging	U-0.5 (2.86)	
Opaque Doors – Non-Swinging	U-0.5 (2.86)	
Non Metal Frame Windows (Vinyl, Fibreglass and Wood)	U-0.35 (2.0)	
Metal Frame Windows (Aluminum)	U-0.55 (3.1)	
Metal Frame Curtainwall & Storefront	U-0.45 (2.57)	

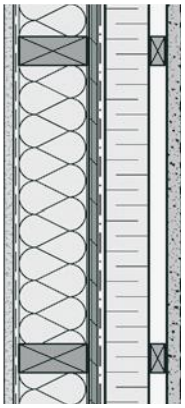
c.i. - denotes continuous insulation



1. Interior Insulated



2. Exterior Insulated



3. Split Insulated

Building Enclosure Trade-off Path

This compliance path allows for the trade-off of the thermal performance of one enclosure assembly with another (for example, providing more insulation within the roof to offset less insulation in the walls or providing better windows to offset less insulated walls).

In this trade-off path an energy simulation is undertaken for a baseline building model (the entire building enclosure using minimum prescribed R-values and prescriptive requirements for 40% vertical glazing area), and is compared to the proposed building (using actual building enclosure component R-values and glazing percentages). The proposed building vertical glazing percentage can exceed the prescriptive path limit by using better thermally performing walls and/or windows, as long as the Energy Performance Factor (EPF) is lower (i.e. better) than the EPF for the same enclosure configuration with minimally compliant enclosure characteristics of the baseline building.

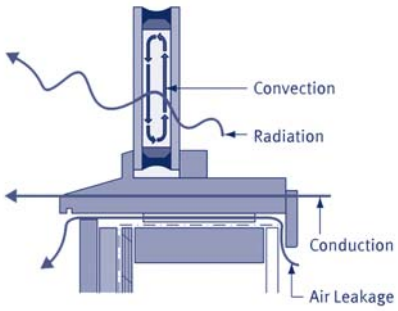
The building enclosure trade-off method also considers daylighting and solar heat gains through windows. However, it does not consider the impact of mechanical system improvements. The simulation is undertaken using the EnvStd software provided with ASHRAE 90.1. This simulation tool is not difficult to use, but requires the user to be able to accurately assess the R-values (U-values actually used) of the proposed assemblies.

Energy Cost Budget Path

Whole building energy performance encompasses all key building systems impacting energy use together. Mechanical and lighting are examined together with the performance of the building enclosure in order to meet overall building energy cost budgets. For example, mechanical improvements can be traded off, or compensated for poorer building enclosure performance, and vice versa. This compliance path also requires simulation software.

The energy cost budget compliance path is also utilized in assessing Leadership in Energy and Environmental Design (LEED)credits. The overall U-value has a large impact on energy consumption, and a better than ASHRAE baseline U-value will achieve more LEED points. Up to 10 points (Energy and Atmosphere – Optimize Energy Performance credit) are available for reducing the energy cost of the designed building by between 15% and 60% over the ASHRAE 90.1 baseline building (for LEED Canada NC 1.0).

The energy cost budget path compares energy costs, whereas the other compliance paths compare energy use. While the difference in energy cost and consumption is not usually significant, it could be if gas and electricity energy pricing were significantly different. Currently when electricity is at approximately $0.07/kWh and gas is at $11/GJ ($0.04/ekWh), savings in electricity will have a larger cost impact than natural gas.



Mechanisms of Heat Flow

Exterior Insulated and Split Insulation Wall Assemblies

To improve the effectiveness of the insulation used in wall assemblies, insulation may be placed solely to the exterior of the sheathing (exterior insulated), or alternately in both the stud cavity and to the exterior of the sheathing (split insulated). These wall assemblies are used in non-combustible construction but currently are uncommon in wood-frame construction. As thermal performance requirements are enhanced there may be a need to consider these wall assembly types in wood-frame construction.

If a split insulation wall assembly is used, the type of insulation and placement of air, water and vapour control layers need to be carefully considered.

In wall #3 the effective R-value for a wood wall assembly with R-12 fibreglass insulation is R-10.8 (ASHRAE Table A3.4); 51 mm (2") of continuous rigid insulation (not bridged by wood framing) has an effective R-value of R-8 depending on insulation type. Therefore, the effective R-value for this assembly is summed from the two parts to be R-18.8.

The exterior airspace and cladding cannot be considered in the R-value calculation as the cavity is ventilated.

This wall meets the prescriptive requirements for Climate Zones 5 and 6 in ASHRAE 90.1-2004, but does not meet the requirements in Climate Zones 7 and 8. The wall also does not meet the prescriptive requirements for Climate Zone 5 (Vancouver) in ASHRAE 90.1-2007 (Table 5.5-5). It may be possible to achieve compliance in these latter situations however it will require the use of the building envelope trade-off method or energy modeling for compliance.

