Building America

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Affordable Window Retrofit Solutions

Panelists:

Katherine Cort – Pacific Northwest National Laboratory

Thomas Culp – Birch Point Consulting

Sarah Widder – Pacific Northwest National Laboratory

2015 ACI National Conference | Envelope Track | May 5, 2015 | PNNL-SA-109988

Today's Speakers

- Katherine Cort is an economist with PNNL and team lead of Building America's Window Retrofit Solutions program. She has over 15 years of experience analyzing energy-efficiency programs, technologies, and research and provides technical support for the Department of Energy's (DOE) Building Technologies Program.

- Thomas Culp is the owner of Birch Point Consulting, LLC which provides engineering and strategic consulting services in the areas of energy efficient window performance, building code development, glass performance, and glass coatings.

- Sarah Widder is an engineer with PNNL. Her work focuses on sustainable design, energy efficiency, and green house gas management. Ms. Widder is currently involved in using whole building performance metrics to analyze the impact and effectiveness of current sustainable design trends.

Key Staff and Partnerships

Pacific Northwest National Laboratory

- Katie Cort
- Sarah Widder
- Joe Petersen
- Jessie Melvin
- Jake Knox
- Graham Parker

Partners

- Thomas Culp, Birch Point Consulting
- Greg Sullivan, Efficiency Solutions
- Consortium for Energy Efficiency (CEE)
- Todd Stratmoen, Larson Manufacturing Company
- Quanta Technology
- Hunter Douglas
- Northwest Energy Efficiency Alliance, Energy Trust of Oregon

Overview of Building America

Oak Ridge National Laboratory

Pacific Northwest National Laboratory

Berkeley Lab
Lawrence Berkeley National Laboratory

Alliance for Residential Building Innovation

Home Innovation Research Labs

NREL
National Renewable Energy Laboratory

NorthernSTAR

Research Alliance

CARB
Consortium for Advanced Residential Buildings

bsc Building Science Corporation

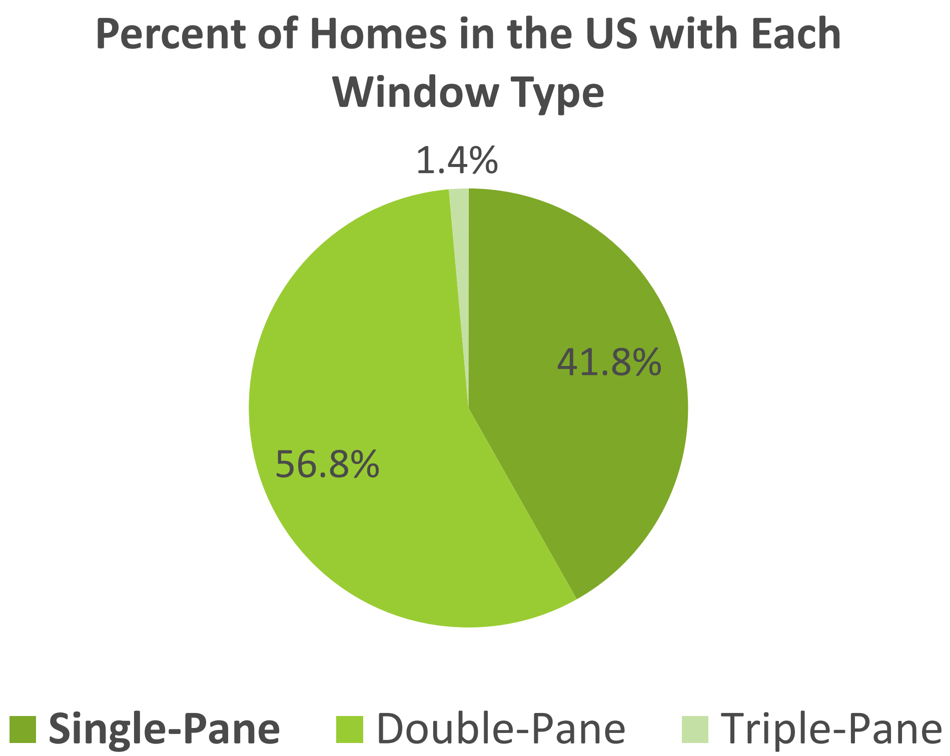
BA-PIRC

ARIES Collaborative

IBACOS®
| Home Quality + Performance |

PARR
The Partnership for Advanced Residential Retrofit

Window Retrofit Opportunities



- 19 billion ft^2 of existing windows, ~40% with single pane glass
- ~47 million homes with single glazing, another ~46 million with double pane clear[1]

[1]Cort (2013) and DOE-EIA

Window Attachments

LEGEND

- ● "Greatest benefit"
- ◐ "Moderate benefit"
- ○ "Neutral or average"
- ⊙ "Potential detriment or weak point"

	Insulation	Airtightness	Solar Heat Control	Winter Comfort	Summer Comfort	Condensation Resistance	Ventilation	Maintains View	Daylighting	Glare Control	Privacy	Low Product Cost	Low Installation Cost [9]	Durability/Service Life [10]	Adjustability	Protection for Window	Noise Control	Egress	Security
Exterior Attachments																			
Low-e storms windows	●	◐	○ [1]	●	○ [1]	◐	●	●	◐	○	○	○	○	●	◐	●	◐	○	◐
Awnings	○	○	●	○	●	○	●	◐ [2]	◐	●	○	○	⊙ [3]	◐	◐ [4]	◐	○	●	○
Roller shades	○	○	●	○	●	○	◐	○	○	◐	●	◐	◐	○	◐	◐	○	○	○
Roller shutters	◐	○	●	○	●	○	○	⊙	⊙	●	●	⊙	⊙	●	◐	●	◐	○	●
Interior Attachments																			
Conventional roller shades	○	○	◐	◐	◐	○	○	○	◐	◐	●	●	●	○	◐	○	○	○	○
Conventional drapes	○	○	◐ [5]	◐	◐	○	○	○	○	◐	●	●	●	○	◐	○	○	○	○
Louvered blinds	○	○	◐	○	◐	○	◐	◐	●	●	●	●	●	○	●	○	○	○	○
Insulated window panels	◐ [6]	◐	○ [1]	◐	○ [1]	◐	⊙	●	◐	○	○	◐ [7]	●	○	⊙	○	◐	⊙	◐
Insulated cellular shades [8]	●	◐	◐	●	◐	⊙	○	○	◐	◐	●	○	◐	◐	●	○	◐	○	○
Window quilts	●	◐	◐	●	◐	⊙	⊙	⊙	⊙	○	●	○	⊙	○	◐	○	◐	○	○
Surface-applied films	○	○	◐	○	◐	○	○	◐	◐	◐	◐	◐	◐	○	○	○	◐	●	◐
Other																			
Existing window rehab	○	◐	○	◐	○	○	●	●	◐	○	○	●	⊙	◐	●	◐	◐	◐	○
Solar Screens	○	○	●	○	◐	○	◐	⊙	⊙	◐	○	◐	●	◐	⊙	○	○	○	○
Seasonal single-use film kits	◐	●	○	◐	○	●	⊙	◐	◐	○	○	●	●	⊙	⊙	○	○	○	○

General Notes:

- Cell values often do not do justice to the *range* of product performance; see individual fact sheets for more detailed information.
- Values for adjustable attachments assume that they are optimally deployed for their strongest performance feature.

Footnotes:

1. Current low-e, *high* solar heat gain exterior storm windows and interior window panels will soon be joined by low-e, *low* solar heat gain options.
2. Fixed awnings may partially block view.
3. Fixed awnings are much less expensive than motorized retractable awnings.
4. Assumes awning is retractable.
5. Assumes drape with light-colored exterior.
6. Low-e glass and double-layer plastic panels have greatest insulation benefits.
7. Plastic fixed panels are the most affordable.
8. Assumes cellular shade is top-down/bottom-up type.
9. Many attachments can be DIY installations; only full solid circles assume DIY in this table.
10. Assumes that warranty serves as a proxy for service life/durability and that the individual values mean that a warranty corresponding to the value is available for that window attachment.

For more information visit: *www.windowattachments.org*

For more information visit: www.efficientwindowcoverings.org

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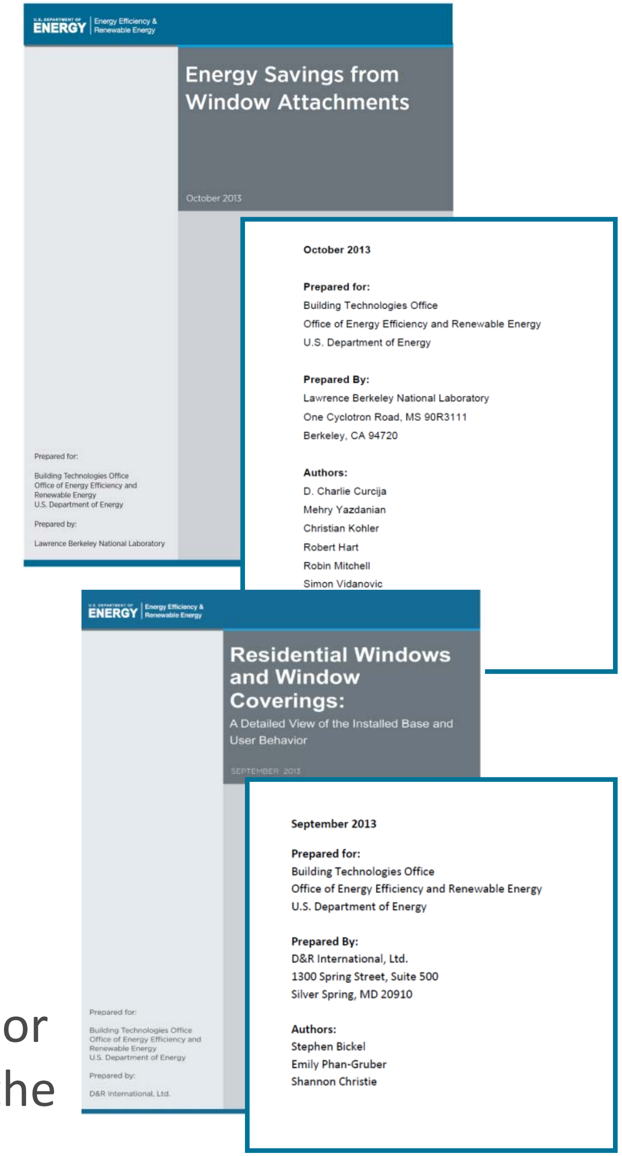
Energy Savings Potential of Window Attachment Products

- Comprehensive energy-modeling study that examined a variety of 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 climatic zones
- Operation assumptions based on DRI 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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Energy Savings from Window Attachments

October 2013

Prepared for:
Building Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy
Prepared by:
Lawrence Berkeley National Laboratory

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Residential Windows and Window Coverings:
A Detailed View of the Installed Base and User Behavior

SEPTEMBER 2013

Prepared for:
Building Technologies Office
Office of Energy Efficiency and Renewable Energy
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Prepared by:
D&R International, Ltd.

