Beyond ENERGY STAR Windows to Carbon Savings

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October 16, 2018
Glass is Energy Intensive

• Melt sand to make clear glass
• Sputter silver to make low-E
• Temper glass for safety glazing
• Fabricate into insulating glass units

• What’s the payback for Improvements?
## Window Energy Ratings

### World's Best Window Co.

**Millennium 2000+**
- Vinyl-Clad Wood Frame
- Double Glazing • Argon Fill • Low E
- Product Type: **Vertical Slider**

### ENERGY PERFORMANCE RATINGS

<table>
<thead>
<tr>
<th></th>
<th>U-Factor (U.S./I-P)</th>
<th>Solar Heat Gain Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>0.35</strong></td>
<td><strong>0.32</strong></td>
</tr>
</tbody>
</table>

### ADDITIONAL PERFORMANCE RATINGS

<table>
<thead>
<tr>
<th></th>
<th>Visible Transmittance</th>
<th>Air Leakage (U.S./I-P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>0.51</strong></td>
<td><strong>0.2</strong></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. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer’s literature for other product performance information. [www.nfrc.org](http://www.nfrc.org)
Windows from 30 Years Ago

South: R1
- Aluminum Frames
- Single Pane (clear or tinted)

North: R2
- Non-Metal Frames (wood, vinyl)
- Double Pane (IG or single + storm)
Window U  0.55 – 0.80 with Double Pane Clear
Window U ~ 0.35 with Quad Pane and Non-Metal Frame
Low-E Glass Introduced Mid-1980’s

• Triple pane insulating value in a double pane package

• Low-E + Argon = Quad pane performance

• High solar gain (HS)

• Used mostly in the north (heating dominated climates)
Non-Metal Window

U ~ 0.30

2 Pane
+ Low-E
+ Argon
+ Warm Edge
“Clear” Low-E Options Today

- High Solar Gain (window SHGC ~0.50)
  - HS

- Medium Solar Gain (window SHGC ~0.30)
  - MS

- Low Solar Gain (window SHGC ~0.20)
  - LS
Spectrally Selective Low-E
<table>
<thead>
<tr>
<th>Low-E</th>
<th>Clear Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Solar</td>
<td>High Solar</td>
</tr>
</tbody>
</table>
Low-E units are warm on winter night. Clear glass is cool.
MSLE  HSLE  Clear 2-Pane
Roomside Glass Temperatures on Winter Day
Next Gen U-Factor Options

• Add 2\textsuperscript{nd} low-E to roomside surface of double pane unit with low-E in cavity
  – Glass improves from R4 to R5
  – 10\% reduction in window U
R5 Glass: Low-E #2 and #4
Next Gen U-Factor Options

• Add 2\textsuperscript{nd} low-E to roomside surface of double pane unit with low-E in cavity
  – Glass improves from R4 to R5
  – 10\% reduction in window U

• Triple pane with low-E in each gap
  – 30\% reduction in window U
R8 Glass: Low-E #2 and #5
Today’s Low-E Windows

![Bar Chart]

- **HSLE**: Blue (U), Orange (SHGC)
- **MSLE**: Blue (U), Orange (SHGC)
- **LSLE**: Blue (U), Orange (SHGC)
Add 4th Surface Low-E: -10% $\Delta U$
National Home Energy Analysis

BIG rabbit hole!
Real World Tests Match Energy Plus

![Bar Chart](chart.png)

The chart compares cooling and heating costs for different scenarios:
- **Clear**
- **HSLE SOUTH**
- **LoE²**
- **Clear**
- **HSLE WEST**
- **LoE²**

The costs are represented in dollars, ranging from $0 to $700.
Start with PNNL Code Determination

- Energy Plus program
- TMY3 weather data
- Heat, Cool, and Fan energy
- Population weighting
135,000,000 Existing Houses

[Map showing percentages across different states, with states labeled with percentages such as 1%, 7%, 22%, 25%, 29%, 14%, 1%, 2%.]
118 Climate Groupings
Use LBNL Window Regression Analysis

• Routine used since 2001 Energy Star Windows analysis

• Linear regression of multiple window U & SHGC (interactions of heat loss and solar gain)
2 Parameter Linear Regression

Multiple parameter form in LINEST function:

\[ Y = b + m_1 \times \text{U-Factor} + m_2 \times \text{SHGC} \]