Whole Building Enclosure Energy Performance

Regardless of which of the trade-off compliance paths are used, the considerations for the building enclosure are very similar.

It is important to understand the relative significance of each element of the enclosure and what the best opportunities are for improving overall performance. The weaker thermally performing elements (such as windows), or large thermal bridges (such as exposed floor slab edges or balconies) provide the best opportunity for improving performance and, therefore, establish a focal point for the design team.

A simple trade-off calculation can be performed by determining the component U-values and area weighted U•A factors for a building. It is clear in examining this calculation for a typical building that the performance of windows has a disproportionately high influence on the overall enclosure energy performance. For example, consider a building with R-2 windows within R-20 walls and an R-40 attic roof.

Baseline Wood-frame Building – ASHRAE 90.1 Compliant

Component	Area	U-value (Btu/ft²•°F•hr)	U•A Factor	Thermal Weight
Walls, R-20 effective	12000 ft² (46.2%)	0.05	600	12.6%
Windows, R-2 thermally broken aluminum frames	8000 ft² (30.1%)	0.50	4000	84.2%
Attic, R-40 effective	6000 ft² (23.1%)	0.025	150	3.2%
		Sum U•A	4750	
Overall U-value = Sum U•A/Total A (Btu/ft²•°F•hr)			0.183	
Overall R-value = 1/Overall U-value (ft²•°F•hr/Btu)			5.47	

Baseline Wood – Frame Building: ASHRAE 90.1 Compliant

In the adjacent example, windows carry a weight of 84% in thermal calculations despite the fact that the windows only comprise 31% of the building enclosure area. The impact of adding insulation to the walls or attic can be explored but will have a minimal influence on overall performance until the window performance is improved. For example, doubling the attic insulation to R-80 would only increase the overall R-value of the enclosure to R-5.56, a less than 2% improvement. However, if the windows are modified to triple glazed insulated glass units (IGUs) within low conductivity frames with a U-value of 0.17, then significant overall enclosure performance improvements may be realized.

Proposed Energy Efficient Building – Improved Windows

Component	Area	U-value (Btu/ft²•°F•hr)	U•A Factor	Thermal Weight
Walls, R-20 effective	12000 ft² (46.2%)	0.05	600	28.4%
Windows, R-5.9 triple IGUs, low-conductivity frames	8000 ft² (30.1%)	0.17	1360	64.5%
Attics, R-40 effective	6000 ft² (23.1%)	0.025	150	7.1%
		Sum U•A	2110	
Overall U-value = Sum U•A/Total A (Btu/ft²•°F•hr)			0.0812	56% reduction
Overall R-value = 1/Overall U-value (ft²•°F•hr/Btu)			12.3	125% improvement

Proposed Energy Efficient Building – Improved Windows

The improvement from R-2 to R-5.9 triple glazed windows (an increase of R-3.9) improves the R-value for the whole building by 125% or by R-6.83 over the baseline to R-12.3. In addition, the weighting of the energy use of components changes, with a shift of thermal weight towards the walls and attics. As a result, further improvements could be made to those components resulting in greater benefits attributable to these improvements (i.e. adding attic or wall insulation).

