4.401/4.464 Environmental Technologies in Buildings

Christoph Reinhart
LI3 Insulation Materials & Windows
Thermal Module

- Thermal Mass & Heat Flow
- Insulating Materials & Window Technologies
- Shading
- Ventilation
- Internal Gains & Load Calculations
- HVAC for Small Buildings
- HVAC for Large Buildings
- Simulation Game
Insulation Materials
Recommended R-values

Conversion: 1 m²K/W ≈ 5.67446 h ft²·F /Btu

Public domain image courtesy of the US Department of Energy.

Recommended insulation levels for retrofitting existing wood-framed buildings

<table>
<thead>
<tr>
<th>Zone</th>
<th>Add Insulation to Attic</th>
<th>Existing 3–4 Inches of Insulation</th>
<th>Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R30 to R49</td>
<td>R25 to R30</td>
<td>R13</td>
</tr>
<tr>
<td>2</td>
<td>R30 to R60</td>
<td>R25 to R38</td>
<td>R13 to R19</td>
</tr>
<tr>
<td>3</td>
<td>R30 to R60</td>
<td>R25 to R38</td>
<td>R19 to R25</td>
</tr>
<tr>
<td>4</td>
<td>R35 to R60</td>
<td>R38</td>
<td>R25 to R30</td>
</tr>
<tr>
<td>5 to 8</td>
<td>R49 to R60</td>
<td>R38 to R49</td>
<td>R25 to R30</td>
</tr>
</tbody>
</table>

Wall Insulation: Whenever exterior siding is removed on an

Uninsulated wood-frame wall:
- Drill holes in the sheathing and blow insulation into the empty wall cavity before installing the new siding, and
- Zones 3–4: Add R5 insulative wall sheathing beneath the new siding
- Zones 5–8: Add R5 to R6 insulative wall sheathing beneath the new siding.

Insulated wood-frame wall:
- For Zones 4 to 8: Add R5 insulative sheathing before installing the new siding.
Thermal Bridging

In order to calculate the mean ‘R’ value of a construction that consists of different types of constructions, i.e. a wood stud construction, one has to calculate the ‘R’ value for each individual construction and then calculate the area weighted mean as the heat flow through the two constructions goes ‘in parallel’.

\[
\frac{1}{R_{\text{wall}}} = 0.2/R_{\text{Wood Studs}} + 0.8/R_{\text{EPS Insulation}}
\]
U-Value Analysis

U-Wert: 1,60 W/m²K
EnEV Bestand: U<0,24
PEI n.e.: >16 kWh/m²
Gut

U-Wert: 0,39 W/m²K
EnEV Bestand: U<0,24
PEI n.e.: >33 kWh/m²
Mangelhaft

Temperature Profile

Moisture Profile

http://www.u-wert.net/berechnung/u-wert-rechner/

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Thermal Bridging in Archsim
Status of Commercial Energy Codes

http://www.energycodes.gov/status-state-energy-code-adoption

Public domain image courtesy of the US Department of Energy.
Status of Residential Energy Codes

IECC = International Energy Conservation Code

http://www.energycodes.gov/status-state-energy-code-adoptions

Updated as of June 2018

http://www.energycodes.gov/status-state-energy-code-adoptions

IECC = International Energy Conservation Code

Public domain image courtesy of the US Department of Energy.
1. What is the ‘stretch’ code?
The ‘stretch code’ is an optional appendix to the Massachusetts building energy code that allows cities and towns to choose a more energy-efficient option. This option increases the efficiency requirements in any municipality that adopts it, for all new residential and many new commercial buildings, as well as for those residential additions and renovations that would normally trigger building code requirements.
Some Insulation Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>R-Value Per Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Space</td>
<td>1</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>2</td>
</tr>
<tr>
<td>Perlite</td>
<td>3</td>
</tr>
<tr>
<td>Cellulose</td>
<td>4</td>
</tr>
<tr>
<td>Mineral Fibre</td>
<td>5</td>
</tr>
<tr>
<td>Polymeric Foam</td>
<td>10</td>
</tr>
</tbody>
</table>
Expanded Polystyrene (EPS)

- Glass Fiber Board: ~5 R per inch
- Economical
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Glass Fiber

- Glass Fiber Batt: ~4 R per inch
- Economical

Photo courtesy of Best And Worst Ever Photo Blog. License: CC BY.
Mineral Fiber/Wool

- Mineral Fiber: ~4 R per inch
- More pleasant to work with than glass fiber.
Cellulose

- Cellulose: ~3.5 R per inch
- Can be blown into existing wall cavities during energy retrofits.
- Can fill cavities of any shape.
- Make sure that cavity is dry all year round.
- Make sure that the whole cavity gets equally filled.
Straw Bale

- Straw bale: ~2.7 R per inch - Can be built very thick (18")

Photo courtesy of yanmicols on Flickr. License CC BY-NC.
Vacuum Insulation Panels (VIP)

- Air Space
- Vermiculite
- Perlite
- Cellulose
- Mineral Fibre
- Polymeric Foam
- VIP
Vacuum Insulation Panels (VIP)

- VIP are typically installed where space is very limited, for example in a basement or for a retrofit in a room with limited floor-to-ceiling height.
Vacuum Insulation Panel (VIP)

- VIP: ~35 R per inch
- VIP are typically installed where space is very limited, for example in a basement or for a retrofit in a room with limited floor-to-ceiling height.
- With precast concrete units plus VIP, building assemblies can achieve a U-value of 0.15 W/m²K, which complies with the passive house standard, with a total thickness of only 27 cm as opposed to the more standard 60 cm.