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Window Attachments Development at DOE

Development

- Emerging Technologies Program: over 10+ years, proved concept of using durable low-e coating in modern storm windows & panels in lab testing and demonstration case studies.

Implementation

- Building America Program provided detailed in-field study in side-by-side test homes and guidance. Emerging Technologies completed study of energy savings from window attachments and helped sponsor www.efficientwindowcoverings.org .

Market Transformation

- Expanding scope to examine more window attachments. Working with weatherization, energy-efficiency, and labeling programs to have benefits recognized.

The New Look of Low-E Storms: Not Your Grandmother's Storm Window

- Cost is about one quarter of the cost of full window replacement!

- Aesthetically pleasing
- Operable
- Adds comfort
- Similar energy savings to full window replacement

Images courtesy of Larson Manufacturing Company and QUANTAPANEL

Insulated Cellular Shades

- Aesthetically pleasing
- Operable
- Adds comfort and privacy
- Significant heating and cooling energy savings

Images of Hunter Douglas Duette Architella Trielle shades. Courtesy of Hunter Douglas.

Low-E Storm Windows: Concept

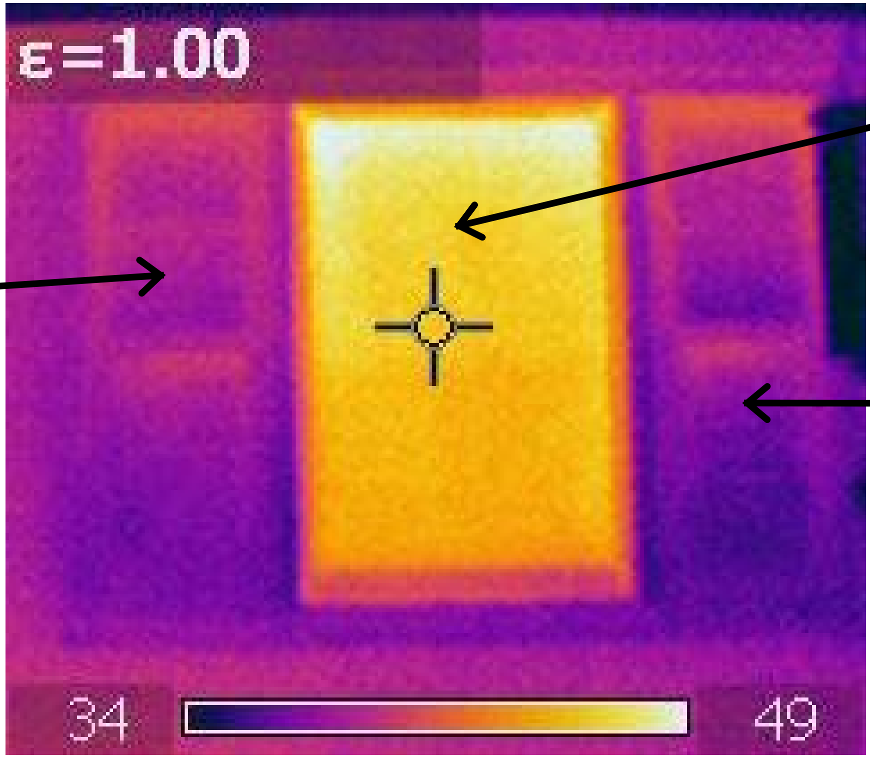
In late 90’s, LBNL suggested that low-e storm windows could be a cost effective **insulating** and **sealing** measure for existing windows:

- 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: Low-E Glass
  - 35% increased performance over clear glass

Low-E Storm Windows: Concept

- IR field images show obvious improvement in reduced heat loss:

With Low-E Storm Window

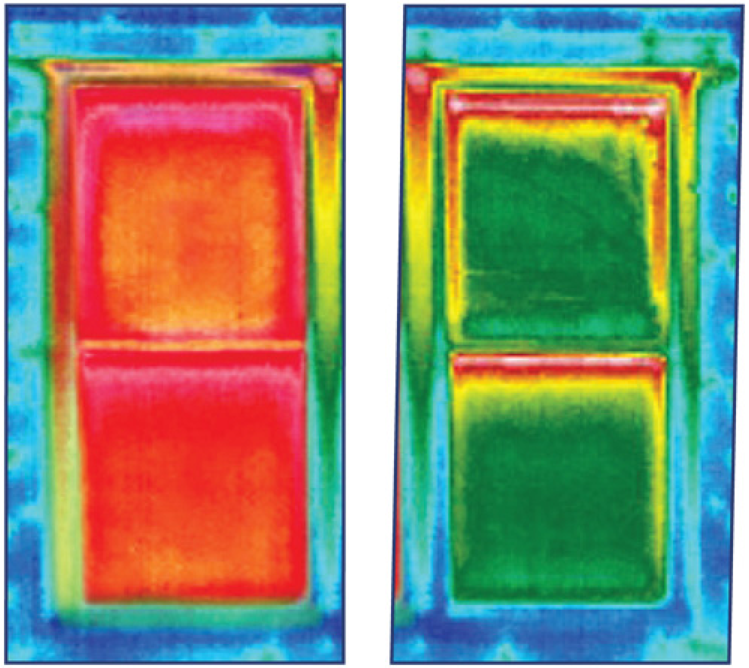


Original single pane window

With Low-E Storm Window

Image taken from the exterior.
Light colors show heat loss.

Insulated Cellular Shades: Concept



No window covering

Duette® Architella™ honeycomb shades

Heating Savings

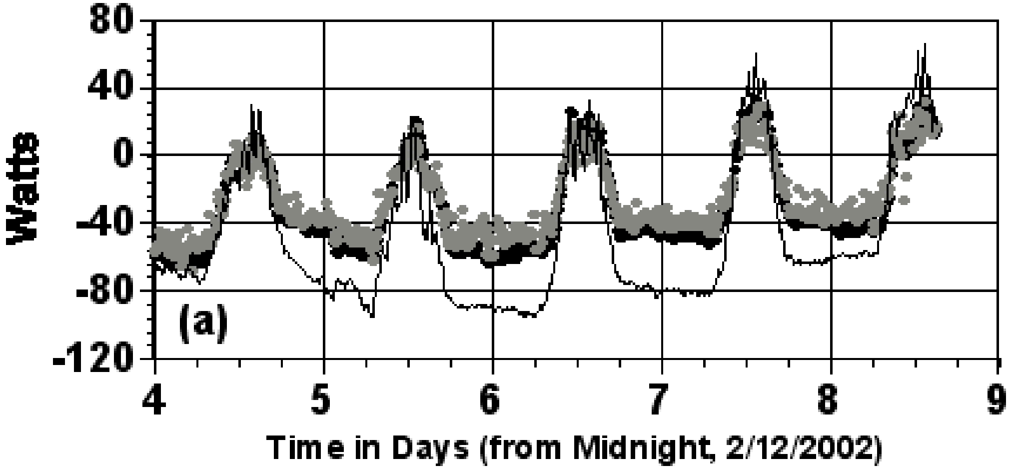
- Approximately half of a home's heating energy goes out the window
- Energy-efficient window coverings can reduce heat loss through windows by 40% or more
- Equates to 20% heating energy cost savings
- Assumes proper operation

Cooling Savings

- With standard double-pane windows, approximately 76% of incident sunlight enters the windows to become heat
- Energy-efficient window coverings can reduce this to 15% or less

Initial Testing Low-e Storm Window

- 2000-2002: side-by-side testing in LBNL's MoWITT facility.
- Demonstrated low-e storm window + primary window performed same as new double-pane low-e replacement window.[1]

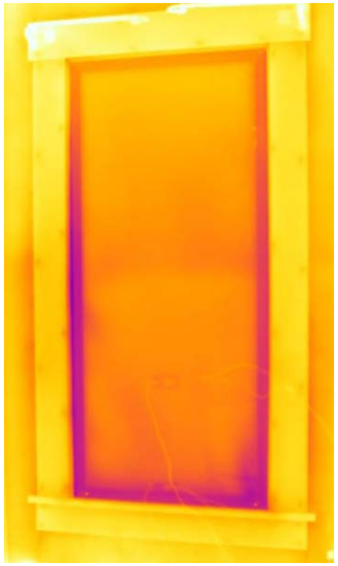


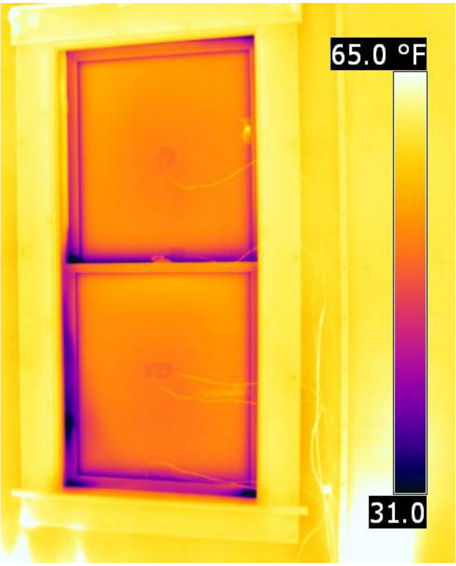
[1] Klems, 2003

IR Imaging with LBNL, Building Green

- Interior low-e storm panel showed comparable performance as replacement sashes with low-e + argon
- Improvement from low-e glass and very good air tightness

interior low-e panel over "vintage" single-pane wood frame window





Single-pane replaced with dual glazed low-e + argon sash inserts

Vermont winter night. Image taken from the interior. Dark colors show heat loss.

