Improving Residential Window Performance: There’s more that can be done.

Panelists: Katie Cort, Pacific Northwest National Laboratory (PNNL)
Steve Selkowitz, Lawrence Berkeley National Laboratory (LBNL)
Christopher Dymond, Northwest Energy Efficiency Alliance (NEEA)
Presentation Objectives

• We hope attendees will leave the session with an understanding of:

• The **energy and non-energy benefits** of low-emissivity (low-e) storm panels and other window attachments

• How **innovations** in **high-R triple-pane windows** are improving the insulating benefits and bringing down installation and technology costs

• **Window-related rating, labeling, and certification** programs and how to interpret the new **AERC Energy Improvement label**

• **Window-related home performance opportunities** with northwest utility and energy-efficiency programs
Agenda

• Part I: Overview of the problem we are trying to solve and potential window retrofit solutions

• Part II: Introduction to window attachments and research results

• Part III: Emerging high-R window technologies (e.g., thin triple-pane windows)

• Part IV: Energy rating, performance labels, and new program opportunities related to windows.
The Problem

Windows make up 29% of residential HVAC consumption

Windows make up 34% of commercial HVAC consumption
The Potential

- 69% Homes with single-pane or double-pane clear glass windows
- 31% homes with thermally improved windows
Current Rate and Type of Window Replacements Not Solving the Problem

Only 2% of homes replace their windows each year

~80 million homes have inefficient windows

It will take 50 years to replace all inefficient windows
High-R Window Replacements

• **Existing Triple Glazing** (w. gas and low-E)
  • Technology elements available, $U \sim 0.1 - 0.2$
  • Large existing market share in N. Europe
  • U.S.: “Too heavy/too wide” -> costly redesign of whole window

• **“New Technology”**
  • Modified Triple Glazing- thin glass
  • Vacuum glazing (emerging technology)
  • Aerogel (early R&D)
Window Attachments

- Storm Windows
- Roller Shades
- Horizontal Blinds
- Cellular Shades
- Awnings
Part II: Window Attachments

Katie Cort
Pacific Northwest National Laboratory
What are Window Attachments?

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<td>Storm Windows (including low-e)</td>
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<td>Interior Attachments</td>
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<td>Conventional Roller Shades</td>
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<td>Conventional Drapes</td>
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<td>Louvered Blinds</td>
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<td>Window Panels (including low-e)</td>
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<td>Insulated Cellular Shades</td>
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<td>Window Quilts</td>
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<td>Surface-Applied Films</td>
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<td>Solar Screens</td>
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</tbody>
</table>

1 The benefits of this technology for the given attribute are not generalized and should be examined on a case-by-case basis.
Window Attachments Value Proposition

- Large market opportunity:
  - Applicable to new and existing homes
  - Over 80% of homes and small commercial buildings have some form of window attachment
  - Over 80% of window attachments that are in place are relatively low-performing vinyl blinds (horizontal slatted)

Energy Savings Potential:
- Reduces home’s HVAC consumption by 3-30%
- Can also reduce infiltration, glare, and noise
Energy Modeling

- Comprehensive energy-modeling study that examined 11 different typical residential window attachments including:
  - shades
  - blinds
  - storm window panels
  - surface-applied films
- Baseline with 4 types of houses, 3 types of windows, in 12 climate zones
- Operation assumptions based on empirical study
- For most attachments examined, energy savings significant, but results depend on type of attachment, season, climate, and operation.
- In heating-dominated climates in north/central zones, low-e insulating storm panels (both interior and exterior) and insulating cellular shades are the most effective at reducing HVAC.
The Evolution of Storm Windows

Seasonal Storm Panels

Self-Storing Storm Windows

High Performance Storm Windows with Low-E glass
Low-E Storm Windows

Low-e storm windows are a cost-effective, **insulating**, and **air sealing** measure for existing windows:

- **Air Sealing** of Prime Window
  - Case studies show 10% reduction in overall home air leakage
- Creation of “**Dead Air Space**”
  - Reduce conduction and convective losses across prime window
- **Reflection of Radiant Heat**
  - 35% increased performance over clear glass
Low-E Storm Windows

Cost
- 1/3 of replacement window
- Payback 4-14 years
- Low installation effort (e.g., 80% DIY installation)

Energy Savings
- 10-33% reduction in HVAC in single-pane or double-pane clear glass window homes
- Reduce air leakage

Characteristics
- Operable
- Permanent installation
- Year-round comfort
- Interior or exterior installation
- Aesthetically pleasing

PNNL Lab Homes Testing Platform in Richland, Washington

Lab Homes Characteristics

• Specified to represent existing manufactured and stick-built housing

• 3 BR/2BA, ~1500 ft²

• All-electric with 13 SEER/7.7 HSPF heat pump central HVAC + alternate Cadet fan wall heaters throughout

• R-22 floors, R-11 walls & R-22 ceiling with composition roof

• 195.7 ft² (13%) window area with double-pane clear glass aluminum-framed windows
# Lab Homes – Low-E Storm Windows Impact on Energy Savings

<table>
<thead>
<tr>
<th>Technology (experiment)</th>
<th>Baseline and Experiment Description</th>
<th>Energy Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exterior low-e storm windows, 2014</strong> (Larson Manufacturing)</td>
<td>Double-pane metal-frame clear glass windows (no window coverings)</td>
<td>Average Annual Savings: <strong>10.1 ±1.4%</strong></td>
</tr>
<tr>
<td><strong>Interior low-e storm windows, 2015</strong> (Quanta Technologies)</td>
<td>Covering 74% of window area over double-pane metal-frame clear glass windows</td>
<td>Average Annual Savings: <strong>7.8 ±1.5%</strong></td>
</tr>
</tbody>
</table>

