CHANGING WHAT'S POSSIBLE

Single-pane window efficiency

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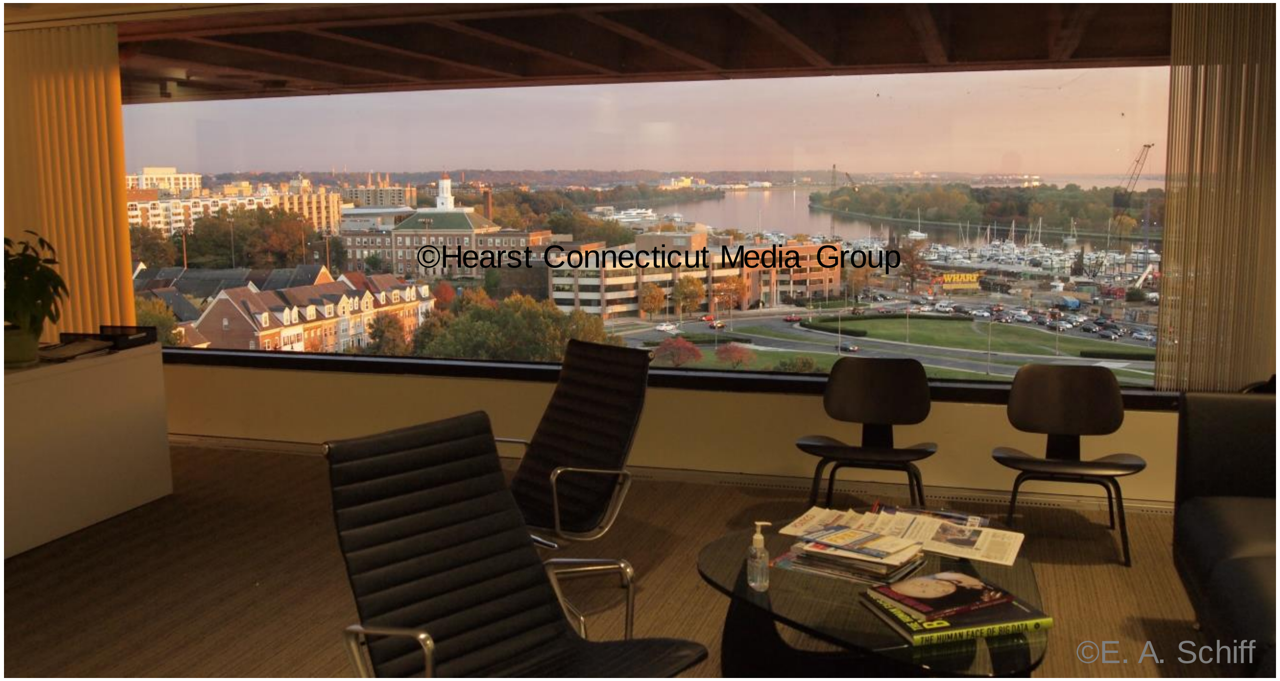
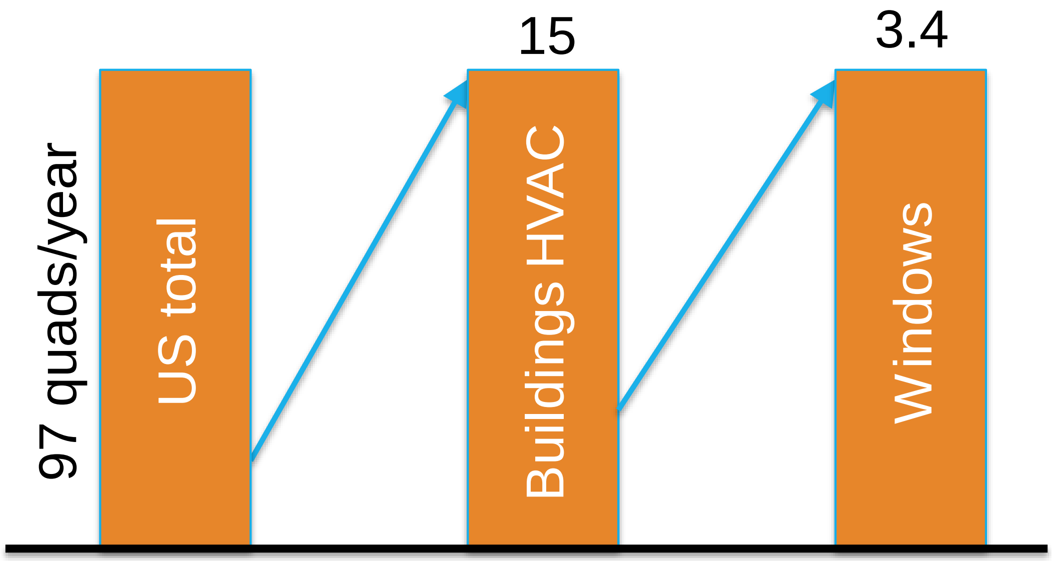
The US has a great many windows …

- 43×10^9 square feet (4×10^9 m^2) in the US
- 140 square feet (13 m^2) per person



