Bringing Window Innovations To Market: Doubling the Insulating Value of U.S. Windows

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A Platform For Window Innovation

Programs
Energy Star
Utility Rebates, CEE
Energy Codes
Tax Incentives

Ratings
U, SHGC, VT, CR, EP

Technical Standards
ASTM C1199, E1423, E908, C518
ISO 15099, 12567, 9050, 18292

Tools for Assessment
WINDOW, THERM, OPTICS
Hot Box, Solar Calorimeter

Enabling Building Science
Simulation and Measurement Infrastructure
Field Studies, Validation Database

DOE Programs
Codes, Residential and Commercial Integration, FEMP
State, Regional Agencies, GSA, DOD

Industry Collaborations
Technology Development - Technology Applications
Companies, Partnerships, Trade Associations...
Summary

• Window Energy Overview

• Heat Loss from Windows: $20B/year cost
  – Low-E Market Saturation, Success, but Stalled at R3
  – R6+ Windows -> Net Zero envelope, 2Q Savings

• Create Industry “Alliance” to Advance Near Term, Cost Effective, Scalable Solutions
  – “R8 Thin Glass/IGU” Innovation Platform
  – LBNL has established technical viability
  – 3 year, Public/Private Partnership

• Window industry support across supply chain

• ENERGYSTAR, Utility Role to Enhance Market Pull
Energy/Cost Impacts

• Window Impacts
  – 10% of building Energy; 4% of total US Energy; $50B/yr
  – Energy, Demand, Carbon Impacts
    • HVAC Energy: ~ 4Q; Electric Lighting Energy: ~ 1Q
    • Summer cooling peak, load shape, grid impacts
    • Winter Peak heating impact for electric heating
  – Occupant: Comfort, View, Daylight, etc
  – Owner: Views etc- property values

• Traditional DOE/EPA/Utility Goals: Reduce Energy Impacts
  – ET Focus-> Technology development goals
  – Transform Markets to drive impact

• Supports Longer Term 2030 Goals
  – “Net Zero” Buildings $\rightarrow$ Net Zero Envelope
# Getting to “Net Zero” Windows

*Annual Heating Cost simulated for a heating climate*

<table>
<thead>
<tr>
<th>Windows Type</th>
<th>Annual Heating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Glazed w/Storm</td>
<td>$1310</td>
</tr>
<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>
</tr>
<tr>
<td>“SuperWindow”</td>
<td>$960</td>
</tr>
</tbody>
</table>
Highly Insulating Windows Can Become Energy Producers in Cold Climates

Single Glaze: $U = 1.1$
Double Glaze: $U = 0.5$
Double, Low “e” $U = 0.3 - 0.4$ (Energy Star)
Window $U = 0.1 - 0.2$ (Triple or Vacuum)
Window $U < 0.1$
Window Energy Snapshot

• Good news:
  – With DOE support, industry transformed markets from single (R1) -> double (R2) -> double, low-E, argon (R4)
  – 90%+ sales of all window are low-E
  – NAHB study: Low-E window most cited Green feature

• Bad news: little market movement since 1990
  – Biggest Energy Opportunity- highly insulating glazing for heating dominated climates (~1-2Q at stake)
  – Market “Saturated” at double, low E: 96% Market Share
  – Triple glazing: only 1.7% market share, unlikely to rise
    • too heavy, too wide => too costly to redesign windows
Market Snapshot

Performance distribution of NFRC-Rated Windows

Source: EPA ENERGYSTAR analysis, Horiz. sliding windows

Residential Windows
60M windows/yr -> $25B/year investment
In place for 30+ years…. Do it Now- Don’t Wait for Future Retrofit!
Success of Low-E, Double Glazing: R2 -> R4

- 3 stage “adoption” process to increase market share
  - Introduction -> ~20% market share: **Innovation push**
  - 20% -> 60% NFRC Ratings, Energy Star market pull
  - 60% -> 95%: **Codes and Standards**

- “Criteria” for Initial rapid adoption: double-> low-E
  - Leading wood window manufacturers are early adopters
  - Low-E/argon glass package is affordable
  - “Drop-in glass replacement”- no costly redesign of window needed to accommodate the low-E IGU

- **Can We Repeat It?**

- Biggest Opportunity for National Energy Savings is Reducing Heat Loss from Windows
Hi-R Glazing Options

• Existing Triple Glazing (w. gas and low-E)
  – Technology elements available (e.g. European triples)
  – Too heavy/too wide -> costly redesign of whole window

• “New Technology”
  – Vacuum glazing: cost, lifetime, durability, manufacturing capacity all unknowns
  – Aerogel- after 30 years still R&D: cost, haze, durability

• “Thin, Lightweight Triple” w/ low-E and gas fills
  – Innovative but affordable, available tech options
  – Solvable manufacturing challenges
  – Need push/pull strategy and partners
U.S. INSULATING GLAZING Landscape Today:

**R5-10**

- **Market Today**
  - Single
  - Double
  - Two low-e
  - Three low-e

- **Emerging**
  - One low-e Vacuum
  - Two low-e Vacuum Hybrid
  - Two low-e, Thin glass, single seal, Krypton gas

- **Future**
  - Aerogel

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

Super-insulating frame with highly insulated glazing
Why “Thin Glass Triple”?  