Infrared Images – Interior Storm Windows

**Baseline Home**

**Experimental Home**
LES – Climate Zone Modeling

Over all single-pane windows or double-pane metal-framed windows:

NEAT and RESFEN analysis expanded to 22 cities across all 8 climate zones.¹

Cost effective in climate zones 3-8 with Savings to Investment Ratio = 1.2 – 3.2

¹ Culp et al. 2014 and 2015. PNNL-22864 rev2 and PNNL-24826
Installation: Exterior Storm Windows

See PNNL youtube video that includes installation instructions: https://www.youtube.com/watch?v=DeU6wn0psrU
Installation: Interior Storm Windows
Honeycomb or Cellular Shades

<table>
<thead>
<tr>
<th>Technology (experiment)</th>
<th>Baseline and Experiment Description</th>
<th>Energy Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Efficiency Cellular Shades:</strong> Static Operation – always down</td>
<td>Blinds remain closed for the duration of experiment. Compared to standard vinyl blinds remaining closed for full experiment.</td>
<td>Cooling: <strong>13.3 ±2.8%</strong>  Heating: <strong>10.5 ±3.0%</strong></td>
</tr>
<tr>
<td><strong>High Efficiency Cellular Shades:</strong> Optimum Operation Comparison</td>
<td>Blinds operated per the Hunter Douglas recommended energy-saving schedule. Compared to standard vinyl blinds operated with same schedule.</td>
<td>Cooling: <strong>10.4 ±6.5%</strong>  Heating: <strong>16.6 ±5.3%</strong></td>
</tr>
<tr>
<td><strong>High Efficiency Cellular Shades:</strong> Optimum Operation</td>
<td>Blinds operated per the Hunter Douglas recommended energy-saving schedule. Compared to no blinds in baseline home (double-pane clear glass windows)</td>
<td>Cooling: <strong>14.8 ±2.1%</strong>  Heating: <strong>14.4 ±2.0%</strong></td>
</tr>
</tbody>
</table>
Thermal Performance of Double-Cell Cellular Shades compared to the most Common Window Coverings

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Season</th>
<th>HVAC Savings % (+/- 95% confidence)</th>
<th>Average W-hr/day Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Shades Down: Cellular Shades versus Vinyl Venetian Blinds</td>
<td>Cooling</td>
<td>13.3 (±1.3)</td>
<td>2,650</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>9.3 (±1.9)</td>
<td>7,011</td>
</tr>
<tr>
<td>Typical Use: Cellular Shades versus Vinyl Venetian Blinds</td>
<td>Cooling</td>
<td>5.8 (±0.5)</td>
<td>1,487</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>2.0 (±1.3)</td>
<td>1,505</td>
</tr>
</tbody>
</table>

Semi-opaque double-cell shade pulled down (left) allows filtered natural light into north-side bedroom. Close-up view of same shade (right).

“Typical Use” Settings

Energy Savings Potential of Cellular Shades in the Summer

<table>
<thead>
<tr>
<th>Experimental Home</th>
<th>Baseline Home</th>
<th>HVAC Savings % (+/- 95% confidence)</th>
<th>Average W-hr/day Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular shades always down</td>
<td>No shades</td>
<td>24.8% (±8.6%)</td>
<td>3,359</td>
</tr>
<tr>
<td>Typical Use with Cellular Shades</td>
<td>No shades</td>
<td>4.7% (±1.3%)</td>
<td>1,808</td>
</tr>
</tbody>
</table>
Heating Season: Shades drawn down (always) versus “optimal” operation

• **Closed Shades Scenario:** Cellular shades covering all windows in Lab Home B (experimental home) and no shades on Lab Home A (control home) windows

• **Results:** Modest average savings (2%) when shades down all the time. Average of 5% savings recorded on very cloudy days, but negative savings on some sunny days.

• **Optimal Operation Scenario:** Cellular shades up during some portion of the day and closed at night (3 operating scenarios tested).

• **Results:** Achieved consistent HVAC savings between 5% to 9% compared to the home with blinds operated with typical settings.

Beneficial heat gains not fully realized when shades are drawn down during the day (Sunny day, avg. temp 31° F)
Automation and Window Attachments

Allowable Solar Penetration

- June 21
  - Shaded Position: 1
- December 21
  - Shaded Position: 3
- March 21 / September 21
  - Shaded Position: 2
- Overcast Sky
  - Shaded Position: 3

Shadow-Override Module

When zones are in shadow from the adjacent buildings for 20 minutes or more, the shades will rise to maximize natural daylight and view automatically.
Demand Response (DR) – Combining Thermostat Adjustments with Shading

**HVAC Cycling during Peak Period:**
DR Participant vs Non-Participant

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>HVAC Lab Home B</th>
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<tbody>
<tr>
<td>1:30 AM</td>
<td></td>
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<tr>
<td>2:30 AM</td>
<td></td>
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<tr>
<td>3:30 AM</td>
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<tr>
<td>4:30 AM</td>
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<tr>
<td>5:30 AM</td>
<td></td>
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<tr>
<td>6:30 AM</td>
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<tr>
<td>7:30 AM</td>
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</tbody>
</table>

Lab Home B: DR participant (with cellular shades drawn down during peak event)

**Whole House Energy Use Comparison**
Both homes participating in DR (i.e., thermostat setback during peak period), but only Lab Home B pulls down cellular shades in living room during peak event. HVAC savings = 3,936 W-hrs with cellular shades on this day.