P. Yost, Building Green; H. Goudy and D.C. Curcija, LBNL

Demonstration Case Studies

2003-2006 Chicago field study

(DOE, HUD, NAHB Research Center, LBNL)[1]

- Energy monitoring on 6 weatherization homes with single glazing
- Reduced heating load of the home by 21%
- Simple payback of 4.5 years
- Overall home air infiltration reduced by 6-8% (15 cfm_{50} reduction per window)

[1] Drumheller, 2007

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Demonstration Case Studies

2011-13 Atlanta field study

(NAHB Research Center, Larson Manufacturing, QUANTAPANEL)[1]

- 10 older homes with single glazing
- Approx 15% heating savings, 2-30% cooling savings (large variability)
- Overall home air leakage reduced by 17% (3.7 ACH50)
- Occupants ranked other benefits:
  - improved home appearance
  - reduced drafts
  - improved comfort
  - reduced noise

[1] Culp et al, 2013

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Demonstration Case Studies

2012-13 Philadelphia multifamily field study

(NAHB Research Center, QUANTAPANEL, Larson Manufacturing)[1]

- Two large 3-story apartment buildings (101 apartments)
- Replaced old clear storm windows over single glazing with new low-E storm windows
- 18-22% reduced heating energy use
- 9% reduced cooling energy use
- Apartment air leakage reduced by 10%

[1] Culp et al, 2013

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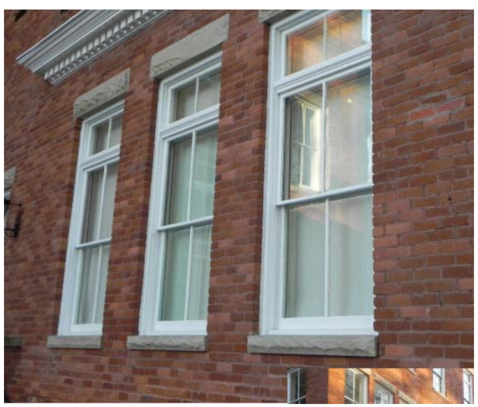
Real World Examples



Photos courtesy of QUANTAPANEL

Application - Weatherization

- 2009: Ability to include low-E storm windows added to NEAT / Weatherization Assistant software
- 2010: With DOE support, low-E storm windows added to Pennsylvania's Weatherization Measure Priority List for single-family homes[1]
  - NEAT analysis for 37 home types in 4 cities
  - SIR 1.4-2.2 over single pane windows
  - SIR 1.3-2.1 over metal-framed dual pane windows
  - SIR much higher when using propane fuel

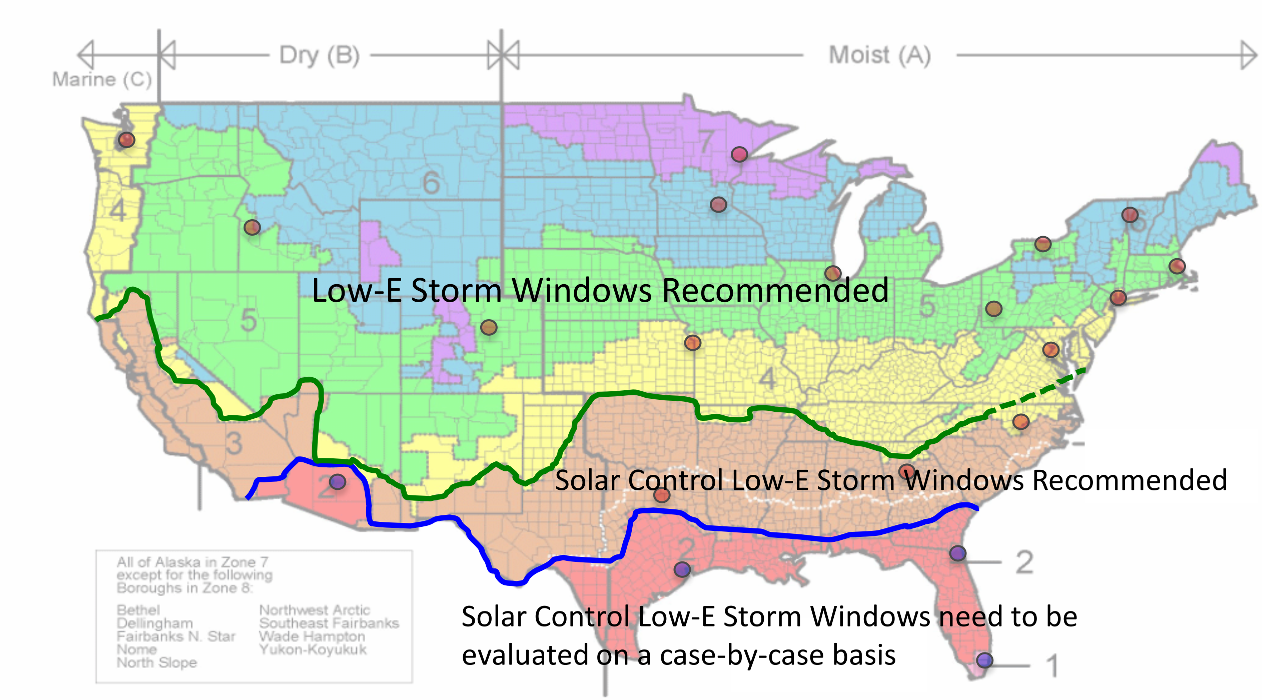
SIR = Savings-to-Investment Ratio. Must be > 1 to qualify.

[1] Zalis et al, 2010

Application - Weatherization

Expanded NEAT analysis to 22 cities across all 8 climate zones.[1]

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



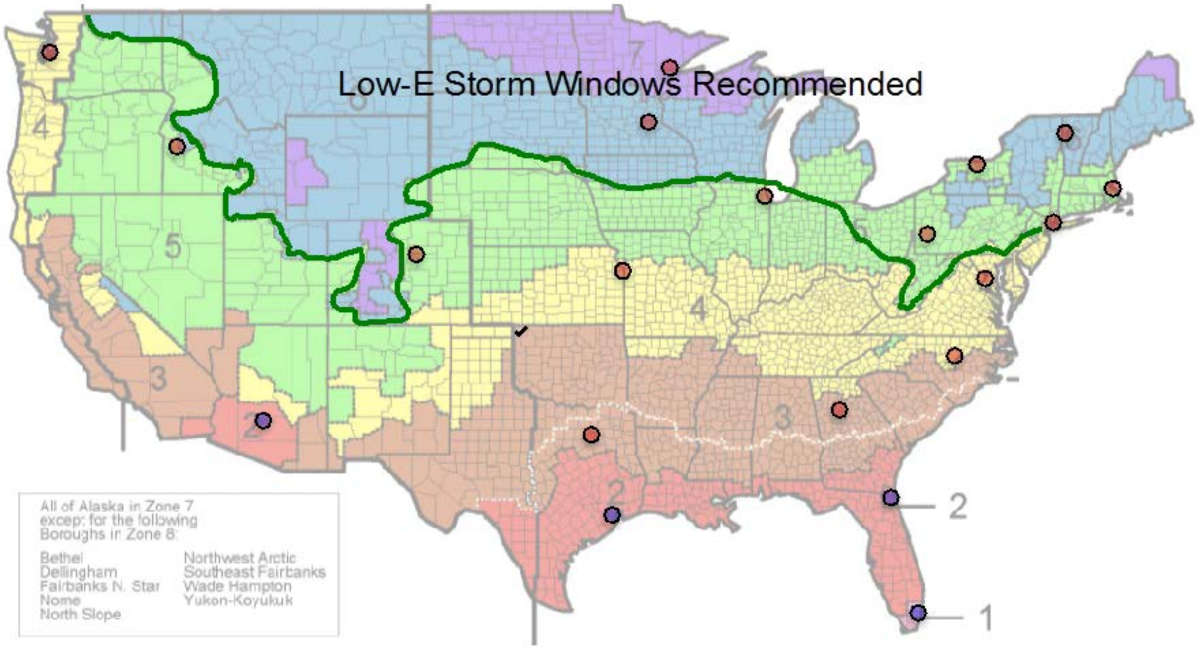
Cost effective in climate zones 3-8 with SIR 1.2 – 3.2

[1] Culp, et. al. 2014

Application - Weatherization

Expanded NEAT analysis to 22 cities across all 8 climate zones.[1]

Over double-pane wood or vinyl-framed windows:



Cost effective in climate zones 6-8 and eastern part of zone 5 with SIR 1.1 – 1.9.

Recommended over even larger range with propane or electrical resistance heat.