… with substantial energy costs in quads and cash

- Heat flow through windows (mainly winter):
  – 3.4 quads/year (primary “thermal load”)
  – $34 billion/year (@$10 /MBtu)

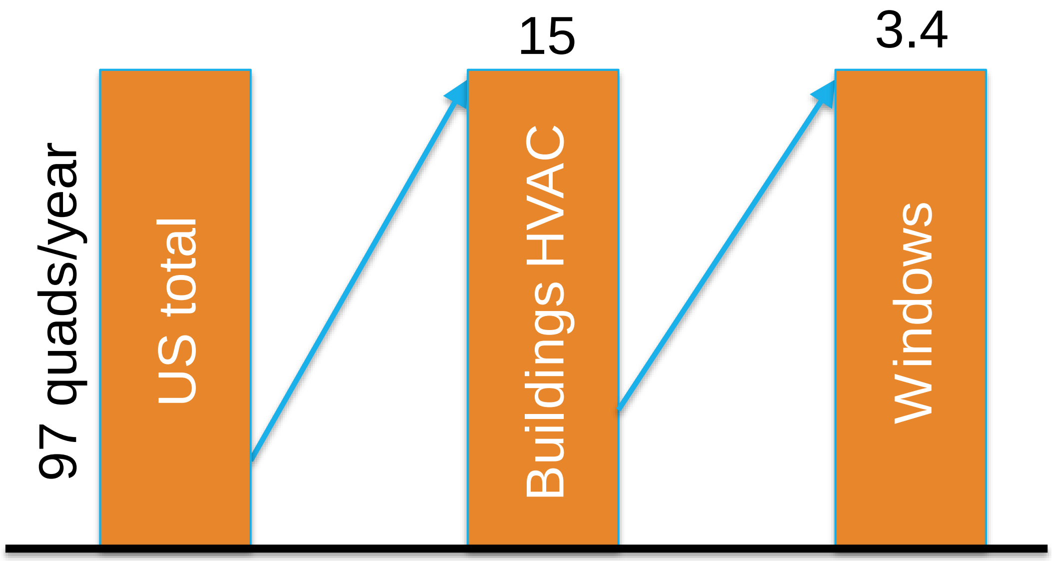


Solar heat gain is not included in this figure.
BTO workshop report (2014) Table 2. Edited by K. Sawyer.

1 quad ≡ 10^{15} Btu = 1.06×10^{18} J

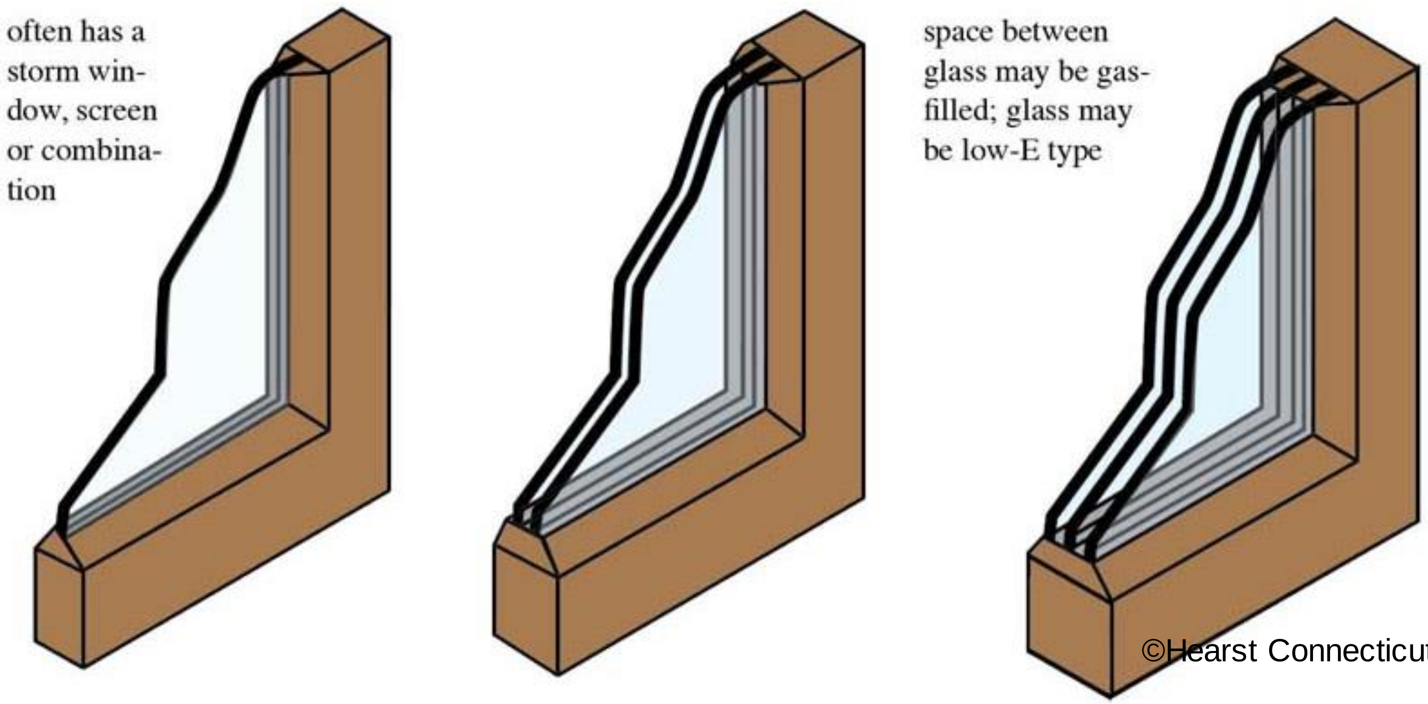
… with substantial energy costs in quads and cash