<table>
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<tr>
<th>Energy Use (Wh)</th>
<th>Time (h)</th>
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<td>06:00</td>
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<td>12:00P</td>
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<tr>
<td>18:00</td>
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Lab Home A: Typical blinds, typical use and no participation in DR during peak event
Upcoming Experiments... Exterior Shades

- Summer season testing
  - Reduces cooling load (and added comfort for those with and without AC)
  - Blocks UV rays before it hits the window
  - Automation available (including solar-powered motors)
  - Non-energy benefits (e.g., privacy, comfort, protection of window, etc.)
Home Performance Retrofit Opportunities

• Utility incentive programs
• Weatherization programs (low-e storms typically meet criteria for Federally subsidized programs)
• Historic homes
• Retirement and assisted living facilities
• Automation and Integrated Control

Retirement Home in Enumclaw, Washington
Part III: Highly Insulating Windows

Steve Selkowitz
Lawrence Berkeley National Laboratory
1970: If Windows are thermally poor, then use less of them....
Current State of Windows

Whole window U-factor

- No heat transfer
- Typical Insulated Walls
- Highly insulating windows
- Typical windows
  - Building Code
  - Double pane Low-E
  - Energy Star
- Standard double-pane windows
<table>
<thead>
<tr>
<th>Windows Type</th>
<th>Annual Heating Cost</th>
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<tbody>
<tr>
<td>Single Glazed w/Storm</td>
<td>$1310</td>
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<tr>
<td>Double Glazed</td>
<td>$1218</td>
</tr>
<tr>
<td>Double w/Low-E</td>
<td>$1120</td>
</tr>
<tr>
<td>House with no windows</td>
<td>$1000</td>
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<tr>
<td>“SuperWindow”</td>
<td>$960</td>
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"North-facing Windows Outperform Insulated Walls during winter heating season" (from 1989!)
Residential Windows: 2.3 Q Annual Energy (Heating: 1.30 Q  Cooling: .94 Q)

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<thead>
<tr>
<th>Window Type</th>
<th>Energy Savings over Current Stock (quads)</th>
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<tr>
<td></td>
<td>Heating</td>
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<tr>
<td>Sales (Business as usual)</td>
<td>0.49</td>
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<tr>
<td>Energy Star (Low-e)</td>
<td>0.69</td>
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<tr>
<td>Dynamic Low-e</td>
<td>0.74</td>
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<td>Triple Pane Low-e</td>
<td>1.20</td>
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<tr>
<td>Mixed Triple, Dynamic</td>
<td>1.22</td>
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<tr>
<td>High-R Superwindow</td>
<td>1.41</td>
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<tr>
<td>High-R Dynamic</td>
<td>1.50</td>
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Heat Transfer Crash Course

• **U factor**: overall heat transfer rate, Btu/ft$^2$-hr-F
  - U ranges: ~1 (single) → .1 (high R window, Superwindow)

• **R**: Resistance = 1/U
  - R1 → R10

• **Glazing properties**
  - Insulating glass unit = “IGU”

• **Whole window properties**

• **SHGC, Tv, Air leakage...**
  - Properties of glass, window

• **Annual Energy Impact...**
  - Location, orientation, HVAC...
U.S. Residential Glazing Market Share

“IGU”: Double glazing, Insulating Glass Unit

$150B saved

Source: Ducker Associates

2019 HPC Northwest Regional
HOME PERFORMANCE CONFERENCE & TRADE SHOW
New Energy Supply Technology for the 21st Century

High Tech Window Coatings "Supply" Energy Services

Buildings account for over one third of all U.S. energy consumption. Energy policy has emphasized the development of new secure energy supply options such as off-shore oil. But advanced building technology that effectively reduces the need for current consumption can also be viewed as a supply option.

Consider the following two choices for "supplying" $1 billion of energy services:

**Low-E Window Technology**

Heat loss from windows is responsible for about 4% of total U.S. energy consumption, or the equivalent of 1.4 million barrels of oil per day. Transparent low emissivity (low-E) coatings provide one-third reductions in window heat loss.

This industrial low-E coater (See Recipe 1) can coat over 20 million square feet of glass for windows each year. Savings accumulate rapidly since each window continues to save energy over its entire lifetime, at least 20 years.

**Offshore Oil Wells**

Oil under the continental shelf is a secure, but environmentally fragile, costly and depletable supply option. (See Recipe 2).

---

**Recipe #1**

**Low-E Window Technology**

Step 1: Invest $8 million in a low-E coating system.
Step 2: Coat 20 million square feet of windows per year for the 10 year nominal life of the coating system.
Step 3: Accumulate energy savings over the 20 year life of the window.
Step 4: RESULT: Savings of 36 million barrels of oil equivalent!

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**Recipe #2**

**Offshore Oil Wells**

Step 1: Invest $300 million in a 10 well offshore oil platform, producing 10,000 barrels per day.
Step 2: Pump oil for the 10 year nominal life of the oil field (don't spill a drop).
Step 3: RESULT: Supply of 36 million barrels of oil!
Window Energy Snapshot: Progress...