[1] Culp, et. al., 2014

Code Compliance: Low-e Storm Windows

- What are the code requirements?
  - Storm windows are already exempted from the energy code.
  - Generally, structural, wind load, and fire resistance requirements are met by the primary window.
  - Check if any storm windows will be in hazardous locations defined by the building code (e.g. interior panels near a bathtub) that require tempered safety glazing.
- Do I have to file for a permit?
  - Generally, most jurisdictions will not require a permit to install low-e storm windows, but always check with the local building department.
- Should I check with my homeowners association before installing?
  - Yes, just like any other modifications to the exterior of the home.
  - They should approve if looking at modern low-e storm windows.
    In fact, low-e storm windows are often preferred in historic preservation over replacement windows.
  - Can also consider interior panels.

Code Compliance: Window Coverings/Attachments

- Are there code compliance issues related to other window attachments?
- Generally not for interior blinds, shades.
- For exterior attachments (rolling shutters, sun screens, etc.):
  - Check whether a permit is required, or if there are special requirements. (e.g. rolling shutters may have certain requirements regarding attachment.)
  - Check for approval by homeowners association or for historic applications.

PNNL Lab Homes Field Testing

LAB HOMES

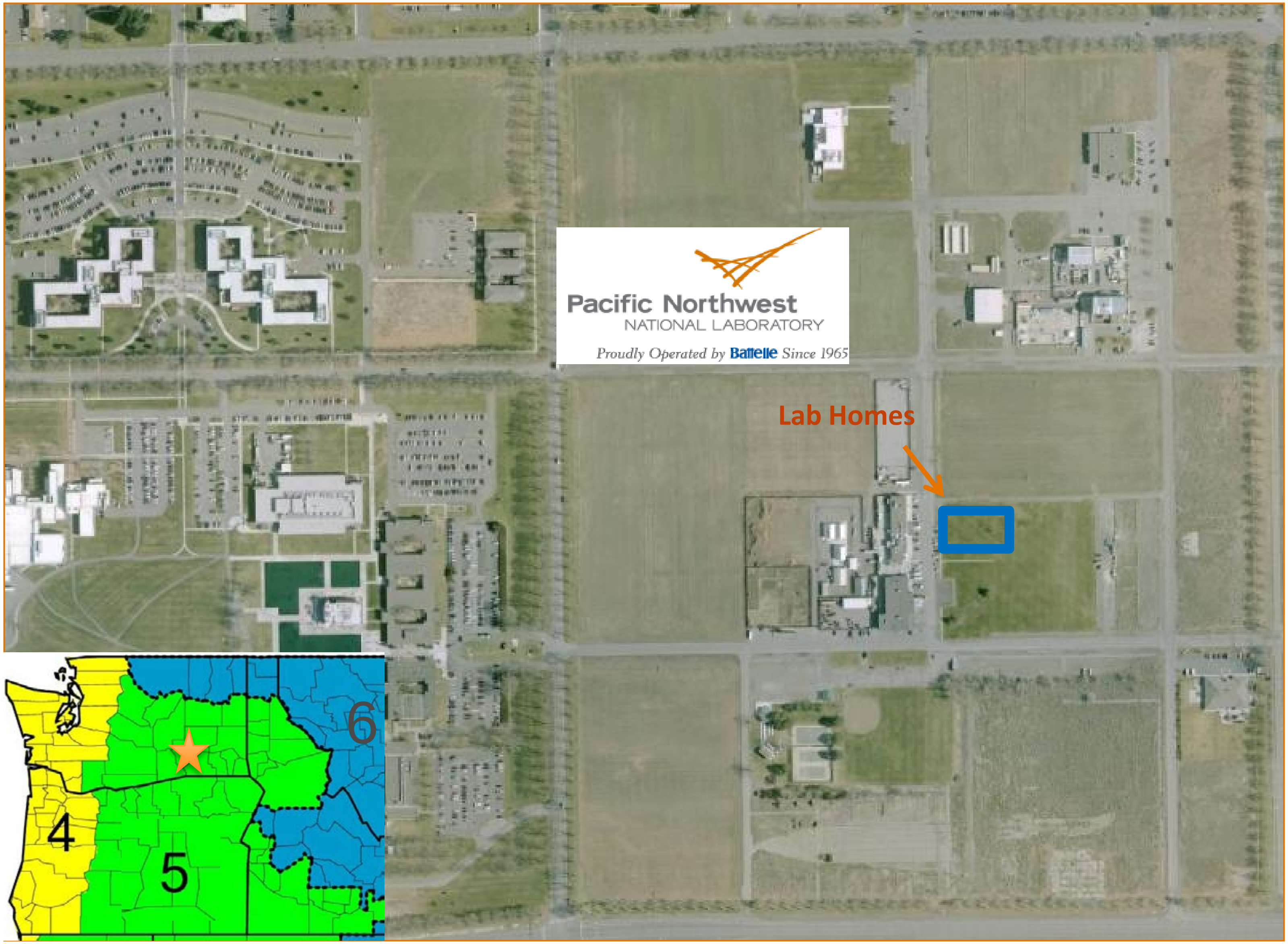
Demonstrating tomorrow's efficient and smart technologies.

Side-by-side simulated field environment provides a unique platform for efficiently and cost-effectively demonstrating new energy-efficient and grid-responsive technologies.

Lab Homes Partners

- Initial Partners
  - DOE/BTO/Building America-ARRA
  - DOE/BT/Windows and Envelope R&D
  - Bonneville Power Administration
  - DOE/OE
  - PNNL Facilities
  - Tri Cities Research District
  - City of Richland
  - Northwest Energy Works
  - WSU-Extension Energy Program
  - Battelle Memorial Institute (made land available)

Sited Within the Tri-Cities Research District in Richland, WA



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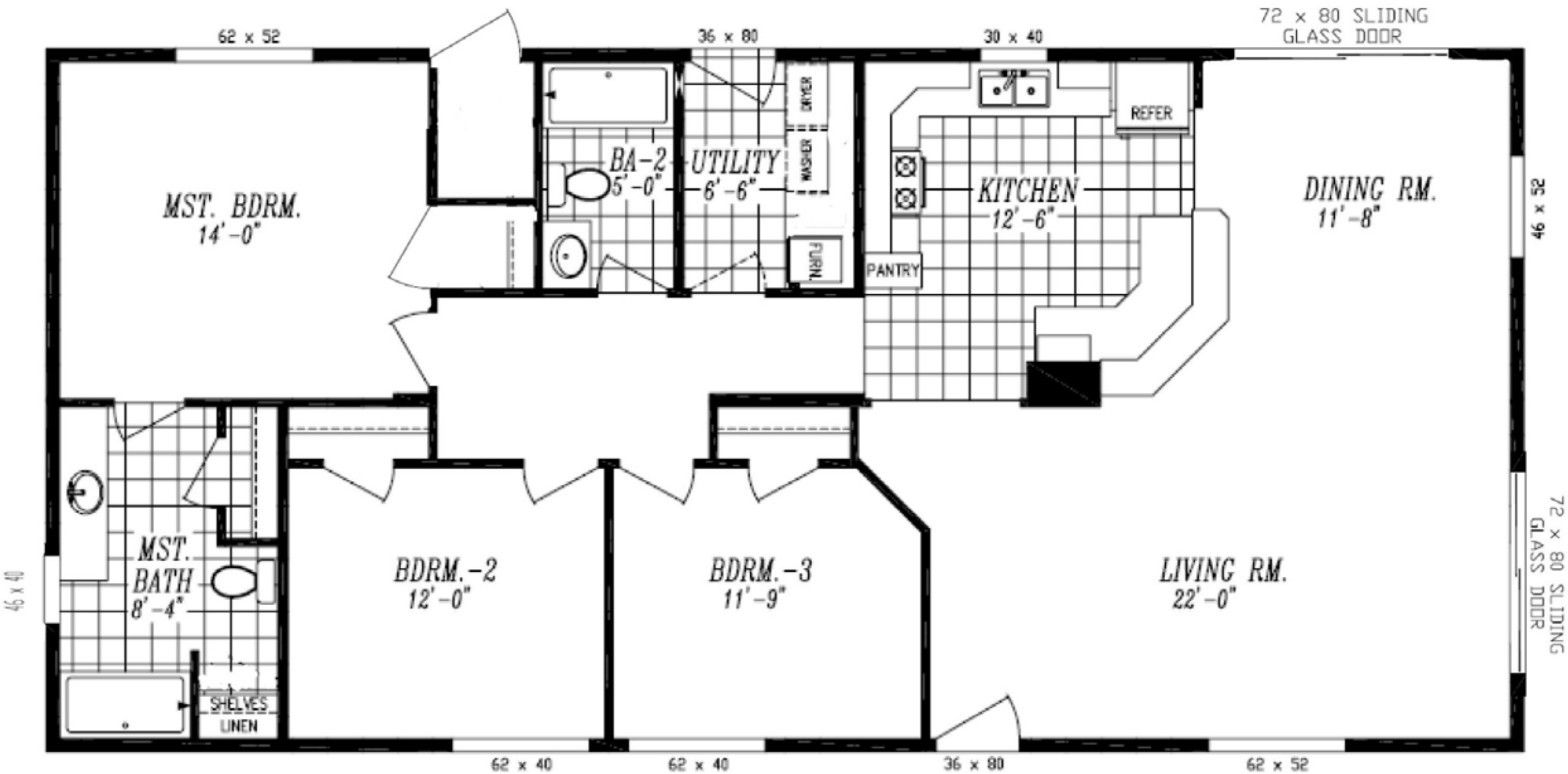
Lab Homes Characteristics

- Specified to represent existing manufactured and stick-built housing
  - 3 BR/2BA 1493-ft2 double-wide, factory-built to HUD code.
  - 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% of floor) window area**
  - Wood siding
  - Incandescent lighting
  - Bath, kitchen, whole-house exhaust fans
  - Carpet + vinyl flooring
  - Refrigerator/range/washer/dryer/dishwasher
  - All electric

