Retrofit, Restore, or Replace: Understanding the Whole Life Carbon of Windows

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Curated by Michael Simons (Abode)

Northeast Sustainable Energy Association (NESEA)
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Retrofit, Restore, or Replace
Understanding the whole life carbon of windows
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NSG Pilkington
Description

Windows and glazing play a disproportionate role in a building's performance compared to other parts of the assembly. As we strive to meet our 2030 and 2050 climate goals the design strategies for both our new and existing buildings must be closely evaluated.

A case study of the Albert Kahn building will demonstrate how emerging glass technologies can play an important role in a building’s restoration, maintaining its architectural characteristics, and can create jobs in urban environments. A detailed examination will be paid to the embodied and operational carbon of different design strategies.

Learning Objectives

1. Compare the energy reduction challenges of retrofitting versus new construction
2. Identify emerging technologies that can help upgrade existing buildings and significantly reduce carbon usage.
3. Analyze how the embodied carbon and operational carbon from case studies can be applied to reduce the whole life carbon of windows.
4. Maximize triple bottom line results - historic restoration, energy efficiency, and equity focused workforce development - while still delivering an effective and cost-efficient project.
Agenda

• Building consumption and window impact
• Window overview – performance, design, and current state
• Baseline expectations
• Albert Kahn building – case study review
• Triple bottom line project management
• Albert Kahn building – energy and carbon impact
• Emerging technologies
Buildings use lots of energy...

U.S. Energy Consumption by Sector

Credit – Architecture 2030, US Energy Information Administration
Windows are huge opportunity...

New Build: Windows are falling behind!

<table>
<thead>
<tr>
<th></th>
<th>IECC 2021</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R-60 Ceilings</td>
<td>R-20 Walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-3.3 Windows</td>
</tr>
</tbody>
</table>

|        | Windows            |          |
|        |                    |          |
|        | Area: 8%           | Heat loss: 47% |
|        |                    |          |

48 million Single-Pane Homes (41%)

*2015 RECS

Credit – Steve Selkowitz, LBNL
Performance basics

- Think of coatings in two primary functions
  - Filter - Solar energy, light transmission, reflection, etc.
  - Insulator - Manage re-radiation of absorbed energy (both from sun and from room)
- Potential concerns with color and aesthetics.
Window performance measurements

The lower the U-Factor, the better the window insulates.

Inverse of R-value
U-Factor = 0.25
R-value = 4.0

Visible Light Transmittance (VLT)

Solar Heat Gain Coefficient (SHGC)

The amount of visible light that passes through the glass.

U-Factor

SHGC

Zones

Performance and aesthetics are not mutually exclusive.

SHGC is expressed as a number between 0 and 1. The lower the SHGC, the less solar heat it transmits.
Thermal comfort

Credit – Steve Selkowitz, Robert Hart, LBNL
How did we get here?
Glass complexity

1970

Today
IG construction

- More than one piece of glass (double glaze, triple glaze)
- Different types of seals used
- Variety of gases to fill space
  - Impacts convection, conduction

Potential concerns with seal failure, moisture, aesthetics
Upgrade v. replace

Secondary glazing
U-factor = 1.0 → (<0.5 to 0.35)
SHGC = 0.8 → (<0.70-0.65)

Credit – Steve Selkowitz, LBNL, Kimber Degling - Innerglass
Market status

Markets Evolve Slowly...How to Accelerate?

Residential Market Share By Glazing Type

- Double pane, clear
- Double, low-e
- Triple
  - ~R5, U~0.2
  - (~3% Market share)

*Ducker Worldwide (2018)

Innovation push tech development

Market Pull: Utilities, Energy Star

Codes and standards

Credit – Steve Selkowitz, LBNL
Higher performance available

HIGHER INSULATING GLAZING SOLUTIONS:

- Market Today: $U \sim 0.25$ Btu/hr-ft$^2$-F
- Emerging: $U \sim 0.1$ Btu/hr-ft$^2$-F
- Future: 
  - One low-e Vacuum
  - Two low-e Vacuum Hybrid
  - Aerogel

- Single
- Double
- Two low-e, Thin glass single seal Krypton
- Three low-e
- Quad
- Super-insulating frame with highly insulated glazing

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

Credit – Steve Selkowitz, LBNL
IG versus VIG construction

- IG: Glass units are sealed in a frame with an argon or air fill.
  - Low-e coating
  - Glass
  - Gap 0.2mm
  - Pillar: 0.5mm diameter

- VIG: Voids are sealed under vacuum.
  - Low-e coating
  - Glass
  - Pump out tube: ~2mm diameter, 4mm long
  - Vacuum: ~0.1 Pa
  - Solder glass

Building exterior
IG versus VIG construction
Albert Kahn office building – Detroit

- 1931
- 11 story
- 320,000 ft² building, 17,500 ft² glazing area
- Bronze, double-hung windows, monolithic ¼” glass
Energy and carbon impact
Counting Carb_{on}s — 40% buildings