• **Good news:**
  • With DOE R&D support, industry transformed markets from single -> double -> double, low-E, argon
  • 90%+ sales of all window are low-E

• **Bad news: little tech innovation since 1990**
  • Biggest Energy Opportunity- highly insulating glazing for heating dominated climates ( ~ 1-2 Q at stake)
  • Market “Saturated” at double, low E: >90% Market Share
  • Triple glazing: only 1.7% market share, no recent change
  • Need: “Better” triples or new technology options
Why Not Make Better Windows Now... ??

- Window Manufacturers “could” redesign product lines to offer triple glazing
  - No easy path to high performance window today
  - Costly – to manufacturers to retool; → costly to end-users
  - “No Demand” now; uncertain demand at higher price point
- Europe – Northern countries “mandate” triple glazing;
  - Base window accommodates triple IGU
  - Offered by all suppliers
  - Supported by codes, higher energy prices
  - So no fundamental “technical” obstacle to adoption
Success of Low-E, Double Glazed IGU: U: 0.5 -> 0.3

• 3 stage “adoption” process to increase market share
  1. Introduction -> ~20% market share: **Innovation push**
  2. 20% -> 60% **NFRC Ratings, Voluntary market pull (ES)**
  3. 60% -> 95%: **Codes and Standards**

• “Criteria” for rapid adoption:
  • **Window manufacturers** must accept cost and risk
    • New Investment, Disruption to manufacturing process?
    • See a Competitive Market opportunity – or threat
  • **Glass package** is affordable, durable, ...
  • **Market Acceptance and Demand:**
    • Work with Early adopters, Niche Markets, Incentives,...
National Fenestration Rating Council - NFRC


ENERGY PERFORMANCE RATINGS
U-Factor (U.S. / I-P) Solar Heat Gain Coefficient
0.35 0.32

ADDITIONAL PERFORMANCE RATINGS
Visible Transmittance Air Leakage (U.S. / I-P)
0.51 ≤ 0.3

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.
Choosing Better Windows
Efficient Window Collaborative
www.efficientwindows.org

How to Choose Windows

This site provides unbiased information on the benefits of energy-efficient windows, descriptions of how they work, and recommendations for their selection and use.
Selecting Energy Efficient New Windows in Oregon

1. Meet the Energy Code & Look for the ENERGY STAR®

Windows must comply with your local energy code. Windows that are ENERGY STAR certified often meet or exceed energy code requirements. To verify if specific window energy properties comply with the local code requirements, look for the NFRC label.

2. Look for Efficient Properties on the NFRC Label

The National Fenestration Rating Council (NFRC) label is needed for verification of energy code compliance. The NFRC label displays whole-window energy properties and appears on all fenestration products which are part of the ENERGY STAR program (www.nfrc.org).

3. Compare Annual Energy Costs for a Typical House

Use computer simulations for a typical house to compare the annual energy performance of different window types. A comparison of the performance of a set of windows for this climate begins on Page 3 or use the Window Selection Tool on the EWC web site or the Window Selection Tool Mobile App (www.efficientwindows.org).

4. Customize Energy Use for a Specific House

For superior energy performance, select windows with a U-factor of 0.25 or less. If air conditioning is not a concern, look for a higher Solar Heat Gain Coefficient (SHGC) of 0.35–0.60 so winter solar heat can help offset the heating energy need. If cooling is a significant concern and no shading is available, select windows with a SHGC less than 0.32.
<table>
<thead>
<tr>
<th>ID</th>
<th>Panes</th>
<th>Glass</th>
<th>Frame</th>
<th>U-factor</th>
<th>SHGC</th>
<th>VT</th>
<th>Standards</th>
<th>Performance</th>
<th>Info</th>
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</thead>
<tbody>
<tr>
<td>18</td>
<td>3</td>
<td>HSG Low-E</td>
<td>Non-metal, Improved</td>
<td>≤0.22</td>
<td>0.41-0.60</td>
<td>0.41-0.50</td>
<td>Yes</td>
<td>Yes</td>
<td>products</td>
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<tr>
<td>21</td>
<td>2</td>
<td>HSG Low-E</td>
<td>Non-metal, Improved</td>
<td>0.23-0.30</td>
<td>0.41-0.60</td>
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<td>HSG Low-E</td>
<td>Non-metal, Improved</td>
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<td>Yes</td>
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<td>products</td>
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<td>MSG Low-E</td>
<td>Non-metal, Improved</td>
<td>≤0.22</td>
<td>0.26-0.40</td>
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## Summary

**ORIENTATION**
- Equal
- North
- East
- South
- West

**WINDOW AREA**
- Small
- Moderate
- Large

**SHADING TYPE**
- Typical
- None
- Interior
- Overhangs
- Maximum

**LOCATION**
- Portland, Oregon

**HOUSE TYPE**
- 1 Story

**WINDOW TYPE**
- Windows

### Energy

#### Window System

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Generic Window

Window 18

*Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas*

Non-metal, Improved

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>View Products</th>
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<tr>
<td>Accurate Dorwin</td>
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<tr>
<td>Fibertec Window &amp; Door Mfg.</td>
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<tr>
<td>Great Lakes Window</td>
<td>Products Available»</td>
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<tr>
<td>Wasco Windows</td>
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</table>

U = ≤0.22

SHGC = 0.41-0.60

VT = 0.41-0.50

**LOCATION:** Portland, Oregon  
**HOUSE TYPE:** 1 Story  
**WINDOW TYPE:** Windows

Disclaimer: Manufacturers have agreed that products listed here meet the energy performance requirements of the Efficient Windows Collaborative and have been tested and certified according to NFRC standards.