THERM Analysis
Windows
**Interaction of Radiation with Windows**

Solar heat gain coefficient (SGHC): Fraction of incident total solar radiation that reaches the interior.

Visual Transmittance ($\tau$): Fraction of incident visible radiation that reaches the interior.
Coated glazings have a faster transmittance falloff with rising incidence angles than single pane windows.
# Window Label NFRC

![NFRC Label](image)

**Essentials Window**

Vinyl Extruded, Dual Glazed, Power E Glass with Argon Fill

Product Type: Vertical Slider

<table>
<thead>
<tr>
<th>ENERGY PERFORMANCE RATINGS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U-Factor (U.S./I-P)</td>
<td>0.30</td>
</tr>
<tr>
<td>Solar Heat Gain Coefficient</td>
<td>0.29</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADDITIONAL PERFORMANCE RATINGS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Transmittance</td>
<td>0.56</td>
</tr>
<tr>
<td>Air Leakage (U.S./I-P)</td>
<td>0.1</td>
</tr>
<tr>
<td>Condensation Resistance</td>
<td>58</td>
</tr>
</tbody>
</table>

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. Consult manufacturer’s literature for other product performance information.

[www.nfrc.org](http://www.nfrc.org)
Heat Balance Equation with Solar Gains

Outside environment

- $T_{\text{out}}$
- Conduction losses: $(T_{\text{in}} - T_{\text{out}}) \times \sum_{\text{Envelope}} (A \times U)$
- Solar gains: $G \times \sum_{\text{Envelope}} (A \times \text{SHGC})$

Indoor environment

- $T_{\text{in}}$
- $T_{\text{in}} = T_{\text{in}} \times (T_{\text{Current time step}} - T_{\text{Future time step}})$
New England Home
In a multi-zone thermal model we are treating each room as a well-mixed thermal entity.

All windows are modeled coincident with the walls that they belong to.

External shading objects (entrance roof) are modeled separately.

The basement is being ignored and it is assumed that there is no heat flow between basement and the 1st floor.

Friday’s tutorial will discuss building a simple thermal model in Archsim.
Glazing Study using DIVA/Archsim

Rhino viewport

Two zone energy model.
Glazing Study of the New England House

Monthly Energy Use [kWh/m²]

Base case (uninsulated) with single pane glazing
Glazing Study using DIVA/Archsim

Two zone energy model.
Varying glazing types. What is ‘Sgl_Clr_6’?
**SglClr_6**

Single pane glazing, 6 mm clear glass

\[ \tau_{\text{vis}} = 88.4\% \]

\[ \text{SHGC} = 81.8\% \]

\[ R \sim 1 \quad (U = 5.818 \text{ W/m}^2\text{K}) \]
Dbl_Clr_6_6_Air

Double glazing: 6 mm clear glass, 6 mm air gap, 6 mm clear glass

$\tau_{\text{vis}} = 78.6\%$

$\text{SHGC} = 70.2\%$

$R \approx 2$ ($U = 3.114 \text{ W/m}^2\text{K}$)

Annual Energy Use for Different Glazing Types [kWh/m²yr]
Double glazing: 6 mm clear glass, 13 mm argon gap, 6 mm clear glass

$\tau_{\text{vis}} = 78.6\%$

$\text{SHGC} = 70.5\%$

$R = 2.2$ ($U = 2.531 \text{ W/m}^2\text{K}$)
Double glazing: 6 mm clear glass, 1 mm vacuum, 6 mm clear glass

\[ \tau_{\text{vis}} = 78.6\% \]

\[ \text{SHGC} = 70.6\% \]

\[ R = 2.5 \quad (U = 2.238 \text{ W/m}^2\text{K}) \]

Vacuum effective to keep a glazing unit thin
Vacuum Glazing in Building 2
Selective Coatings

Low-E Coating Performance

EXTERIOR

Sunlight: All wavelengths

Long Wavelength: Infrared radiation (heat) reflected

Daytime or In Hot Climates: Heat gain to structure is reduced

Low-E storm window over clear single-pane primary

INTERIOR

Low-E Coating: Transmits or reflects selected wavelengths

Short Wavelength: Visible light passes through glazing

Long Wavelength: Infrared radiation (heat) reflected

Nighttime or In Cold Climates: Heat loss from structure is reduced

Public domain image courtesy of US EPA.
Double glazing: 6 mm clear glass Low-\(\varepsilon\) coating high solar gains on 3\(^{rd}\) surface, 13 mm argon gap, 6 mm clear glass

\[ R = 4 \quad (U = 1.434 \, \text{W/m}^2\text{K}) \]

\[ \tau_{\text{vis}} = 76.2\% \]

\[ \text{SHGC} = 62.9\% \]

Surfaces are counted from the outside. The coating is on surface 3.