Operational Carbon

• Carbon emissions from use of energy to heat and power a building

Goal = Lose weight

1 lb / week

2 lb / week

1st add 50 lbs

Embodied Carbon

• Carbon emissions from manufacturing, production, and transportation of building materials

Goal — reduce overall carbon impact / usage
Embodied - Glass and window impact

- Glass – skin of building
  - Structural elements - majority

- Improve operation performance with minimal embodied impact
  - Right size glass
  - Better gas
  - Longer life
  - Buy local
  - Design strategy
The Kahn

Existing building – ¼” monolithic (reference)

1. Storm windows (steel)
2. Storm windows (Aluminum)
3. VIG re-glaze
4. Replacement Aluminum windows

Typical IGU – 1” Thick

VIG – ¼” Thick
DOE reference building

Software:
- Energy Plus
- DOE Commercial reference buildings

Building
- Existing building pre-1980
- Climate Zone - ne 5a – Chicago, IL
- Large office (498,558 ft² – 12 floor)
- mixed humid
## DOE reference building

<table>
<thead>
<tr>
<th></th>
<th>Reglazing with VIG</th>
<th>Interior Storm with Steel Frame</th>
<th>Interior Storm with Aluminium Frame</th>
<th>Aluminium replacement windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Embodied Carbon (tonnes CO₂ E)</td>
<td>25</td>
<td>33</td>
<td>43</td>
<td>73</td>
</tr>
<tr>
<td>Operating Carbon Annual Savings (tonnes CO₂ E)</td>
<td>-226</td>
<td>-161</td>
<td>-161</td>
<td>-233</td>
</tr>
<tr>
<td>Total Y1 Carbon Impact (tonnes CO₂ E)</td>
<td>-201</td>
<td>-126</td>
<td>-114</td>
<td>-160</td>
</tr>
<tr>
<td>Embodied Carbon Debt Payback (months)</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Breakeven point – years payback embodied carbon</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

Current operating carbon (metric tons CO₂ eq): 931
Key learnings

1. Building re-use / upgrades
2. Embodied material choices matter
3. Time-based carbon – save now
Emerging technology
**Triple glazing – Juice worth the squeeze?**

### Table 1: RESIDENTIAL ANALYSIS (all windows in model home)

<table>
<thead>
<tr>
<th>Embodied Energy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied primary energy of flat glass</td>
<td>2.16E+04 MJ/MT</td>
</tr>
<tr>
<td>Total window area in analysis home</td>
<td>356 ft²</td>
</tr>
<tr>
<td><strong>Middle lite thickness</strong></td>
<td></td>
</tr>
<tr>
<td>Mass of 3rd lite (total for home)</td>
<td></td>
</tr>
<tr>
<td>Embodied energy of 3rd lite (total for home)</td>
<td></td>
</tr>
<tr>
<td>2.2 mm</td>
<td>1.1 mm</td>
</tr>
<tr>
<td>184 kg</td>
<td>92 kg</td>
</tr>
<tr>
<td>3.98 GJ</td>
<td>1.99 GJ</td>
</tr>
</tbody>
</table>

**Energy Savings – ENERGY STAR Northern Zone**

- **Code baseline** - U lowered from 0.30 to 0.22 Btu/hr ft² F, SHGC kept constant at 0.30
  - Site energy savings: 6.59 GJ/yr
  - Source energy savings: 6.97 GJ/yr
  - **Embodied energy payback period**: 6.8 months | 3.4 months

- **ENERGY STAR v6 baseline** - U lowered from 0.27 to 0.22 Btu/hr ft² F, SHGC constant at 0.30
  - Site energy savings: 4.04 GJ/yr
  - Source energy savings: 4.27 GJ/yr
  - **Embodied energy payback period**: 11.2 months | 5.6 months

MJ/MT = megajoule per metric ton. GJ = gigajoule.
Assumed site-to-source conversion factor: 1.1 for gas, 3.0 for electricity

Credit – Tom Culp, Birch Point Consulting, LLC
Carbon impacts

Embodied carbon

Operating carbon

Metric tons CO2

Metric tons CO2 eq

Code DGU Thin triple

Building DGU Thin triple

Heating Cooling

5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000

0 200 400 600 800 1000 1200

Incentives, manufacturing

Utility Incentives for Better Windows

- Programs throughout the country
  - CEE and EWC compile lists
  - Better than ENERGY STAR and Energy Star
  - Most Efficient programs are growing
    - PG&E, CA New Construction
    - EVERSOURCE, CT Retrofit
    - Minnesota Power, New Construction
    - Energy Trust, OR Retrofit
    - Others?

Credit – Alpen HPP
Key learnings

1. Building re-use / upgrades
2. Embodied material choices matter
3. Time-based carbon – save now
4. Material reuse
5. Operating carbon – Offsets, reduce
6. Design – low embodied impact / high return operating savings
7. Emerging technology –> better windows
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