2019 HPC Northwest Regional  
HOME PERFORMANCE CONFERENCE & TRADE SHOW
## Specific Manufacturer Product Lines

**Window 18**

*Triple-glazed, High-solar-gain Low-E Glass, Argon/Krypton Gas*
*Non-metal, Improved*

**U** = ≤0.22  
**SHGC** = 0.41-0.60  
**VT** = 0.41-0.50

**LOCATION:** Portland, Oregon  
**HOUSE TYPE:** 1 Story  
**WINDOW TYPE:** Windows

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Line</th>
<th>Options</th>
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<th>SHGC</th>
<th>VT</th>
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<td>Series 300 Fixed Window - triple pane Energy Advantage</td>
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2019 HPC Northwest Regional  
HOME PERFORMANCE CONFERENCE & TRADE SHOW
## Summary

**LOCATION:** Portland, Oregon  
**HOUSE TYPE:** 1 Story  
**WINDOW TYPE:** Windows

### Window System

<table>
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<tr>
<th>ID</th>
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<th>Frame</th>
<th>U-factor</th>
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<th>Summer</th>
<th>Winter</th>
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<td>≤0.22</td>
<td>0.41-0.60</td>
<td>0.41-0.50</td>
<td><strong>Cold</strong></td>
<td>Neutral</td>
<td><strong>Hot</strong></td>
<td>Neutral</td>
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<tr>
<td>21</td>
<td>2</td>
<td>HSG Low-E</td>
<td>Non-metal, Improved</td>
<td>0.23-0.30</td>
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<td><strong>Cold</strong></td>
<td>Neutral</td>
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<td><strong>Cold</strong></td>
<td>Neutral</td>
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IECC Compliance Guide for Homes in Oregon

Step-by-Step Instructions

1. Using the climate zone map to the right, match the jurisdiction to the appropriate IECC climate zone. Use the simplified table of IECC building envelope requirements (below) to determine the basic prescriptive requirements for the thermal envelope associated with the jurisdiction.

2. Use the “Outline of 2018 IECC Requirements” printed on the back of this sheet as a reference or a categorized index to the IECC requirements. Construct the building according to the requirements of the IECC and other applicable code requirements.

The 2018 International Energy Conservation Code

The 2018 IECC was developed by the International Code Council (ICC) and is currently available to states for adoption. The IECC is the national model standard for energy-efficient residential construction recognized by federal law. Users of this guide are strongly recommended to obtain a copy of the IECC and refer to it for any questions and further details on compliance. To obtain a copy of the 2018 IECC, contact the ICC or visit www.icecsafe.org. IECC compliance training is also available from many sources.

Limitations

This guide is an energy code compliance aid for Oregon based upon the simple prescriptive option of the 2018 IECC. It does not provide a guarantee for meeting the IECC. This guide is not designed to reflect the actual energy code, with amendments, if any, adopted in Oregon and does not, therefore, provide a guarantee for meeting the state energy code. For details on the energy code adopted by Oregon, including how it may differ from the IECC, please contact your local building code official. Additional copies of this guide are available on www.reca-codes.com.

CLIMATE ZONE 5

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Efficient Window Collaborative
www.efficientwindows.org
Window Replacement Options

• Full frame replacement (new window)

• Pocket solution

• Sash replacement

• In place retrofit
How Do You Fit a 5” Wide Triple Glazed Window into a 2 x 4 Framed Wall? Sash/Frame and IGU Dimensions
Highly Insulating, Low Heat Loss Glazing

**Today:** U-value ~ .3 BTU-sf-h/F

**Nearer Term Objective:** U-value < 0.2 BTU-sf-h/F

**Longer Term Target:** U-value < 0.1 BTU-sf-h/F

**Current Approaches:** 30 years
- Low-Emissivity Coatings
- Low Conductance Gas Fills
- “Warm edge” low conductance spacers
- Insulated Frame Systems

**New Approaches??**
## Glazing Changes to Lower Heat Loss

<table>
<thead>
<tr>
<th>Single</th>
<th>Double</th>
<th>Triple with Low-E, gas fill</th>
<th>Triple with suspended low-E plastic film</th>
<th>Vacuum glazing with low-E</th>
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<td>.5</td>
<td>~.1 -- .15</td>
<td>~.1 -- .15</td>
<td>~.1 -- .15</td>
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</table>

- Single → double
- Double → Triple
- Double → Low-E
- Double → Argon-filled
- Double → Low-E, argon
- Double → Low-E, argon, #4 low-E
Super-insulating frame with highly insulated glazing

Two low-e, Thin glass, single seal, Krypton gas

One low-e Vacuum

Two low-e Vacuum Hybrid

Note: low-E coated polyester film can be alternative middle glazing.