- Platform: R5-R10  
- Thin float glass  
  - .3, .5, .7, 1.1 mm  
- Affordable  
- Multiple suppliers  
- Low-E coatings  
- Krypton gas fill  
- Non-structural  
  - 2 seals  
- Infrastructure exists
Not a New Concept; Thin Glass, Thin Triple Concept Developed “Before its Time”

Key Technical, Market Features

• Light Weight: **Thin glass** can be .5-.9 mm vs 3mm
• Single spacer: two leakage paths, not 4
• Glass is Durable: Polymer films have lifetime issues
• **Kr Gas** achieves high R with Thin gap- same IGU dimensions as Double
• **Premature in 1990 -> 2015**
  • Thin glass and Kr are now market ready and cheaper
Why Will It Work Now? => $$$

• **Thin Glass:**
  – Four 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**
  – Four years ago: variable demand from other sources kept prices high and volatile; Gas fill process wasted 50% -> Net cost > $2.50/sf
  – Today: Xenon requirements make Kr available; traditional Kr use for halogen lamps has been reduced; suppliers will now sign long term contracts at ~$0.50/ sf
  – New high rate gas fill w/ 10% loss

• **Market Demand:**
  – Energy Star V7- Potential New Market Pull
  – Utility Programs
IT WORKS!: LBNL Built and Tested Options
Validating the Optimization Studies

Figure 1(a-k) – Cross-sectional geometry of the prototype insulated glazing units tested. Drawings are not to scale. Refer to Table 1 for dimensions. Specimens 16 and 19 have one low-e despite the

Figure 3 – Examples of false color plots showing warm side surface temperature maps from infrared thermography (not accurate in black and white)
Net Zero Windows Are Feasible in Cold Climates:
Minn: Annual energy use vs. window properties

Residential Energy Use (MBTU/yr) vs Window Thermal Properties (U, SHGC)

Specific windows plotted on map of iso-energy use

House with no windows uses 82MBTU
~20% savings vs E*
Typical Window U (and Center-of-glass, COG U)

Typical wood frame (clear window is Aluminum)
Stainless steel warm-edge spacer
Low-E to meet IECC 2012 climate zones <= 3
# Annual Energy Model Locations

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>MN</td>
<td>Minneapolis</td>
<td>6</td>
<td>0.32</td>
<td>NR</td>
<td>0.35</td>
<td>NR</td>
</tr>
<tr>
<td>DC</td>
<td>Washington</td>
<td>4</td>
<td>0.35</td>
<td>NR</td>
<td>0.35</td>
<td>NR</td>
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<tr>
<td>SC</td>
<td>Charleston</td>
<td>3</td>
<td>0.35</td>
<td>0.25</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>TX</td>
<td>Houston</td>
<td>2</td>
<td>0.4</td>
<td>0.25</td>
<td>0.65</td>
<td>0.3</td>
</tr>
<tr>
<td>UT</td>
<td>Salt Lake City</td>
<td>5</td>
<td>0.32</td>
<td>NR</td>
<td>0.35</td>
<td>NR</td>
</tr>
<tr>
<td>CA</td>
<td>Los Angeles</td>
<td>3</td>
<td>0.32(^1)</td>
<td>0.25</td>
<td>0.5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\(^1\) Title 24

*U*-factor and *SHGC* (Solar Heat Gain Coefficient) values are given for each location, indicating the energy model requirements.

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[Map Image]

The map shows the climate zones across the United States, with circles indicating the locations of Minneapolis, Washington, Charleston, Houston, Salt Lake City, and Los Angeles. The legend differentiates between the various climate zones, and the map provides a visual representation of the energy model locations.

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*Note: All of Alaska is in Zone 7 except for the following locations: Bethel, Dillingham, Fairbanks, Haines, Yakutat, and Nome.*
5 Alternative Window Designs

End use multipliers: Elec=3.167, Gas=1.084
Energy Cost and Payback in 6 Climates: 5-7 years (Similar in All Climates (?))
Vs Existing Window; House w/357 SF window (15% of wall area)

<table>
<thead>
<tr>
<th>Window #</th>
<th># Panes</th>
<th>Glass Type</th>
<th>Gas</th>
<th>IG width (in)</th>
<th>Glass</th>
<th>Gas</th>
<th>Assembly and Spacers</th>
<th>total</th>
<th>Incremental Markup (1.9x)</th>
<th>Energy cost savings</th>
<th>Simple Payback (YR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>clear</td>
<td>Air</td>
<td>0.74</td>
<td>$1.00</td>
<td>$0.00</td>
<td>$2.00</td>
<td>$3.00</td>
<td>$5.70</td>
<td>$0.72</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>low solar gain (#2)</td>
<td>Argon</td>
<td>0.74</td>
<td>$1.50</td>
<td>$0.01</td>
<td>$2.00</td>
<td>$3.51</td>
<td>$0.96</td>
<td>$0.79</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>low solar gain (#2) high solar gain (#4)</td>
<td>Argon</td>
<td>0.74</td>
<td>$2.50</td>
<td>$0.01</td>
<td>$2.00</td>
<td>$4.51</td>
<td>$2.86</td>
<td>$0.79</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>TG</td>
<td>low solar gain (#2, #5)</td>
<td>Krypton</td>
<td>0.74</td>
<td>$3.00</td>
<td>$0.31</td>
<td>$5.81</td>
<td>$5.34</td>
<td>$0.89</td>
<td>6.0</td>
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<tr>
<td>5</td>
<td>3</td>
<td>opt</td>
<td>low solar gain (#2, #5)</td>
<td>Krypton</td>
<td>1.05</td>
<td>$2.50</td>
<td>$0.81</td>
<td>$6.64</td>
<td>$6.92</td>
<td>$0.94</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Payback 5-7 years