- **Y** = Energy (heat, cool, total)
- Opaque Building Load = \( b \)
- Window Conductance = \( m_1 \) * U-Factor
- Solar Effect = \( m_2 \) * SHGC
Energy Star Windows

Note: A complete list of ENERGY STAR Climate Zones by state and county or, where applicable, zip code is available at [https://www.energystar.gov/index.cfm?fuseaction=windows_doors.search_climate](https://www.energystar.gov/index.cfm?fuseaction=windows_doors.search_climate).
## Energy Star Requirements by Zone

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>U-Factor(^1)</th>
<th>SHGC(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern(^*)</strong></td>
<td>≤ 0.27</td>
<td>Any</td>
</tr>
<tr>
<td></td>
<td>= 0.28</td>
<td>≥ 0.32</td>
</tr>
<tr>
<td></td>
<td>= 0.29</td>
<td>≥ 0.37</td>
</tr>
<tr>
<td></td>
<td>= 0.30</td>
<td>≥ 0.42</td>
</tr>
<tr>
<td><strong>North-Central</strong></td>
<td>≤ 0.30</td>
<td>≤ 0.40</td>
</tr>
<tr>
<td><strong>South-Central</strong></td>
<td>≤ 0.30</td>
<td>≤ 0.25</td>
</tr>
<tr>
<td><strong>Southern</strong></td>
<td>≤ 0.40</td>
<td>≤ 0.25</td>
</tr>
</tbody>
</table>

\(^1\) U-Factor: A measure of the heat loss through a window. Lower values indicate better insulation.

\(^2\) SHGC: Solar Heat Gain Coefficient. Higher values indicate better performance in terms of energy efficiency.
Lazy Modeling (my terminology)

Use Equal Distribution of Windows to Represent “Average” of Asymmetric Window Configurations
Equal Distribution w/o Fan

![Graph showing HVAC cost intensity with data points and labels]

- Fan
- Cool
- Heat

Parameters:
- $b = 0.33$
- $m1 = 0.31$
- $m2 = 0.01$
Equal + Fan = Solar Neutral
South Facing = Passive Benefit
West Facing = Solar Penalty
Climate Zone 4

SF_TOP_slab_2006 w/Regional Electric Scalars

HVAC Cost Intensity, $/CFA (above grade)

- Fan
- Cool
- Heat

(v8.8) b=0.43, m1=0.20, m2=0.08
Climate Zone 2

SF_SAT_gas_slab_2006 w/Regional Electric Scalars

HVAC Cost Intensity, $/CFA (above ground)

- **Green**: Fan
- **Orange**: Cool
- **Blue**: Heat

$(v8.8) \ b=0.30, \ m1=0.08, \ m2=0.18$
Carbon Translation from Energy

- EPA eGrid
- State level energy costs
- State level CO2 emissions
- Updated annually
- Costs and emissions don’t correlate well
  - Public utility commissions?

2016 coal = $\frac{1}{2}$ of 2005
- Replaced with natural gas
Carbon Dioxide Equivalent: CO$_2$e

• Global Warming Potentials for pollutants 100 years lifetime
  – Carbon Dioxide (CO2) GWP = 1
  – Methane (CH4) GWP = 28
  – Nitrous Oxide (N2O) GWP = 265

• Emissions data comes from EPA eGRID
Source: CMIC Source Energy and Emissions Analysis Tool (www.cmictool.com)
FIGURE ES-1. Electric Vehicle Global Warming Pollution Ratings and Gasoline Vehicle Emissions Equivalents by Electricity Grid Region

Note: The MPG (miles per gallon) value listed for each region is the combined city/highway fuel economy rating of a gasoline vehicle that would have global warming emissions equivalent to driving an EV. Regional global warming emissions ratings are based on 2012 power plant data in the EPA's eGRID 2015 database (the most recent version). Comparisons include gasoline and electricity fuel production emissions. The 68 MPG U.S. average is a sales-weighted average based on where EVs were sold in 2014.