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



A windows glossary

single pane	double pane	triple pane
$U \approx 0.7 - 1.1$ Btu/sf/hr/F	$0.3 - 0.7$	$0.2 - 0.3$
33% (res) 40% (com)	66% (res) 59% (com)	small



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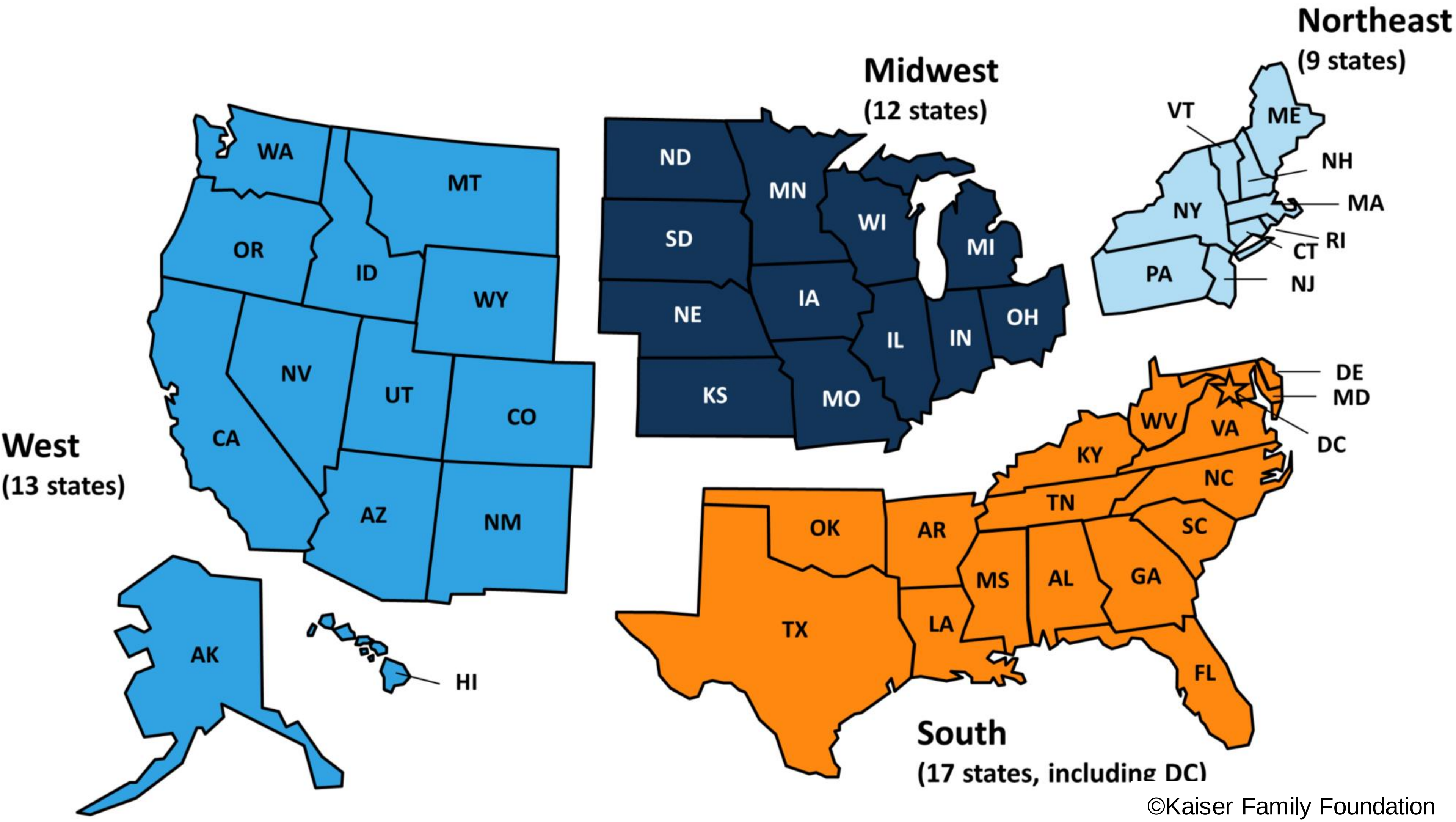
units: 1 Btu/sf/hr/F $\cong$ 5.7 $\mathrm{W/m^2/C}$