Based on Cardinal Glass low-e 180 on 6 mm
Double glazing: 6 mm clear glass Low-\(\varepsilon\) coating high solar gains on 2nd surface, 13 mm argon gap, 6 mm clear glass

\(\tau_{\text{vis}}=76.2\%\)

\(\text{SHGC}=60.1\%\)

\(R=4\ (U=1.434 \text{ W/m}^2\text{K})\)

Based on Cardinal Glass low-e 180 on 6 mm
Low-$\epsilon$ Locator Test
Selective Coatings

**Low-e low solar gain**

Idealized transmittance of a glazing with a low-E coating designed for low solar heat gain. Visible light is transmitted and near-infrared solar radiation is reflected (suitable for a warm climate).

**Low-e high solar gain**

Idealized transmittance of a glazing with a low-E coating designed for high solar heat gain. Visible light and near-infrared solar radiation is transmitted. Far-infrared radiation is reflected back into the interior (suitable for a cold climate).

Figure 3-4. Ideal spectral transmittance for glazings in different climates. (Source: McCluney, 1996.)


Image courtesy of W.W. Norton & Co. Used with permission.
Double glazing: 6 mm clear glass Low-{$\varepsilon$} coating all climates, 13 mm argon gap, 6 mm clear glass

{$\tau_{vis}=62.8\%$}

{$\text{SHGC}=27.1\%$}

{$R=4.3 \ (U=1.328 \text{W/m}^2\text{K})$}

Based on Cardinal Glass low-e 366 on 6 mm
Double glazing: 6 mm clear glass Low-$\varepsilon$ low solar gains, 13 mm argon gap, 6 mm clear glass

$\tau_{vis} = 37.5\%$

$SHGC = 18.0\%$

$R = 4.2$ ($U = 1.343$ W/m$^2$K)

Based on Cardinal low-e 340 on 6 mm
Triple glazing: 6mm clear glass, 1mm vacuum gap, 6mm clear glass, 1mm vacuum gap, 6mm Low–e high solar gains on 6mm clear glass

$\tau_{\text{vis}} = 68.2\%$

$\text{SHGC} = 52.9\%$

$R = 9.3$ ($U = 0.611\text{W/m}^2\text{K}$)

Based on Cardinal Glass low-e 180 on 6mm
Why is the overall effect of replacing glazings moderate in this case?
<table>
<thead>
<tr>
<th>Glazing Unit</th>
<th>U Factor [W/m²K]</th>
<th>SGHC</th>
<th>$t_{vis}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single pane</td>
<td>5.818</td>
<td>0.816</td>
<td>0.881</td>
</tr>
<tr>
<td>Double pane</td>
<td>2.730</td>
<td>0.762</td>
<td>0.811</td>
</tr>
<tr>
<td>Double pane with argon filling</td>
<td>2.568</td>
<td>0.762</td>
<td>0.811</td>
</tr>
<tr>
<td>Double pane with argon filling &amp; low-e coating on surface 3</td>
<td>1.730</td>
<td>0.716</td>
<td>0.749</td>
</tr>
<tr>
<td>Double pane with argon filling &amp; low-e coating on surface 2</td>
<td>1.730</td>
<td>0.653</td>
<td>0.749</td>
</tr>
<tr>
<td>Double pane with argon filing &amp; low-e coating on surface 2 and 3</td>
<td>1.135</td>
<td>0.571</td>
<td>0.629</td>
</tr>
</tbody>
</table>

Fig 12.15 Optical and thermal properties for generic common glazing units
Skylights

Conventional Skylight

R-2
U=2.8 W/m²K

Insulating Glass Skylight

R-10
U=0.5 W/m²K
τ_{vis} = 62%
SHGC= 0.25

Nanogel filled

R-20
U=0.28 W/m²K
Nanogel

0.5 W/m²K ~ R-10
Other Aspects

- 20% of window is frame.
- Center of glazing vs. frame effects.
Historic R-Values for Windows

Advanced glazings have increased windows’ resistance to heat flow, or R-value.
Passive Solar Heating Potential

Passive solar heating study of Anderson Street in Boston

\[ G_{\text{threshold}} \times \text{SHGC} \times \eta > \text{heating degree hours} \times U \]

\[ G_{\text{threshold}} = \frac{24500 \text{Khr} \times 1.6 \text{W/Km}^2}{0.28 \times 0.7} = 200 \text{kWh/m}^2 \]
Heating and Cooling Degree Hours

Seattle

Boston

Phoenix
Windows lead to a net gain on the south; east and west are borderline; north windows lead to a net heat flow loss.
Questions?
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