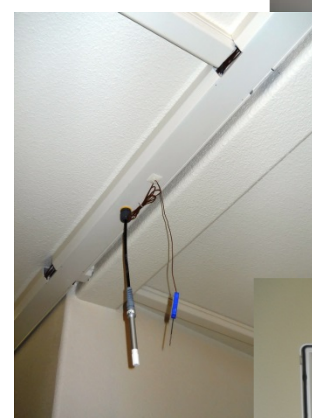
- Modifications include end-use metering, sensors, weather station, and three electric vehicles charging stations

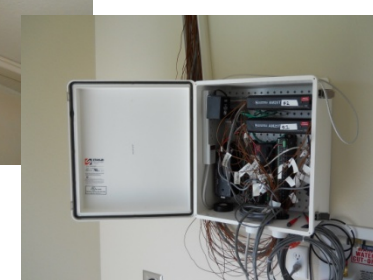
Lab Homes Floor Plan



Metering and Monitoring

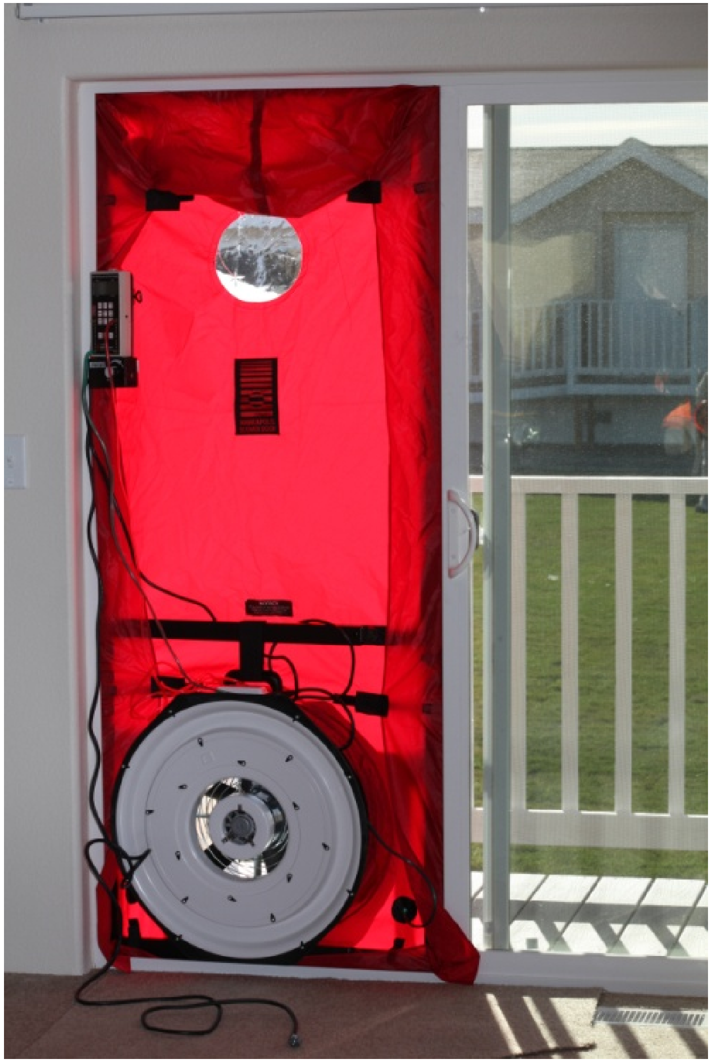
- Energy metering
  - 42 individually monitored breakers with ½ controllable and whole house
  - Itron smart billing meter
- Temperature and relative humidity
  - 15 interior room temperature thermocouples
  - 22 interior and exterior glass surface temperature thermocouples
  - 2 room relative humidity sensors
  - 2 mean radiant temperature sensors
- Water and environment
  - Controllable water flows at fixtures
  - Solar insolation (pyranometer) inside home
  - Site weather station
- Data collection via 2 Campbell Scientific data loggers/home
  - 1 minute, 15 minute, and hourly





Initial Null Testing

- Initial building construction comparison
  - Homes' air leakage (CFM air flow @50Pa) was within 6.2%
  - Homes' duct leakage (CFM air flow @50Pa) was within 2%, similar distribution performance
  - Heat pumps demonstrated similar ΔT across coil and air handler flows within 6%
  - Ventilation fans' flows within 2.5%
- Experimental baseline testing
  - Occurs prior to each experiment to verify similar performance
  - Include blower door and energy use comparison



Window Characteristics

- Baseline primary windows in each home is a double pane, clear glass window with an aluminum frame.

	Baseline Windows		Baseline Windows with Low-E Storms[1]		Highly Insulating Windows[2]	
	Windows	Patio Doors	Windows	Patio Doors	Windows	Patio Doors
U-factor	0.68	0.66	0.33	0.32	0.20	0.20
SHGC	0.7	0.66	0.53	0.50	0.19	0.19
VT	0.73	0.71	0.61	0.59	0.36	0.37

[1] Culp et al, 2013. *Low-E Retrofit Demonstration and Education Program*. Final Report, U.S. DOE project #DE-E E0004015, Quanta Technologies, Malvern, Pennsylvania.
[2] Widder et al, 2012. *Side-by-Side Field Evaluation of Highly Insulating Windows in the PNNL Lab Homes*. PNNL-21678, Pacific Northwest National Laboratory, Richland, WA.

Whole House Energy Savings

- Average savings from low-E storm windows of 10% annually, compared to 12% for triple-pane primary windows.

Experimental Period	Operating Scenario	Average Daily Energy Savings	Average Energy Savings (%)
Summer Cooling Season	With Storm Windows in Lab Home B	3,623 ± 349 Wh	8.0 ± 0.5
Winter Heating Season	With Storm Windows in Lab Home B	14,251 ± 2,720 Wh	10.5 ± 1.2
Estimated Annual Results	With Storm Windows in Lab Home B	2,216 ± 31 kWh	10.1 ± 1.4
Estimated Annual R-5 Results[3]	*With R-5 Windows in Lab Home B*	*1,784 ± 189 kWh*	*12.2 ± 1.3*

[3] Widder et al, 2012. *Side-by-Side Field Evaluation of Highly Insulating Windows in the PNNL Lab Homes*. PNNL-21678, Pacific Northwest National Laboratory, Richland, WA.

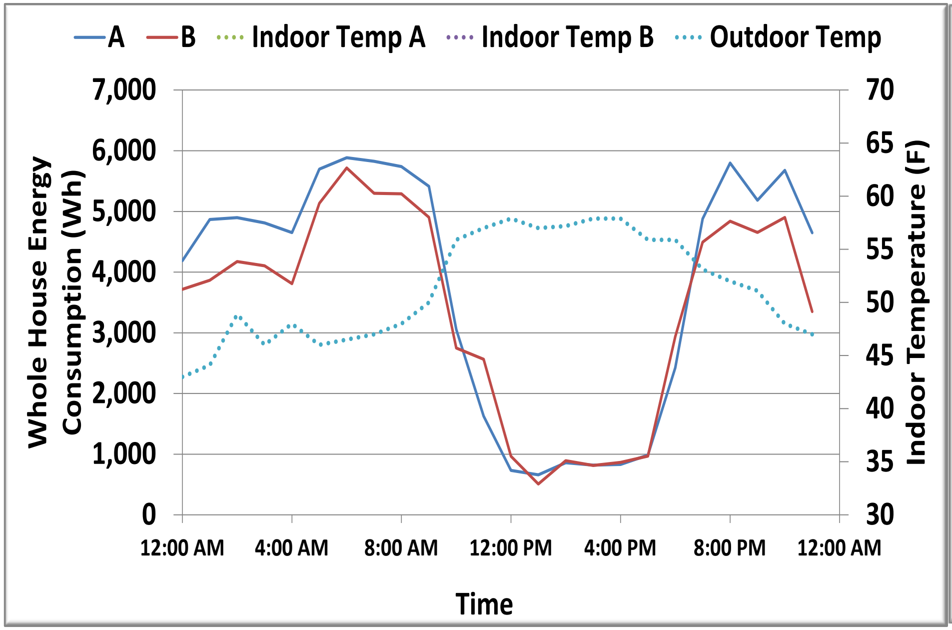
Air Leakage

- Low-E storm windows can improve air leakage
  - Lab Homes primary windows are fairly tight windows, so primary window was still primary air barrier

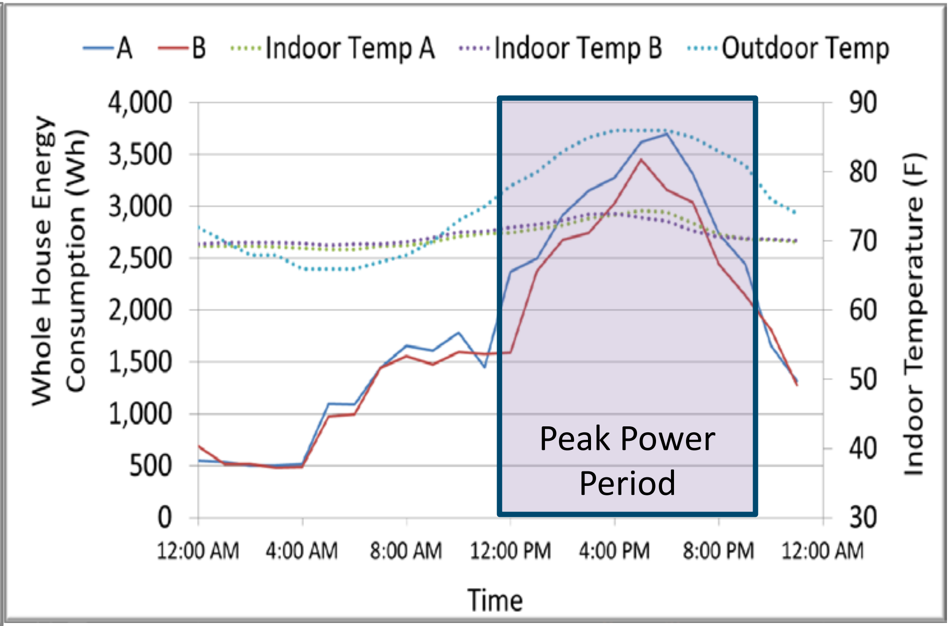
Lab Home	Primary Window	Storm Window	Bottom Edge of Storm Window	Average Value (cfm50)
A	**Closed*	*N/A*	*N/A*	*789.7 ± 25.7*
B	Closed	Closed	Unsealed	803.1 ± 29.3
B	Closed	Open	Unsealed	842.0 ± 31.4
B	Open	Closed	Unsealed	1,445.9 ± 58.9
B	Closed	Closed	Sealed	841.8 ± 41.9
B	Open	Closed	Sealed	1,316.3 ± 58.4