Census regions of the United States



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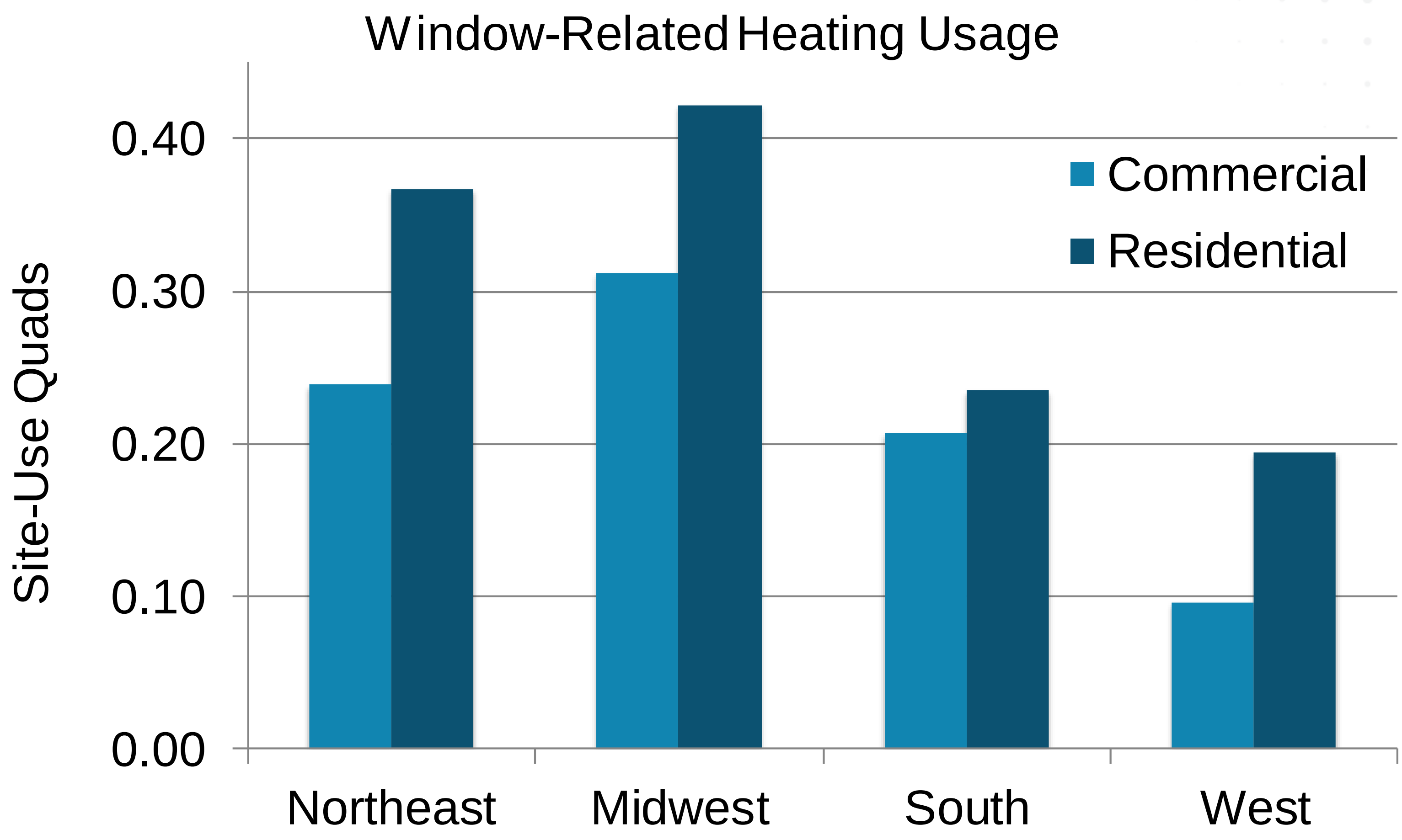
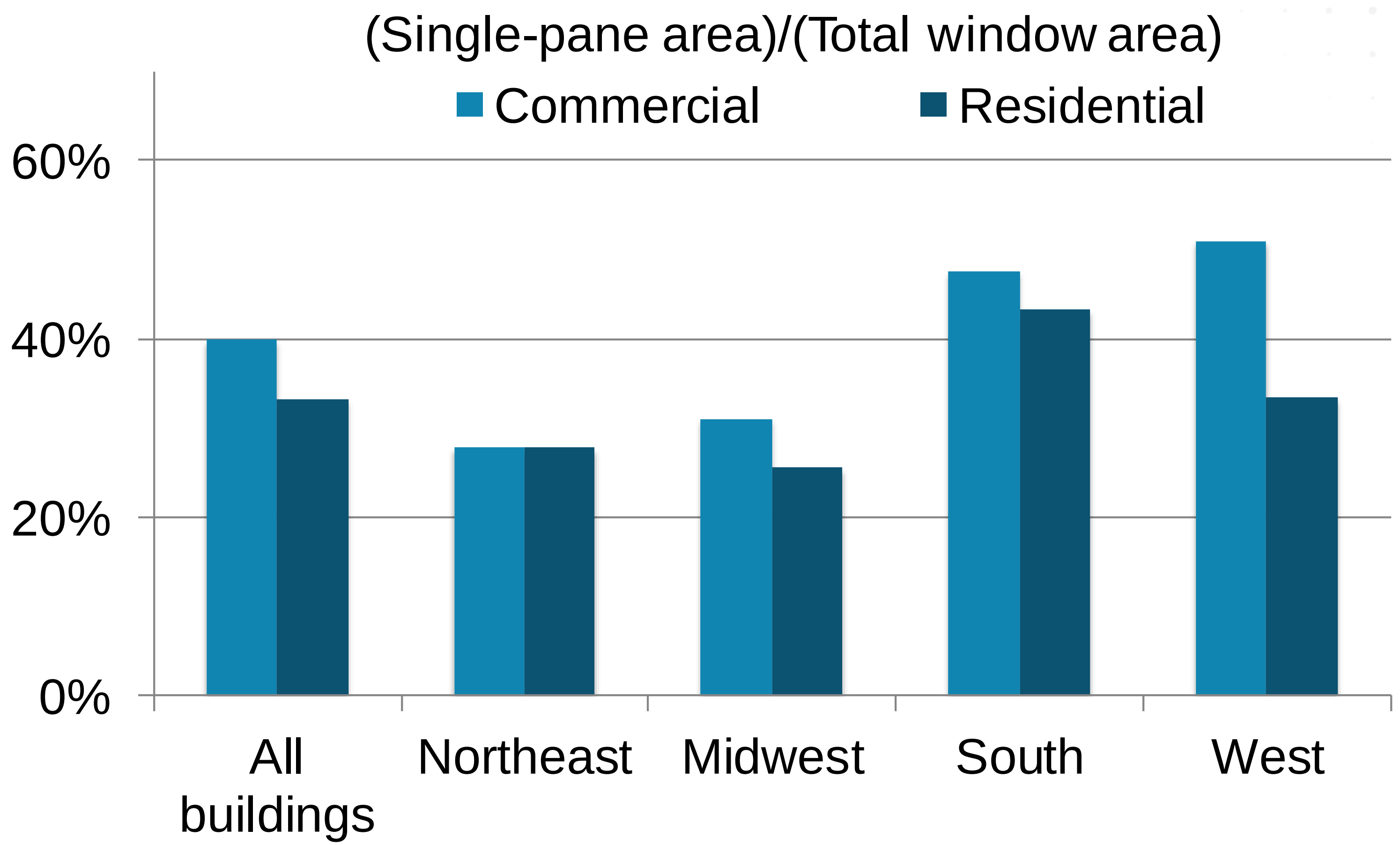
Site use of energy by windows



