Single-pane window efficiency

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The US has a great many windows …

- $43 \times 10^9$ square feet ($4 \times 10^9 \text{ m}^2$) in the US
- 140 square feet ($13 \text{ m}^2$) per person
Heat flow through windows (mainly winter):
- 3.4 quads/year (primary “thermal load”)
- $34 billion/year (@$10 /MBtu)

Solar heat gain is not included in this figure.
BTO workshop report (2014) Table 2. Edited by K. Sawyer.
... with substantial energy costs in quads and cash

- 3.4 quads is certainly significant
- Costs are very diffused: $100/person/year
- Is there a sweet spot to improve windows & reduce usage?

![Diagram showing energy costs in quads and cash]
A windows glossary

single pane

\[ U \approx 0.7 - 1.1 \text{ Btu/sf/hr/F} \]

33% (res) 40% (com)

double pane

0.3 – 0.7

66% (res) 59% (com)

triple pane

0.2 – 0.3

small

units: 1 Btu/sf/hr/F \approx 5.7 \text{ W/m}^2/\text{C}
Site use of energy by windows

![Bar chart showing window-related heating usage by region and sector.](chart.png)

Dan Matuszak, unpublished [1].
Area fraction of single pane windows

Dan Matuszak, unpublished [2].
Thermal load fraction of single pane windows

\[
\text{(Single-pane conduction load)/(Total conduction load)}
\]

- **Commercial**
- **Residential**

Dan Matuszak, unpublished [3]
Single panes: billions and billions of square feet

Single-pane window stock by region

- **Commercial**
- **Residential**

<table>
<thead>
<tr>
<th>Region</th>
<th>Window area [$10^9$ square feet]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td></td>
</tr>
<tr>
<td>Midwest</td>
<td></td>
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<tr>
<td>South</td>
<td><strong>5.0</strong></td>
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<tr>
<td>West</td>
<td></td>
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</tbody>
</table>

Dan Matuszak, unpublished [4]
Primary energy savings from single pane retrofitting

Dan Matuszak, unpublished [5], [6]
Heating cost savings from single pane retrofits

$1.90/sf/yr

$1.60 /sf/yr

$1.10 /sf/yr

$1.40 /sf/yr

Improve single pane $U = 1.15 \rightarrow 0.30$ Btu/sf/hr/F

Change in $ using 2014 local NG prices & degree days (20 C interior)

Note: exterior low-e storm window @ retail: ~$8/sf (+installation)
Present technologies for single-pane retrofits

- Full replacement with modern, insulated glazing units
  - Low-e, double/triple pane, argon/krypton fill
- Add exterior storm windows (low-e)
- Add interior panels (low-e pane)
- Affix window films (solar control &/or low-e)
- Replace panes with low-e panes
- Shrink-film & tape window insulation kits
- …others

All have limitations.
Single pane fraction >35% after decades of retrofits
The single pane window: a canvas for creativity

thermal barrier

radiative barrier

acoustical barrier

thums.dreamstime.com/x/hair-spray-8717489.jpg

lifehackery.com/qimages/6/Spray.jpg
Research goals for single pane window retrofitting

Reduce payback times
- Increase efficiencies of retrofitted windows
- Reduce installed price of retrofits
- Increase attractiveness of a capital investment

Add value beyond energy performance
- Condensation resistance & humidity control
- Noise dampening
- Clarity or other optical properties
- Comfort & security
- Service lifetime
- Form factor (thinness, ease of installation)
- Dynamic elements (cf. electrochromic or thermochromic)
Challenge what’s possible

- EnergyStar U-values with only a thin coating on the single pane?
- Higher clarity and transparency for low-e surfaces?
- 20-year service lifetime for applied films?
- Inexpensive dynamic performance for panels and films?

Credible path to market

- 1 billion sf/year (retrofit most single panes in 10 years)
- $10/sf installed (at scale)
The workshop: ARPA-E needs your help

- Are there research paths that, if successful, would significantly affect the industry?
  - Can there be a substantial (>1%) impact on US energy?
  - What are the price points to get a new technology adopted?
  - What are the other criteria to get energy-efficient technologies adopted?

- Is an ARPA-E *focused research program* the right choice?
  - ARPA-E programs can be as large as $30 M over 3 years
  - We don’t renew programs. We expect successful projects to find new support after 3 years.
  - We don’t compete with other funders.
  - We’re seeking breakthrough technologies.
  - We tolerate high risk. We manage projects actively.
Workshop organization

- Informational talks & panel discussion
  - Engineering and science of windows (Selkowitz, Wright)
  - Getting window retrofits adopted (Krug, Rose, Sawyer, Tegan)
- 3 Breakout sessions – 3 groups for each. Assignment sheets.
  1. Identify what’s needed to get retrofit technologies adopted. Payback period? Perceived risks? Value-added opportunities?
  2. Identify research areas with breakthrough possibilities that could move ahead with ARPA-E support.
  3. Develop technology-agnostic metrics for selecting and managing a program for energy efficiency and commercial success.
Endnotes


[2] Approximates the single-pane fraction of the national window stock as the single-pane fraction of the national floorspace. Floorspace information was obtained from RECS 2009 and CBECS 2003.

[3] The fractional energy usage associated with window conduction is approximated as

\[ f_s U_s / (f_s U_s + (1-f_s) U_m) = f_s / [f_s + (1-f_s) (U_m/U_s)] \]

where \( f_s \) is the fraction of single pane area to total window area in a region, \( U_s \) is the average U-value for single pane window, and \( U_m \) is the average U-value for multi-pane windows. The approximation \( U_m/U_s = 0.5 \) was used. Fractional areas from [2].


[5] The U-factor was changed at a constant solar heat gain coefficient, using the methodology described in J. Apte and D. Arasteh in “Window-Related Energy Consumption in the US Residential and Commercial Building Stock”, LBNL-60146. The regional residential window stock was segmented according to BEDB 2011 Table 5.2.6.

[6] Specific questions may be directed to daniel.matuszak@hq.doe.gov