Peak Energy Use

- Cooling season energy savings coincident with peak power period
  - Average of 11.2% peak load savings



Whole-House Energy Consumption on Cold, Sunny Winter Day



Whole-House Energy Consumption on Hot, Sunny Summer Day

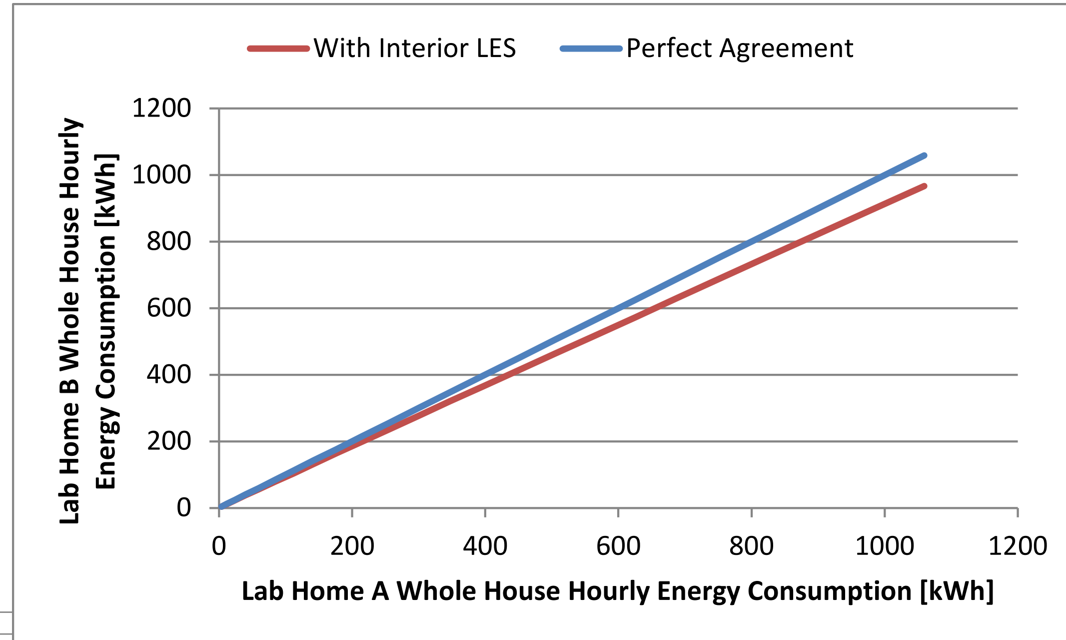
Cost-Effectiveness Calculations

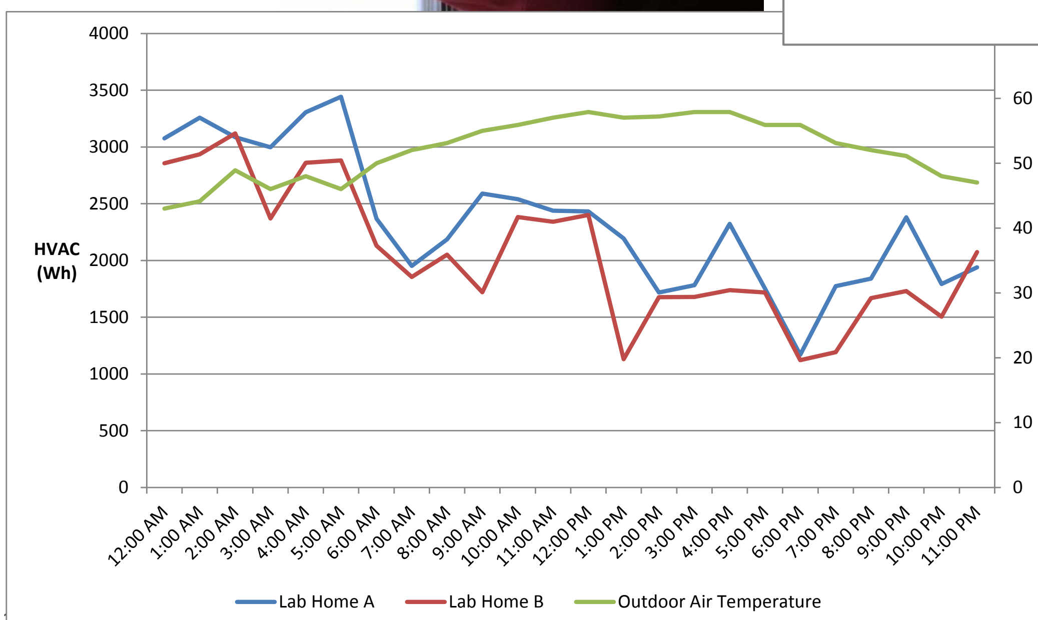
- Low-E storm windows are a cost-effective fenestration retrofit solution when window replacement is not an option
  - Demonstrated payback period of 5-7 years in Lab Homes experiment

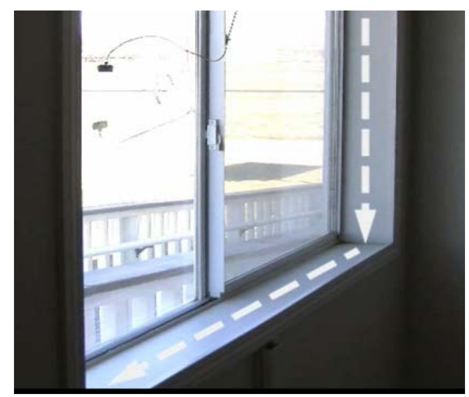
Cost Estimate	Cost ($/sf)	Total Cost	Annual Savings	Simple Payback (Years)
Low	6.91	$1,354	$269	5.0
Medium	8.30	$1,627	$269	6.1
High	9.69	$1,900	$269	7.1
R-5 Windows[4]	*34*	*$6,700*	*$325*	*20.5*

[4] Widder et al, 2012. *Side-by-Side Field Evaluation of Highly Insulating Windows in the PNNL Lab Homes*. PNNL-21678, Pacific Northwest National Laboratory, Richland, WA.

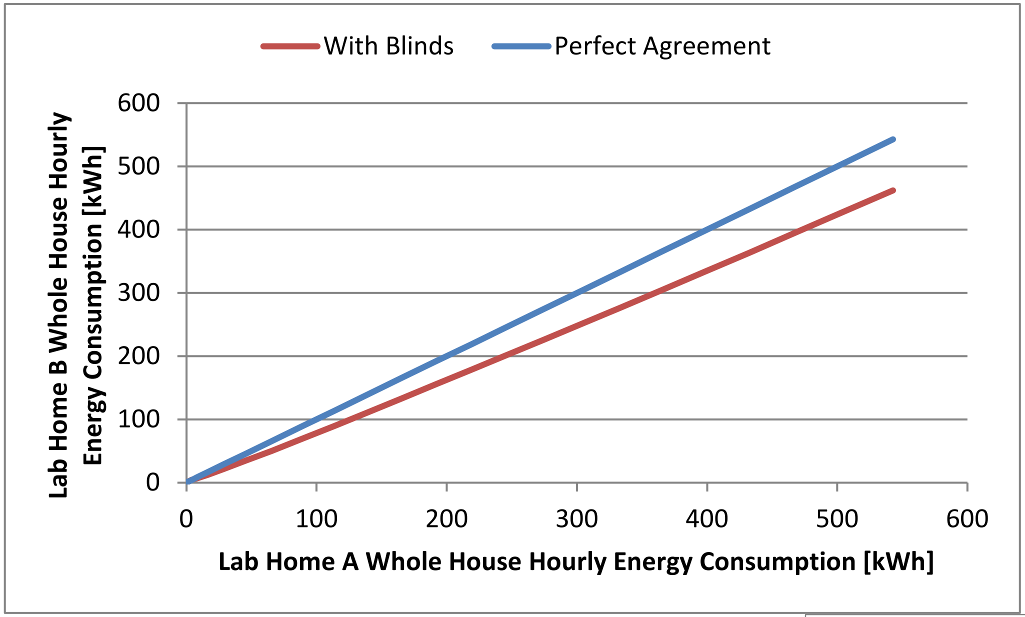
Interior Low-e Panels: Preliminary Heating Season Data