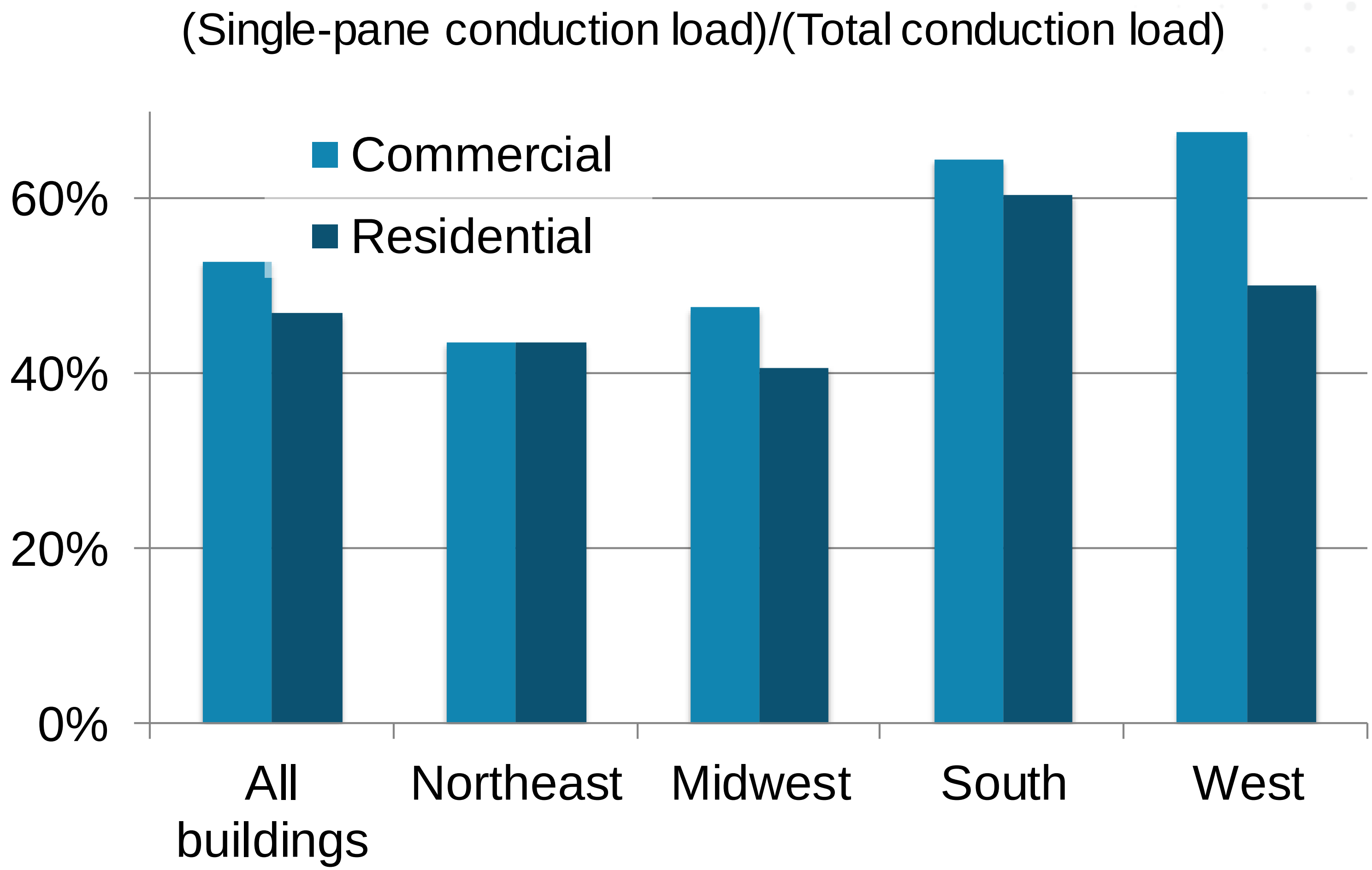
Dan Matuszak, unpublished [1].