Super-insulating frame with highly insulated glazing
Market Snapshot
NFRC-Rated Windows by U

Number of Product Lines

Source: EPA ENERGYSTAR analysis, Horiz. sliding windows
Non-Structural Center-Layers

- **Current technologies for highly insulating products use multiple layers of low-e and gas fill**
  - All glass is heavy
  - Thin film products expensive
  - Multiple spacers can lead to gas leakage

- **LBNL research aims to develop lower-cost, non-structural center layers**
  - Utilize available low-e and gas-fill technologies
  - Research novel center layer designs and materials
Criteria for Success

• Significant Improvement in Thermal Properties: >R5
• Drop-In Replacement for IGU: No Window Redesign
• Affordable Cost: < $5/sf retail
• Scalable Rapidly
• Low Manufacturer Risk
• Acceptable Aesthetics
• Value Proposition to Builder, Homeowner
Drop-In “Thin Lightweight Triple” Upgrade” all R3 double glazed windows to R4-7 without redesign using new IGU with same width, weight

- Platform: U: ~.10-.15
- Thin float glass
  - .3, .5, .7, 1.1 mm
- Multiple suppliers
- 2 Low-E coatings
- Krypton gas fill
- Non-structural center
  - 2 seals, not 4
- Infrastructure exists
- “Affordable”
Not a New Concept; Thin Glass, Thin Triple Concept Developed "Before its Time"

1989 ASME paper

1991 Design Patent
Why Will It Work Now?

• **Thin Glass:**
  - **4 years ago:** Corning offered glass at ~ $5.00/sf
  - **Today:** Major float glass suppliers ~ $0.60/sf due to huge demand for large flat screen TVs

• **Krypton Gas**
  - **4 years ago:** variable demand from other sources kept prices high and volatile; Gas fill wasted 50% -> Net cost > $2.00/sf
  - **Today:** Xenon requirements make Kr available; traditional Kr use has reduced; suppliers now sign long term contracts at ~$0.50/sf
  - New high rate gas fill with only 10% loss
Where Can We Find “Thin” Glass Today?
2017 – Total Glass Area Sold/Year??

Flat Screen TVs  Residential Windows

350M sf  600M sf

Message: Build on the extensive display industry capability in flat glass
Flat Screen TV, Satellites, LEDs → 80+% reductions in cost

Incremental OEM cost over double low-e ($/SF)

- Thin glass
- Krypton gas

2012: $4
2017: $0

Flat Screen TV, Satellites, LEDs

80+% reductions in cost
“Thin-triple” spacer: Single spacer dual seal systems

Products are already entering the market

|----------|------------|------|--------------------------|-------------------|
Technologies to Reduce Heat Loss
Glass, Glass Edge

- Dual, Clear, Alum. spacer
- Dual, Clear, Foam spacer
- Dual, Low-e, Foam spacer
- Superwindow, Foam spacer 4-lites, low-e, Kr

Images from LBNL
Infrared Thermography Lab

-6.0 °C  20 °C
“Warm Edge” IGUs

Reduce heat loss and condensation at perimeter of window with warm edge technology.
Thin Lightweight Triple → Thin Quad

COG U-factor potential with single strength glass. Low-e is mid solar gain, 3P uses 0.7mm center layer.

Thin .7” IGU

Wider 1.2” IGU

Quads: 2 thin glasses, 1 w/ low-E

Double Low-E

Double Low-E; Surf 4
Alpen HPP
Triple and Quad Windows Corner Samples
In Fiberglass Frames
IGU Fabrication: Cost Estimates
Incremental Cost to IGU Fabricator

Short term:
Delta: + ~ $3/SF

Long term:
Delta: + ~ $2/SF

+ Supply Chain Markups
Market Drivers: Who Wants This? Needs This?

• **Builders/Building Owners**
  - Energy/$$ Savings
  - Thermal comfort
  - Larger window area
  - Early Adopters
    - Passive House buyers
    - Zero Net Energy Home buyers

• **Architects/Engineers**
  - Builders- first cost dominated-
    - Emerging early adopters
  - Comfort/Daylight
  - “Justifying” larger window area
  - HVAC system
    - first cost savings- reduced size
    - Duct system reductions, distributed/zonal HVAC
Potential Performance Metrics (+ Energy)

Comfort
- Mean radiant temperature
- Operative temperature
- Uncomfortable hours
- Winter comfort temperature
- Summer comfort temperature
- Draft
- Sound transmission

Health
- Condensation resistance - Interior
- Condensation resistance - Exterior
- UV transmittance
- Sound transmission

Building resiliency
- Demand response
- Life safety (maintain temperature during power/gas outage)
- Mechanical equipment sizing
- Eliminate perimeter heating/cooling
Annual Energy Cost/Savings (6 U.S. Cities)
5 Alternative Window Designs
End use multipliers: Elec=3.167, Gas=1.084

Payback?

Different U.S. Climate Zones
“Early Adopters”

Passive House/Buildings
- Need “highly insulating” windows
- Two Competing Certification Groups, PHI, PHIUS
- Many builders import windows from Europe
- Activity Level ??

Zero Net Energy Homes/buildings
- Role of High Performance Windows
- Systems impacts on HVAC Design, sizing
- Activity Level =?