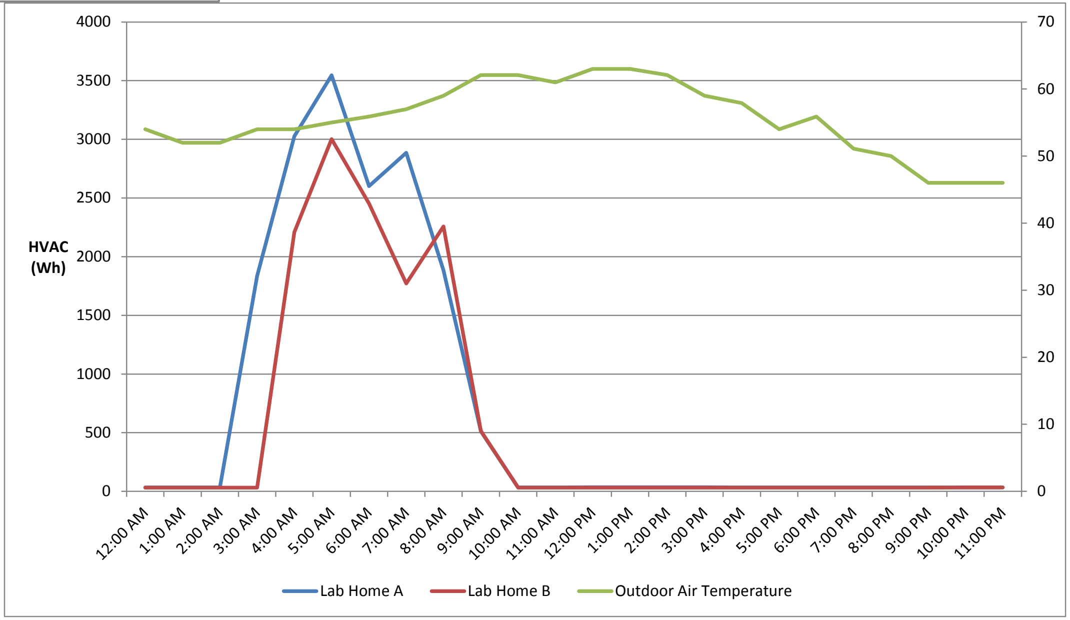




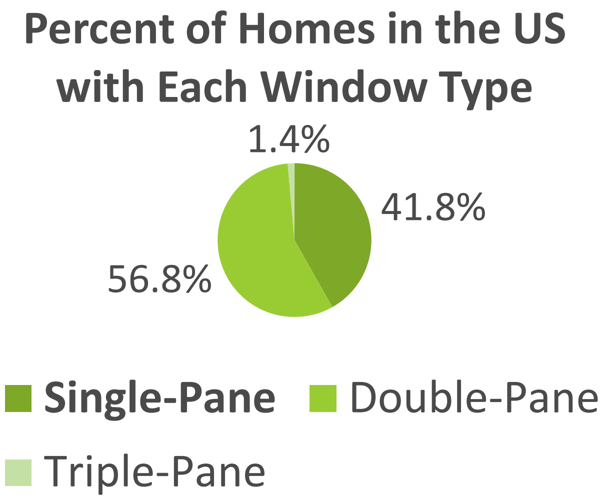


Insulating Cellular Shades: Preliminary Heating Season Data





Window Attachments: Market Assessment



Opportunity

- Window Attachments can offer affordable solution to insulating and air sealing existing windows
- Applicable to existing homes and buildings
- Meets savings-to-investment ratio payback threshold for most weatherization and utility programs
- Easy installation

An Installation Guide to Low-e Storm Windows

- Video Available

Building America's Market Transformation

Market Transformation Progress

- Validate benefits, fill in data gaps
- Identify avenues for market transformation
- Begin developing networks and strategies
- Tailor building models to reach core customers

1. Lab Homes Research
2. Climate-Based Model Analysis
3. Market Assessment
4. Outreach
5. Rating Council (AERC) Support

Market Assessment

Barrier	Strategy/Pathway to Overcoming Barriers
Identity Crisis	CEE, Weatherization programs, Utilities, Codes and rating organizations
Stigma (storm windows)	Utilities, CEE, WAP, and Federal agencies
Not recognized by rating systems	Codes and rating organizations: AERC, Building America's CSI team, ENERGY STAR (EPA/DOE), BEOPT, Home Energy Score (DOE)
Do-it-yourself (or not)	Weatherization programs, Home Performance with ENERGY STAR, Federal Energy Management Program (FEMP)
Permanence and Persistence (utility programs)	Utilities, CEE, follow-up on field studies (e.g., Chicago study follow-up)
Industry structure	No specific strategy identified

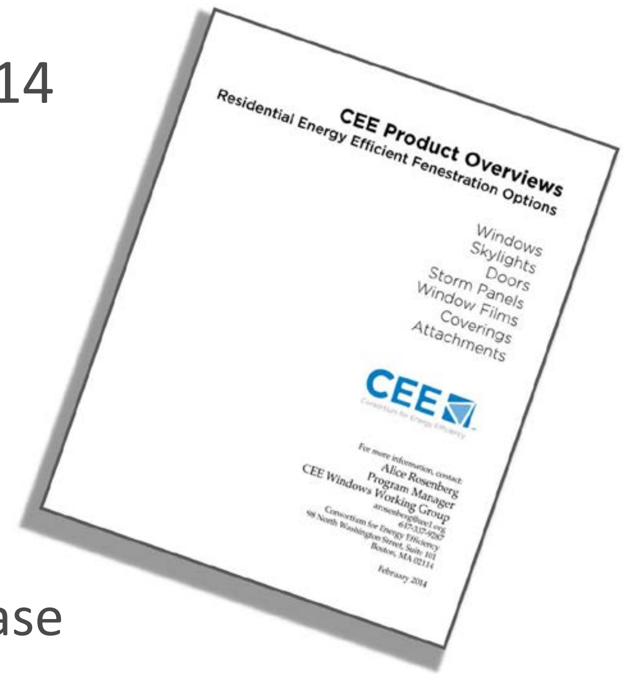
Market Assessment: Key Findings

Market Transformation Pathways Identified

Sales Force: Stakeholders w/Business Interest to Promote Research	→	**Core Customers of Research and Deployment:**	→	**End Customers of Research and Deployment:**
Window Attachment Manufacturers		**Weatherization Programs**		**Private Homeowners/ Occupants (Not Low-Income)**
Installers/Home Performance Contractors		**Utilities**		**Multifamily owners**
Energy-Efficiency Consortiums/ Associations		**Distributors/ Retailers**		**Low-Income Homes and Public Housing**
BA Teams/ BB Teams/CBI Teams		**Federal Agencies Managing Residential Stock**		**Federally Owned Residential Stock**
Federal Energy Management Program (FEMP)		**Standards and Rating Organization (e.g., Energy Star)**		**Applicable Commercial (Small Buildings, Lodging, Nursing Homes, Dormitories)**

Addressing Market Barriers – Consortium for Energy Efficiency

- Windows working group of CEE members (energy efficiency program administrators) and industry stakeholders is working to advance the uptake of efficient fenestration products and practices across the US and Canada
- CEE Window Product Overviews — Feb, 2014
  - Developed from 2010-2014
  - Resource for EE Program Managers
  - Vetted through consensus process
- Subgroup Projects — Current
  - Window Attachments Subgroup
  - Summary Resource Table and Inputs Database


CEE Product Overviews
Residential Energy Efficient Fenestration Options
Windows
Skylights
Doors
Storm Panels
Window Films
Coverings
Attachments
CEE
For more information, contact:
Alice Rosenberg
Program Manager
CEE Windows Working Group
Consortium for Energy Efficiency
98 North Washington Street, Suite 101
Boston, MA 02114
February 2014

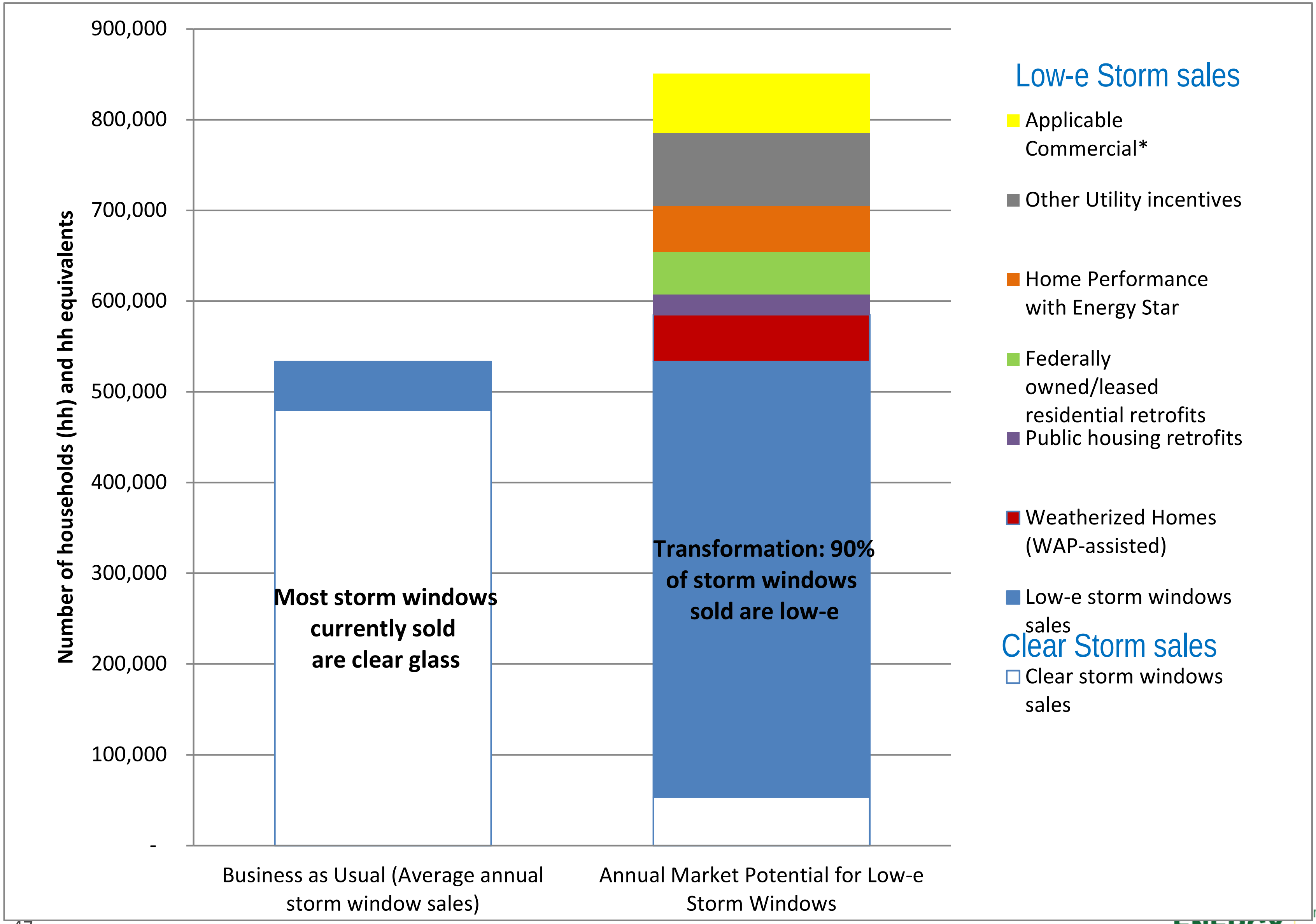
Addressing Market Barriers

- Low-e storm windows integrated in FEDS model (supports most Federal building energy audits). BEOPT next.
- Supporting DOE's Attachment Energy Rating Council (AERC) effort to help develop fenestration attachment rating system.
- Working with CEE to develop tools and resources related to efficient window attachments for energy-efficiency programs.
- Working directly with utility and weatherization programs to provide technical assistance.