Area fraction of single pane windows



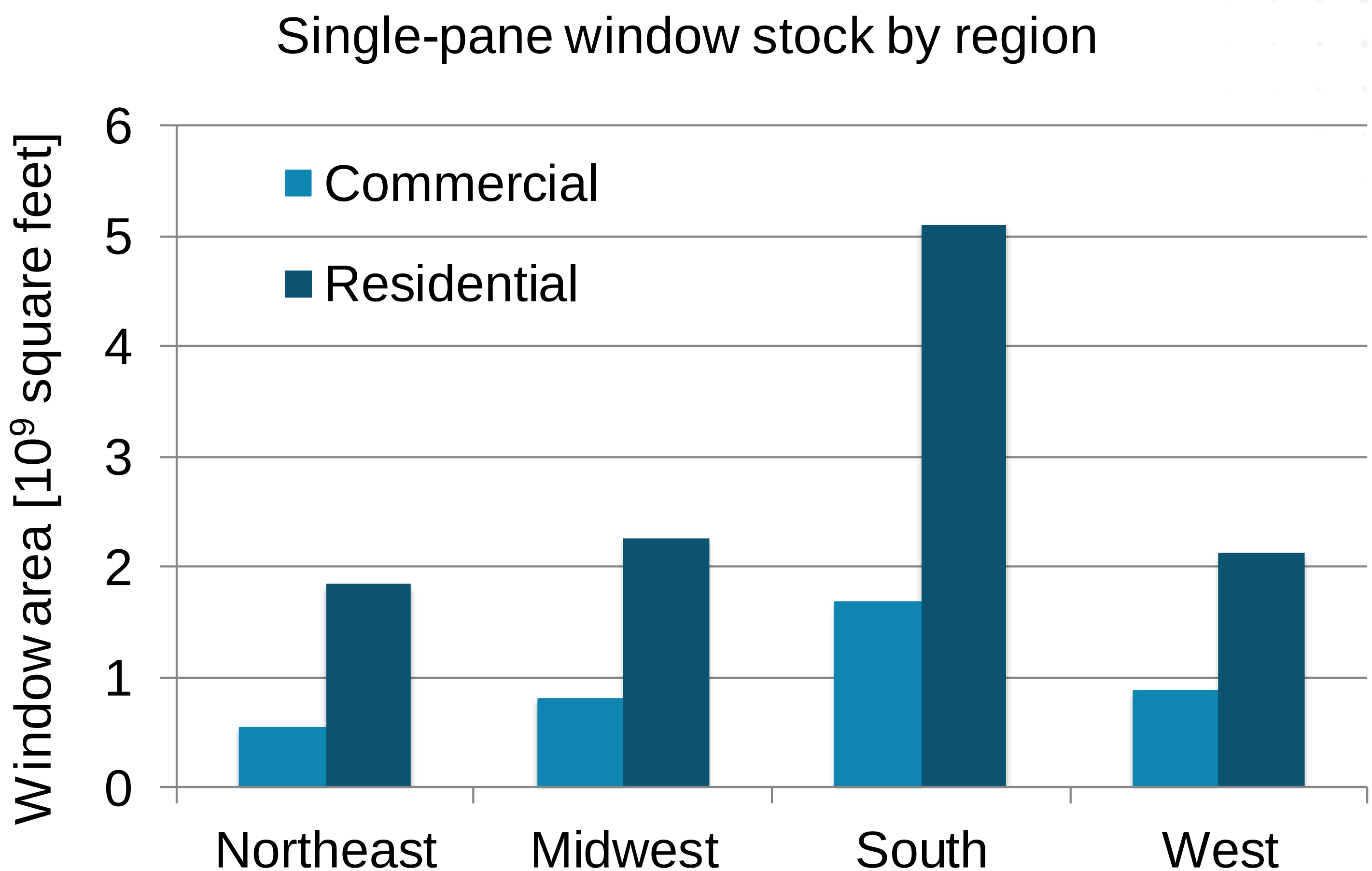
Dan Matuszak, unpublished [2].