Nat’l Totals (yellow = passive)

<table>
<thead>
<tr>
<th>IECC Zone</th>
<th>U.S. Housing Fraction</th>
<th>Dollars</th>
<th>Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2%</td>
<td>0.39</td>
<td>0.33</td>
</tr>
<tr>
<td>2</td>
<td>14%</td>
<td>0.32</td>
<td>0.16</td>
</tr>
<tr>
<td>3</td>
<td>25%</td>
<td>0.30</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>22%</td>
<td>0.39</td>
<td>0.07</td>
</tr>
<tr>
<td>5</td>
<td>29%</td>
<td>0.37</td>
<td>0.04</td>
</tr>
<tr>
<td>6</td>
<td>7%</td>
<td>0.46</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>1%</td>
<td>0.51</td>
<td>-0.04</td>
</tr>
<tr>
<td>8</td>
<td>0%</td>
<td>0.89</td>
<td>-0.01</td>
</tr>
<tr>
<td>U.S.</td>
<td></td>
<td>0.36</td>
<td>0.10</td>
</tr>
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</table>

Weighted Zone Coefficients using Regional Electric Fuel Mix

<table>
<thead>
<tr>
<th>IECC Zone</th>
<th>U.S. Housing Fraction</th>
<th>b</th>
<th>m1</th>
<th>m2</th>
<th>b</th>
<th>m1</th>
<th>m2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2%</td>
<td>0.39</td>
<td>0.00</td>
<td>0.33</td>
<td>3.62</td>
<td>-0.01</td>
<td>3.12</td>
</tr>
<tr>
<td>2</td>
<td>14%</td>
<td>0.32</td>
<td>0.08</td>
<td>0.16</td>
<td>3.64</td>
<td>0.89</td>
<td>1.78</td>
</tr>
<tr>
<td>3</td>
<td>25%</td>
<td>0.30</td>
<td>0.11</td>
<td>0.18</td>
<td>3.20</td>
<td>1.60</td>
<td>0.90</td>
</tr>
<tr>
<td>4</td>
<td>22%</td>
<td>0.39</td>
<td>0.19</td>
<td>0.07</td>
<td>5.17</td>
<td>2.78</td>
<td>0.27</td>
</tr>
<tr>
<td>5</td>
<td>29%</td>
<td>0.37</td>
<td>0.21</td>
<td>0.04</td>
<td>5.57</td>
<td>3.55</td>
<td>-0.18</td>
</tr>
<tr>
<td>6</td>
<td>7%</td>
<td>0.46</td>
<td>0.28</td>
<td>0.00</td>
<td>7.08</td>
<td>4.61</td>
<td>-0.73</td>
</tr>
<tr>
<td>7</td>
<td>1%</td>
<td>0.51</td>
<td>0.34</td>
<td>-0.04</td>
<td>8.44</td>
<td>5.68</td>
<td>-1.07</td>
</tr>
<tr>
<td>8</td>
<td>0%</td>
<td>0.89</td>
<td>0.50</td>
<td>-0.01</td>
<td>11.99</td>
<td>7.06</td>
<td>-1.19</td>
</tr>
<tr>
<td>U.S.</td>
<td></td>
<td>0.36</td>
<td>0.17</td>
<td>0.10</td>
<td>4.73</td>
<td>2.56</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Central Zone Window Energy Costs

The chart shows the energy costs for different window types and compliances in CZ4 and CZ5 zones.

- **CZ4**:
  - Code: Approximately $0.08
  - U0.32 S0.40: Approximately $0.07
  - U0.30 S0.40: Approximately $0.07
  - U0.30 S0.20: Approximately $0.06

- **CZ5**:
  - Code: Approximately $0.08
  - U0.32 S0.40: Approximately $0.07
  - U0.30 S0.40: Approximately $0.07
  - U0.30 S0.20: Approximately $0.06

The costs are depicted in dollars (\$/CFA).
Central Zone Window Carbon Footprint

**CO2e, lb/CFA**

- **CZ4**
  - Code: [Height]
  - U0.32 S0.40: [Height]
  - U0.30 S0.40: [Height]
  - U0.30 S0.20: [Height]

- **CZ5**
  - Code: [Height]
  - U0.32 S0.40: [Height]
  - U0.30 S0.40: [Height]
  - U0.30 S0.20: [Height]
Northern Zone Window Carbon Footprint

CZ6

CZ7

CO2e, lb/CFA

Code
U0.27 S0.27
U0.30 S0.42
U0.20 S0.40
U0.20 S 0.20
Conclusions

- Source energy is changing quickly (fuel mix)

- Climate Zone 5 should drop out of the Northern Energy Star Widnows grouping and merge into the Central

- More analysis to come!