Remaining Research Questions

- Operation and Automation
  - Optimal operation? Likely operation? Value of automation?
- Optimizing Return on Investment
  - Minimizing costs while maximizing benefits
- Combinations of Attachments
- Assessing Durability and any Unintended Consequences and
  - Impacts of heat build-up
  - Condensation

Market Potential



Thank you!

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Time for Q&A

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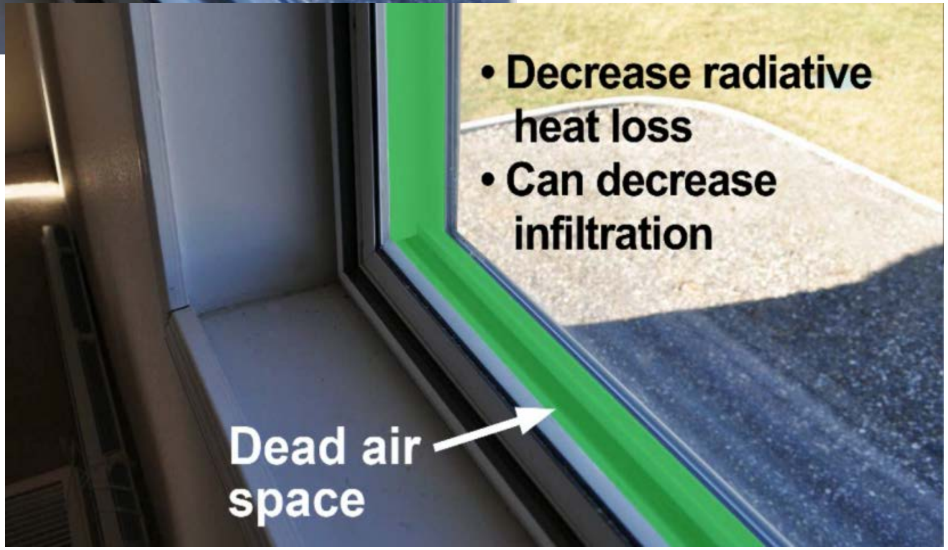
****************Extra Slides*****************

How Low-e Storms Save Energy



Materials Needed

Caulking Gun

Caulk

Putty Knife

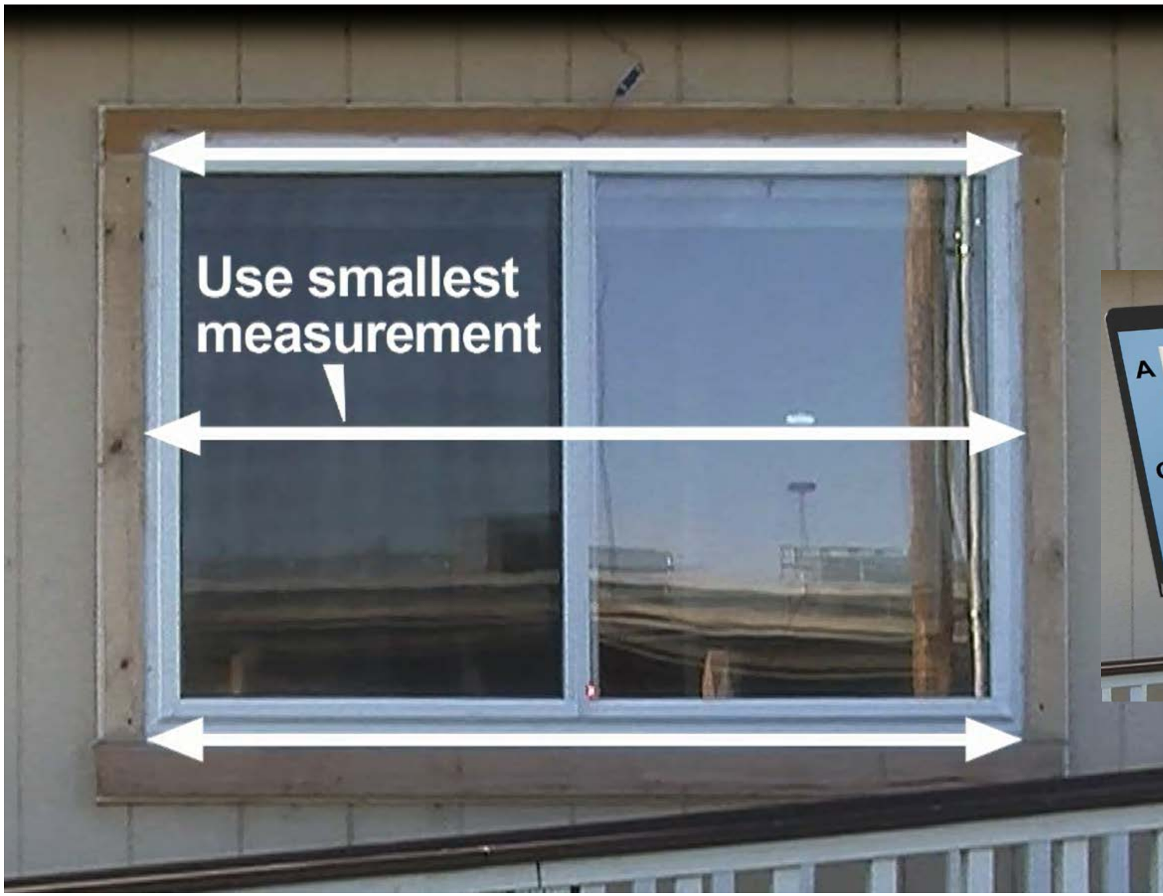
Putty Knife

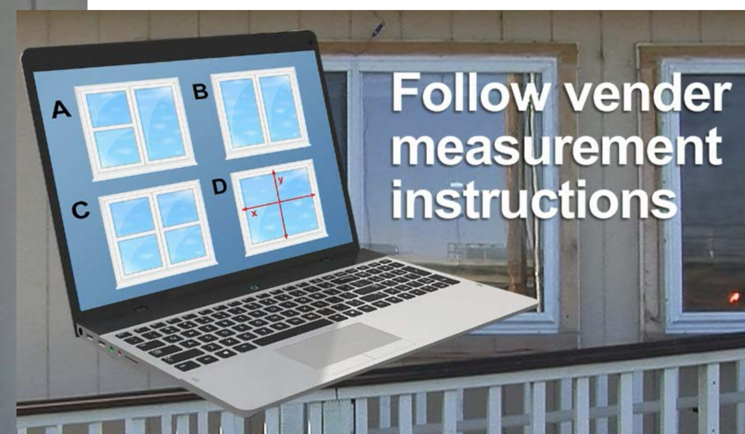
Screw Driver

Measuring Tape

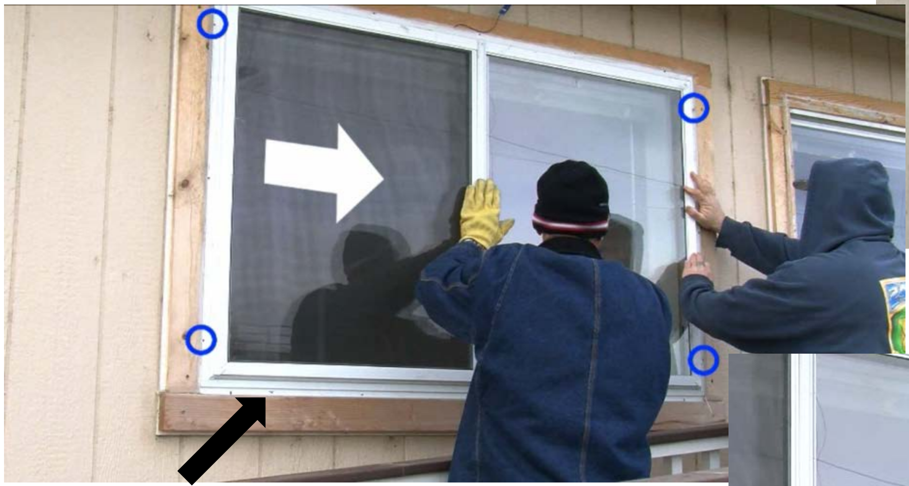
Step 1: Measuring

Measure, Measure, Measure





External Installation



Weep Holes

Permanent Year-Round Installation

Interior Installation

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More Installation Information

- Video instructions for low-e storm window installation found at: http://youtu.be/DeU6wn0psrU.
- More detailed instructions also found on Building America Solutions Center: https://basc.pnnl.gov/resource-guides/
- Product overviews and information about window coverings: http://www.efficientwindowcoverings.org/