Thermal load fraction of single pane windows



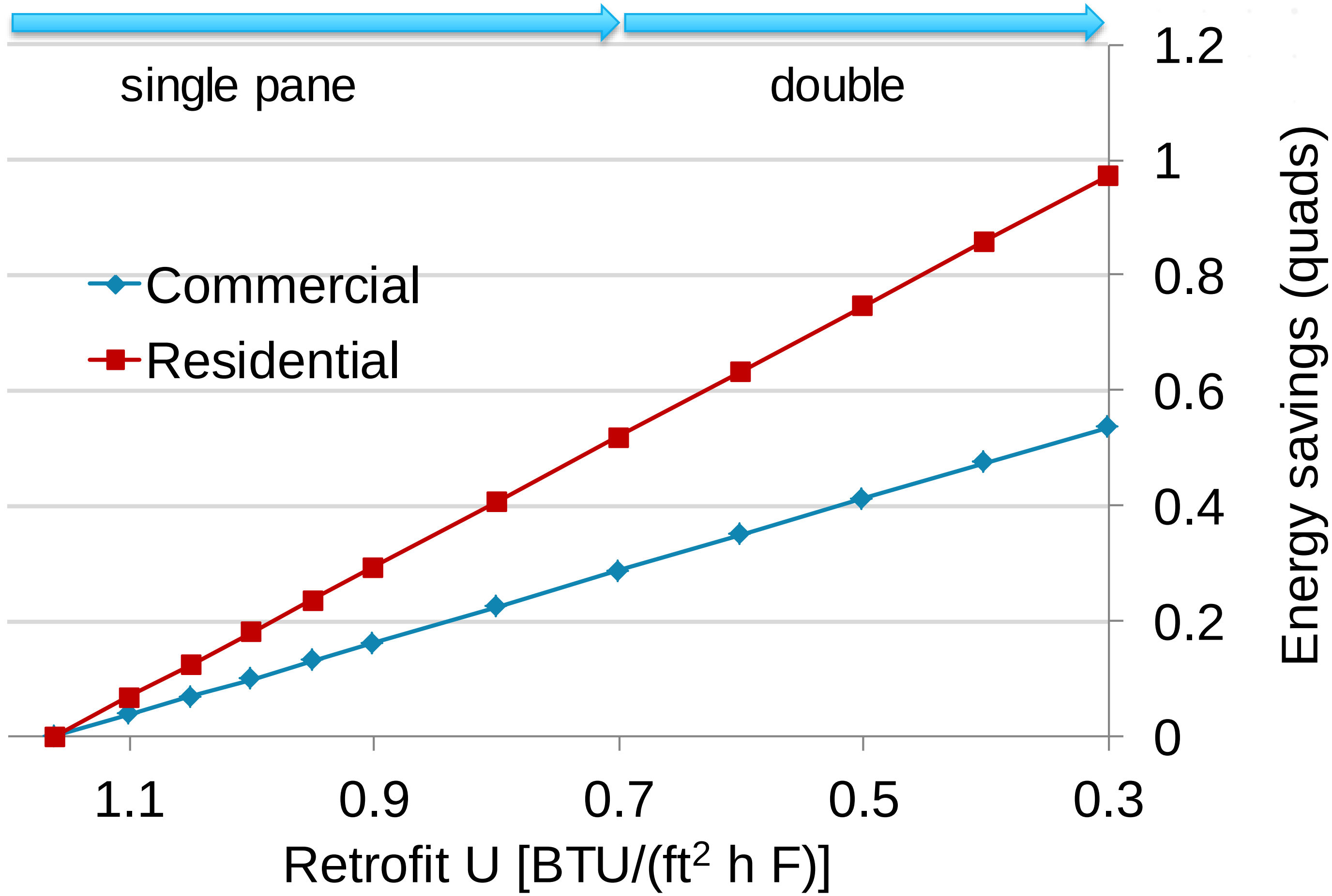
Dan Matuszak, unpublished [3]

Single panes: billions and billions of square feet



Dan Matuszak, unpublished [4]