“Thin” Triple

- MN
- DC
- SC
- TX
- UT
- CA
“Real World” Market Drivers

• **Owner:**
  – Comfort, Condensation
  – Resilience

• **Builder/Developer:**
  – Larger View Windows Meet Code
  – Downsize HVAC (= cost savings)

• **Utility**
  – Energy ( new “service” offering?)
  – Peak heating and cooling
  – Resilience
Reliable System integration → First Cost tradeoffs
Improved Façade = Lower HVAC System Cost

First Cost
Annual Cost

Office Eq.
Peak Cooling Heating Load
Chiller Size
Energy, Peak Electric Demand
Onsite Power Generation
Central Power Generation

$ = First Cost
$ = Annual Cost
## Comfort Considerations
- Condensation Resistance
- Winter Outdoor Comfort Temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2P clear</td>
<td>13</td>
<td>-30.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2P lowe</td>
<td>54</td>
<td>-11.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2P surf4</td>
<td>45</td>
<td>-22.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3P Thin Glass</td>
<td>63</td>
<td>-20.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3P opt</td>
<td>65</td>
<td>-30.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Double Low-E**: -6°C
- **Triple**: -24°C
Commercial Buildings
Recapturing Perimeter Floor Space

Radiant Discomfort (Full-body Discomfort)

Draft Discomfort (Ankle Discomfort)

If this were well insulated

We wouldn’t need this

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>PPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>double clear</td>
<td>27.6%</td>
</tr>
<tr>
<td>Case 2</td>
<td>double lowe</td>
<td>20%</td>
</tr>
<tr>
<td>Case 3</td>
<td>TG triple</td>
<td>16.2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost/ft² Window</th>
<th>Upgrade Double to Triple Pane</th>
<th>$5.47</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add Perimeter Heat to Double</td>
<td>$53.20</td>
<td></td>
</tr>
</tbody>
</table>

*Slide credit and cost numbers: Chris Mackey Payette Architects
Next Steps Forward

• Propose an Enhanced “Industry Partnership” to:
  – Engage Broader Crossection of Window Industry
  – Biggest Concern: Market Demand!
  – Accelerate Process- ~2 years to initial market entry

• Supply Side: Focus on manufacturing and cost issues

• Demand Side: Engage Window manufacturers with new Energy Star criteria to differentiate products, and Utility Programs for Early Market Launch

• Launch Coordinated Technical and Business Program
Hi-R IGU Technology Platform Program Design

LBNL IGU Thermal Optimization and Validation:
- Glass Thickness
- Gas fill and dimensions
- Coating for Hi/Low SHGC
- IR Thermal testing
- Durability Testing: NREL

Industry Component Supply Partners:
- Thin Glass
- Coatings
- Gas supply
- Gas fill
- Spacer design
- IGU fabrication

- Climate Modeling
- EPA ENERGYSTAR Criteria
- IR Thermal/NFRC tests
- MoWitt test

Window Manufacturer Partners
- National, Regional
- Window, Skylight
- New/Replacement
- Resid/Comm’l
- Market Intelligence
- Cost Optimization

DOE $

Industry Cost Share $
Utility Partner Roles

- Demonstration programs
- Local “Cost effectiveness” calculations
- Incentive Program Design
- Supply chain market impact: upstream, downstream
- Timing
- Load management- winter peak management
- Climate optimization- cooling impacts
CONTACT US!

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Framework for Facades as “integrated building systems” – managing light, glare, solar gain, heat transfer, ventilation, power generation, energy storage,
Relative Cost and Complexity?

Electricity from Nuclear power plant
For Heat, Cooling and Light

VS

Heating savings from High R Window
Cooling Savings from Automated Shades
Relative Cost and Complexity? A Story of Two $500B/yr Industries

INDUSTRY “A”

Integrated System: Autonomous Car w/ Smart Sensors

INDUSTRY “B”

Integrated System: Sensor-Driven Automated Shade or EC w/ Daylight Dimming
“B”: Façade Design-Delivery Ecosystem
Who’s In Charge? Who Delivers Complete Solutions?

Industry Supply Chain:

- Glazing, Fenestration
- Daylight Control
- Shading

Design “Team”

Integrated Design-Delivery Process:
Prog - SD - DD - CD - Construction

HVAC

Lighting

Occupants

Owner, Facility Manager

Utility

Operations. Maintenance. Renovation