LEED/ Living Building Challenge
- Need for High Performance Windows?
Building the Case for High R Windows

- Energy (current supply -> decarbonize
- Load shape, demand
- Occupant comfort
- HVAC System peak sizing
- HVAC System type, distribution
- Codes
- Utility Incentives and Rebates
- Energy Star
# Thermal Comfort Considerations

- Condensation Resistance
- Winter Outdoor Comfort Temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2P clear</td>
<td>13</td>
<td>9.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2P lowe</td>
<td>54</td>
<td>-6.1</td>
<td></td>
<td>3 panes</td>
</tr>
<tr>
<td>2P surf4</td>
<td>45</td>
<td>-11.8</td>
<td>?</td>
<td>&gt;</td>
</tr>
<tr>
<td>3P Thin Glass</td>
<td>63</td>
<td>-22.6</td>
<td></td>
<td>2 Panes</td>
</tr>
<tr>
<td>3P opt</td>
<td>65</td>
<td>-30.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- Double Low-E: 21F
- Triple -11F
- 2P Clear
- 2P Lowe
- 2P S4
- 3P
- VIG
Window Industry Partners

• **Alpen HPP**
  - Small, “Boutique” manufacturer, 30+ years, High Performance Markets
  - History: R10 windows with fiberglass frame and heat mirror film
  - Active engagement w/ senior management
  - Currently supplying prototypes for pilot projects
  - Aggressively pursuing thin triple window product designs
    - Double spacer design
    - Fabricating larger size IGUs

• **Andersen Corporation**
  - “Largest” U.S. manufacturer; National markets, 100+ years
  - History: Early adopter of low-E, Energy Star leader
  - Active engagement with R&D/Retrofit window team
  - Fabricating windows for initial LBNL testing
  - Scaling/Manufacturing issues being explored
Thin Glass to Change High-Performance Window Market

Alpen is rolling out triple-pane products that are thinner and lighter—and will eventually be cheaper.

by Peter Vost

February 4, 2019

The good news about window performance is that the market has been transformed by the building industry moving to dual-pane, low-e, argon-filled glazing with performance around R-4, according to Lawrence Berkeley National Laboratory (LBNL). See Figure 2 for a current breakdown of the market based on performance of windows rated by the National Fenestration Rating Council (NFRC).

The bad news is that since around 1990, the performance of the vast majority of our windows has not really changed much. See Figure 2 for a current breakdown of the market based on performance of windows rated by the National Fenestration Rating Council (NFRC).

Yes, we now have triple-pane glazing in the R-6 and beyond range, but these windows are quite heavy, expensive, and not really embraced by the U.S. market.

Enter thin glass triple glazing (TGT) technology. In Figure 3, you can see the key ways TGT is a breakthrough:

1. The “thin”—1 mm—glass is inserted in the middle of a standard dual-pane insulated glazing unit.
2. Krypton gas replaces argon in the now half-as-wide spacing of the three glass panes.

Net-Zero Glass From Flat-Panel TVs Makes Zero-Energy Homes More Feasible

Even with the latest windows producing a U-factor rating of as low as 0.11 (roughly equivalent to R-6) windows have quite a way to go before they catch up to solid walls in insulating performance. Meanwhile, a price check on the best windows shows that current costs are prohibitively high to get to the average homeowner. But a recent report by Rocky Mountain Institute (RMI), an independent, nonprofit organization, suggests that glass borrowed from the flat-panel televisions market is about to spend the costs for triple-pane glass, making it feasible for everyday windows while also making net-zero homes more affordable. The idea has come to our attention.

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Collaboration Around Aggressive Market Acceleration Programs

• Window Manufacturers – Training, Promotion
• Education and Training – Architects, Engineers
• Voluntary Programs – ENERGY STAR
• Builders, Renovators, Developers
• Utility Rebates and Incentives
  • Midstream, Upstream?
• Pilot Programs, Field Demonstration, Test Houses
• Codes and Standards
Energy Trust of Oregon – Window Rebates

Windows
$1.75–$4.00/sq. ft. cash incentive

Windows play a large part in regulating energy use and costs. ENERGY STAR® windows reduce condensation, decrease drafts and air leaks, and can increase curb appeal. Installing new, tight-fitting windows also helps seal your home again intrusion or escape.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Incentive</th>
<th>Requirements</th>
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</thead>
<tbody>
<tr>
<td>Windows</td>
<td>$1.75 per square foot</td>
<td>U-Value 0.28-0.30</td>
</tr>
<tr>
<td>Windows</td>
<td>$4.00 per square foot</td>
<td>U-Value 0.27 or less</td>
</tr>
</tbody>
</table>

Table 1: Percent of Sales by Efficiency Tier

<table>
<thead>
<tr>
<th>U-Value Tier</th>
<th>Relative Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.35</td>
<td>2.78%</td>
</tr>
<tr>
<td>.33 to .35</td>
<td>26.25%</td>
</tr>
<tr>
<td>.31 to .32</td>
<td>15.05%</td>
</tr>
<tr>
<td>.29 to .30</td>
<td>45.87%</td>
</tr>
<tr>
<td>.26 to .28</td>
<td>7.91%</td>
</tr>
<tr>
<td>.25 or lower</td>
<td>2.15%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00%</strong></td>
</tr>
</tbody>
</table>
California T24 Code, 2019 $U: .32 \rightarrow .30$

High Efficiency Window Tradeoffs

<table>
<thead>
<tr>
<th>Measure</th>
<th>EDR Contribution</th>
<th>43.5</th>
<th>18.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPA</td>
<td>4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPW</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QII</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QII+Entire HPA&amp;HPW</td>
<td>7.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-Orientation Impact</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows - 2019 Over 2016</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Windows-0.23U&amp;0.20 SHGC</td>
<td>0.23</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>HP Windows-0.21U&amp;0.21 SHGC</td>
<td>0.21</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>HP Windows-0.20U&amp;SHGC</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R38 Below Deck Insulation</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94 Furnace</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 EER</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.94 Water Heater</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94 Furnace+13EER+0.94 WH</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Storage Credit</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EDRs:
Energy Design Ratings