Primary energy savings from single pane retrofitting

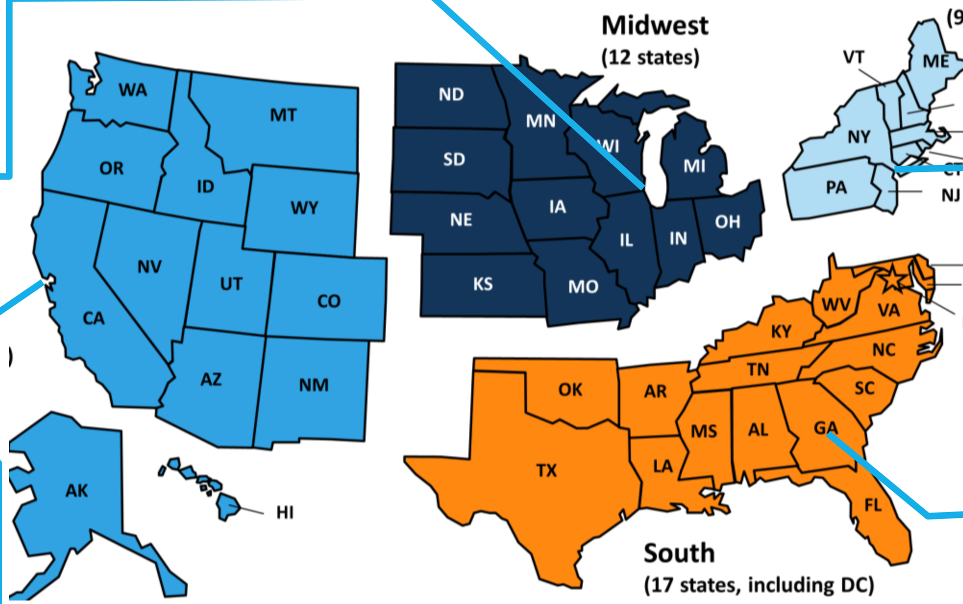


Dan Matuszak, unpublished [5], [6]

Heating cost savings from single pane retrofits

$1.90/sf/yr

$1.60 /sf/yr



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$1.10 /sf/yr

$1.40 /sf/yr

Improve single pane U = 1.15 ⟶ 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)

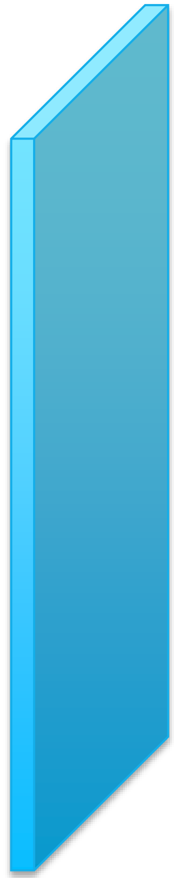
Present technologies for single-pane retrofits

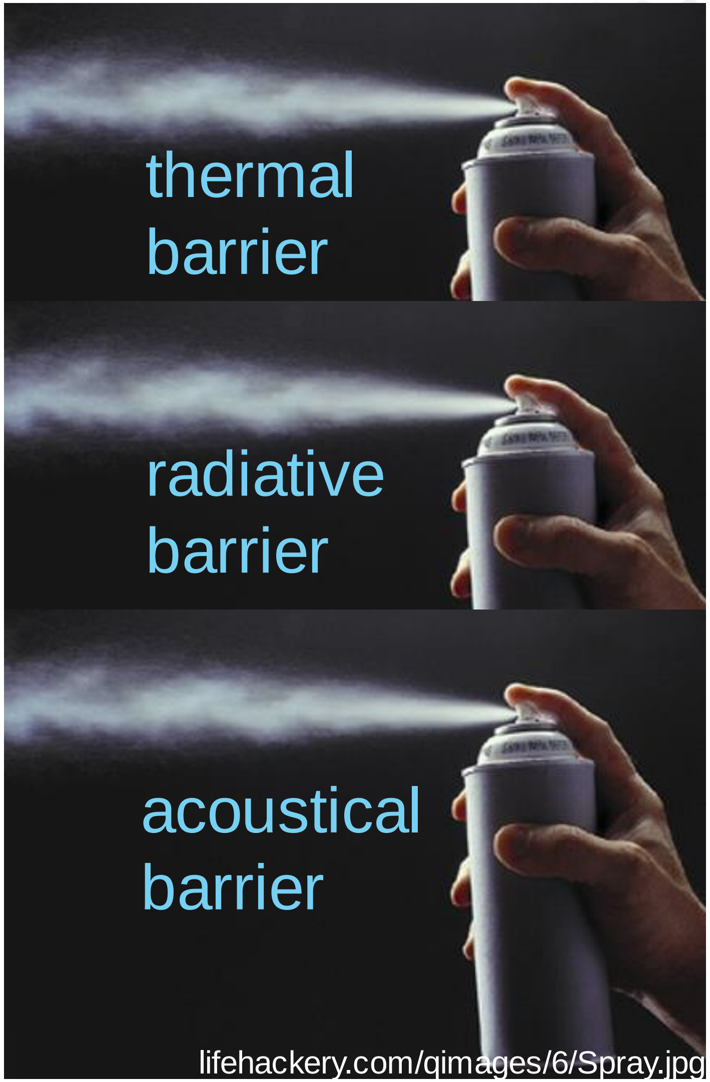
- Full replacement with modern, insulated glazing units
  – Low-e, double/triple pane, argon/krypton fill
- Add exterior storm windows (low-e)
- Add interior panels (low-e pane)
- Affix window films (solar control &/or low-e)
- Replace panes with low-e panes
- Shrink-film & tape window insulation kits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

All have limitations.

Single pane fraction >35% after decades of retrofits

The single pane window: a canvas for creativity





thumbs.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)

ARPA-E program criteria

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

- [1] Residential (Commercial) data are based on end-use consumption information within EIA RECS 2009 (CBECS 2003) and the building ensembles constructed by J. Apte and D. Arasteh in “Window-Related Energy Consumption in the US Residential and Commercial Building Stock”, LBNL-60146.
- [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].
- [4] Assumes an aggregate window area to floorspace ratio of 15%. Floorspace information obtained from EIA RECS 2009 and CBECS 2003.
- [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