Building Enclosure Trade-off Considerations

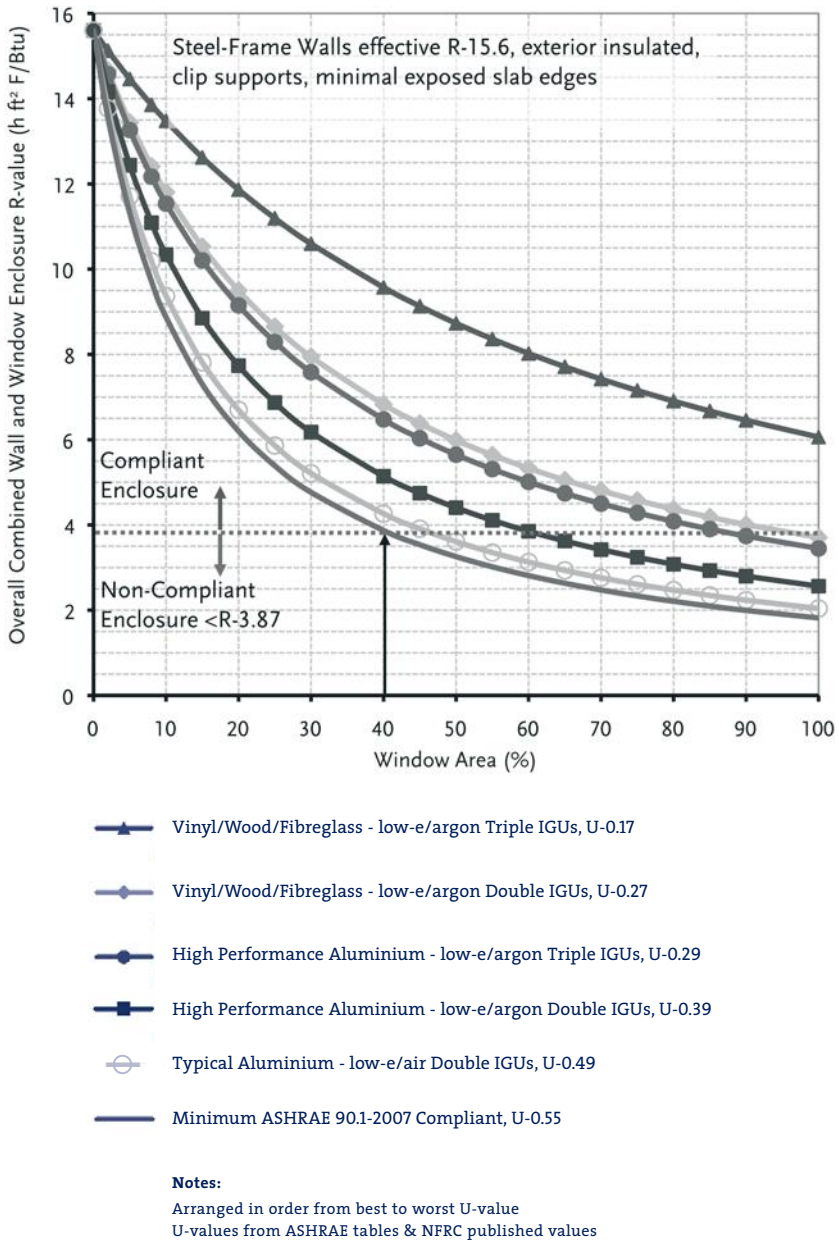
Both the Building Enclosure Trade-off and Energy Cost Budget compliance paths provide greater flexibility for designers. Better thermal performance of one building enclosure component can make up for another component that may not meet the prescriptive standard. This approach also allows for vertical glazing percentages beyond 50%, the use of alternate wall assemblies, as well as the incorporation of thermal bridge elements (i.e. balconies or eyebrows).

The graph below illustrates some of the opportunities that exist in trading off window performance with vertical glazing percentages using ASHRAE 90.1-2007. A minimum compliant wall assembly has been assumed (R-15.6). In this scenario improved windows permit larger glazing percentages. Many other scenarios are possible, including window and wall performance trade-offs, and mechanical and building enclosure trade-offs (if using Energy Cost Budget Compliance Path).

Vestibules

A mandatory provision within ASHRAE 90.1 for most multi-unit residential buildings is a vestibule or revolving entrance door for the main building entrance. Some exceptions apply for smaller buildings, but generally this is a mandatory requirement that cannot be traded off.

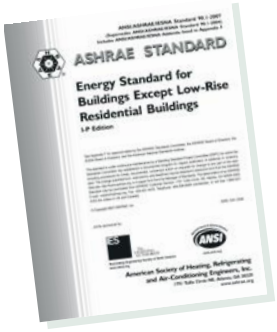
ASHRAE 90.1-2007 Compliance – Influence of Window Framing Type and IGU on Overall Enclosure R-value



Notes:
Arranged in order from best to worst U-value
U-values from ASHRAE tables & NFRC published values

LOOKING FORWARD

The trend towards energy efficiency in buildings will continue and the energy performance of the building enclosure will be a focal point for improved performance. In addition to increased effective R-value requirements for wall, roofs, floors and windows, it is possible that quantitative requirements for airtightness may form part of the requirements. Compartmentalization of suites to control air flow between suites is another requirement that may be introduced to improve overall energy use characteristics of multi-unit residential buildings.



KEYPOINTS

Keypoints to consider:

- There are three ASHRAE 90.1 compliance paths: prescriptive, building enclosure trade-off, and energy cost budget
- The prescriptive compliance path is difficult to use due to thermal bridging, continuous insulation requirements and glazing area restrictions
- Enforcement of ASHRAE 90.1 compliance is becoming a priority
- Effective U or R-values of building enclosure assemblies need to be used for all compliance paths
- Split insulation walls may need to be considered in order to meet requirements for combustible and non-combustible construction
- Windows are usually the best opportunity for thermal performance improvements of the building enclosure
- Windows require National Fenestration Rating Council (NFRC) certified U-values

FOR MORE INFORMATION

ASHRAE Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings. Available at www.ashrae.org

ASHRAE Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. Available at www.ashrae.org

2009 ASHRAE Handbook – Fundamentals (I-P) or Fundamentals (SI). Available at www.ashrae.org

National Fenestration Rating Council (NFRC). Available at www.nfrc.org

Building Enclosure Design Guide – Wood-Frame Multi-Unit Residential Buildings, Homeowner Protection Office, 2010. Available at www.hpo.bc.ca

BC Energy Efficiency Act. Available at www.empr.gov.bc.ca

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