Example: Delete “High Performance Walls”; -1.7 EDR

Add “High Efficiency Windows” +1.8, +2.2 EDR
Canadian Window Code Changes are Coming…
Fenestration Canada Annual General Meeting, June 2017

Aspirational goals for residential windows

- By 2020, residential windows for sale in Canada meet an average U-factor of 1.6 (ER 25) \( U = 0.28 \)
- By 2025,
  - All residential windows for sale in Canada meet a U-factor of 1.2 (ER 34)
  - Residential windows with a U-factor of 0.8 can be manufactured and installed cost effectively.
- By 2030, all residential windows for sale in Canada meet a U-factor of 0.8 (\( \sim \) ER 40) \( U = 0.14 \)
Our Role – Next Steps

- **Window Industry**
  - Work with manufacturers to refine technology
  - Introduce cost effective options to market

- **Supply Chain**
  - Automated assembly -> lower cost

- **Objective Estimates of Savings, Paybacks**
  - + Comfort, HVAC sizing, etc

- **Pilots, Field tests to Validate Performance**
  - California
  - Oregon/Washington
  - National

- **Promote Rebates, Incentives**
- **Enhanced Codes/Standard**
Your Role – Next Steps

• Window Industry messaging:
  • Signal to manufacturers that you want more high performance options
• Sell clients on the full range of performance advantages of better windows
• Engage with Pilots, Field tests to Validate Performance
  • Check with NEEA, ETO, BPA, etc
• Take Advantage of Rebates, Incentives

• Provide Feedback to Us
• Collaborate in our Projects
Part IV: Window-Related Energy Ratings and Efficiency Program Opportunities

Christopher Dymond, NEEA
Window Ratings and Labels (NFRC, Energy Star)

• Energy Star’s “Most Efficient” label includes triple-panes in northern climate zones
• Limited market uptake of “Most Efficient” label
NW Window Replacement Utility Incentives

BPA Utility:
- **Residential** replacing aluminum or single pane windows with 0.22 U-factor or better
  - Incentives depend on HVAC system.
- **Residential (low-income qualifying)** - replace single pane or double pane metal frame as part of Weatherization Specification
  - Incentives tbd

**Energy Trust of Oregon**
- $1.75/s.f. (U-Factor .28-.30)
- $4.00/s.f. (U-factor .27 or less)
- Low-Market Uptake
The window Attachment Energy Rating Council (AERC) is an independent, public interest organization whose mission is to provide consumers with credible, relevant, and comparable information about window attachments and their performance.

- AERC members include:
  - Public Interest Groups
  - National Labs
  - Commercial Labs
  - Product Manufacturers
  - Component Manufacturers
  - Utilities
Why is AERC Necessary?

- Window attachments can save energy
  - However, many consumers are unaware of their energy-saving capability
- Consumers have no way to compare the energy performance of attachments
- Energy Efficiency program managers also benefit from ratings and energy performance information

The AERC rating allows consumers to make more informed decisions.
AERC Energy Improvement Rating

Save energy and make your home more comfortable. Window attachments products with this label—such as blinds, shades, shutters and storm windows—can help you do both.

1. Look for the AERC Energy Improvement Label
   Seeing the AERC Energy Improvement label on a window attachment product means it will help you save energy and make your home more comfortable. This label also allows you compare energy improvement across different product types in order to select the best one for your home.

2. Choose Your Climate
   Since window attachments can help keep your home warmer in cool climates and cooler in warm climates, this label helps you select the best product for where you live.
   - Cool Climate
     If you tend to turn on the heat more throughout the year, be sure to look at the Cool Climate Rating.
   - Warm Climate
     If you tend to use your air conditioning more throughout the year, then take a look at the Warm Climate Rating.

3. Discover Your Energy Savings
   The amount of energy you can save will vary based on the type of product you buy.
   - Cool Climate Rating
     96/110
     The large number indicates the product's energy rating.
     The smaller number indicates the maximum energy rating possible for that product category (storm windows, in this case).
     So, the closer the product's energy rating is to the maximum energy rating in your climate, the greater your energy savings.

ENERGY RATED. ADDED COMFORT.
Want to learn more? Visit www.AERCenergyrating.org

2019 HPC Northwest Regional
HOME PERFORMANCE CONFERENCE & TRADE SHOW
Low-E Storm Windows now Energy Star Certified

AERC Rating
Status of Low-e Storm (LES) Window Program in the Northwest

- RTF Approved Measure
- Utilities with Low-e Storm Programs – Requiring Qualified Home Performance Contractors
  - Chelan PUD – little uptake
  - Snohomish PUD – little uptake
  - Cowlitz PUD - pilot in 2017-2018, no home performance contractors interest
- Expressed Interest
  - City of Richland, Franklin PUD, Benton PUD, and Idaho Power.
  - Clark County
## Retail Pilot Programs – Good Response

<table>
<thead>
<tr>
<th>Pilot (year)</th>
<th>Overall storm window sales increase</th>
<th>Low-E sales increase</th>
<th>Low-E market share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>37%</td>
<td>337%</td>
<td>2014 – 22%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2015 – 70%</td>
</tr>
<tr>
<td>2017</td>
<td>9.6%</td>
<td>125%</td>
<td>2016 – 30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2017 – 62%</td>
</tr>
</tbody>
</table>
Thank you!

Any Questions?
Installation Methods: Exterior Storm Windows

Blindstop Installation
(inside mount)

Overlap Installation
(outside mount)