Building America

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

Low-E Storms: The Next "Big Thing" in Window Retrofits

Moderator:
Pam Cole – Pacific Northwest National Laboratory

Panelists:
Thomas Culp – Birch Point Consulting
Sarah Widder – Pacific Northwest National Laboratory

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Pam Cole, Research Scientist, Pacific Northwest National Laboratory

Pam Cole focuses on adoption and compliance of building energy codes work at PNNL. Ms. Cole is currently involved in Building America's efforts to resolve codes and standards barriers to innovations. She manages the Building Energy Codes Program technical support, addressing questions throughout the U.S. regarding compliance with residential and commercial national energy codes.

Overview of Building America

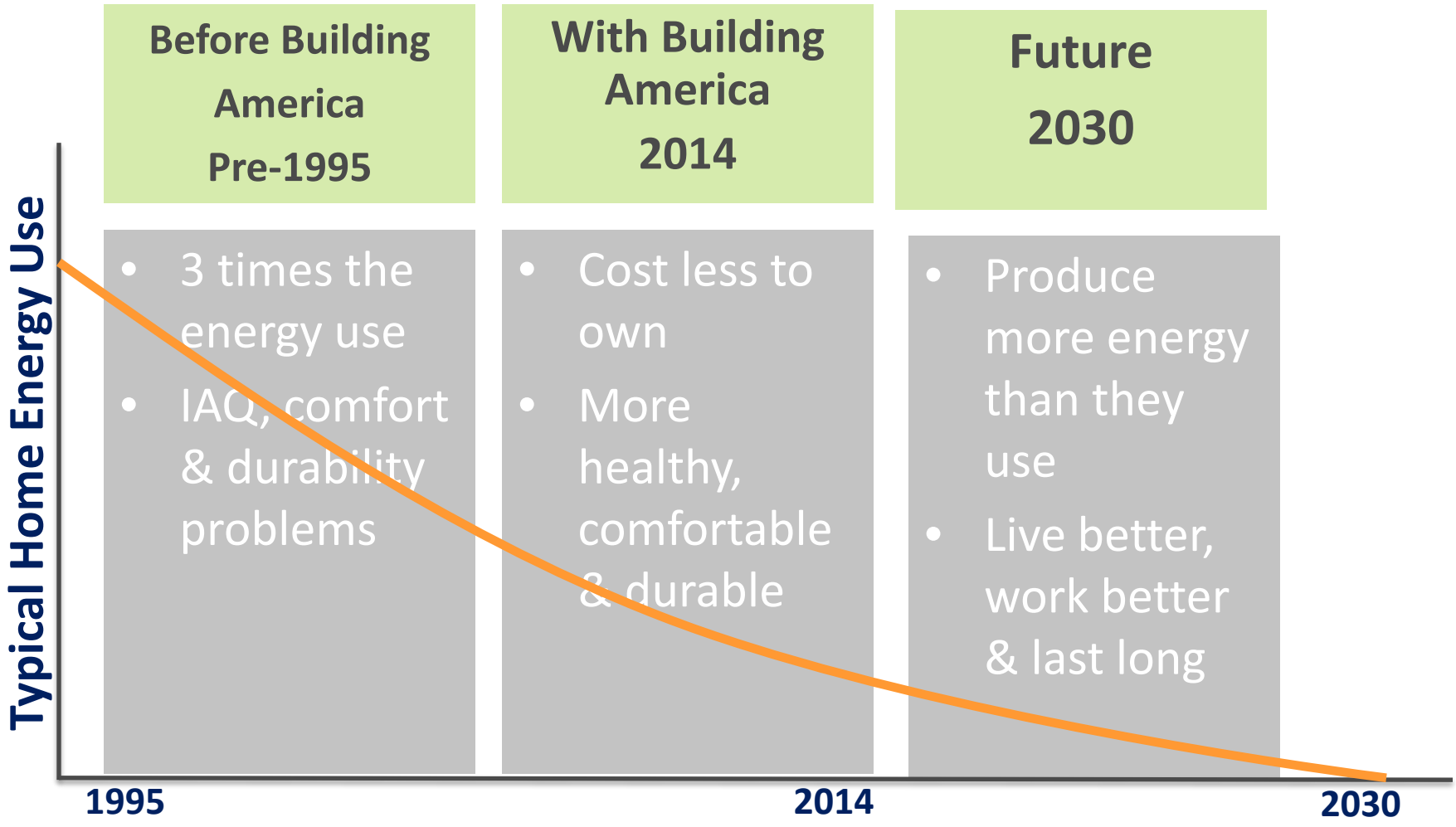
What does Building America Develop?

Building America Top Innovations

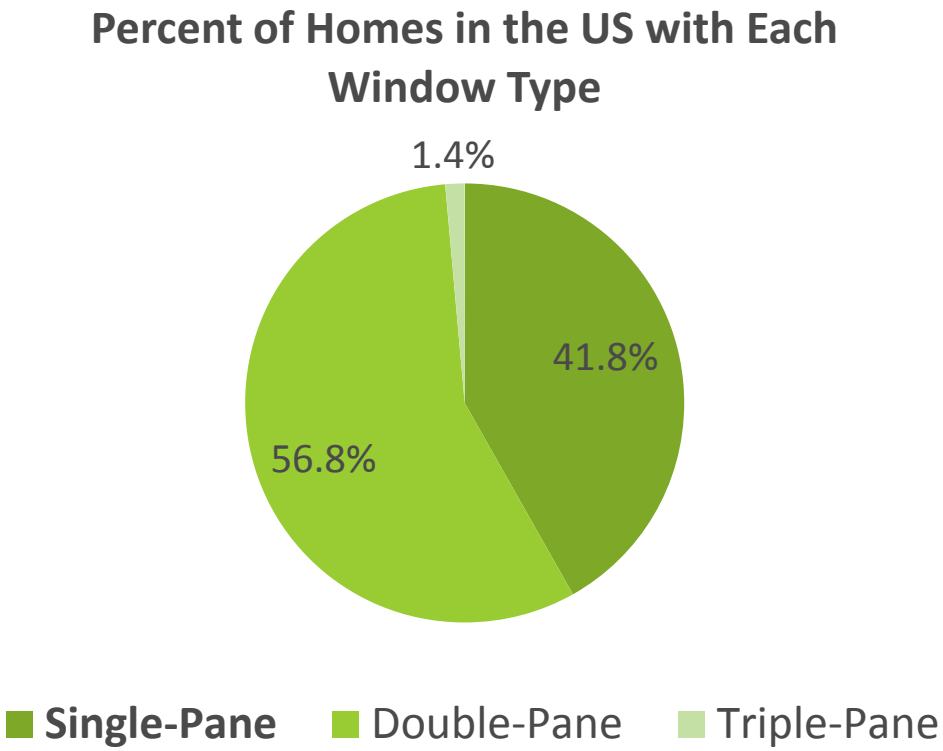
What do we achieve?

Before Building America Pre-1995	With Building America 2014	Future 2030
• 3 times the energy use • IAQ, comfort, & durability problems	• Cost less to own • More healthy, comfortable, & durable	• Produce more energy than they use • Live better, work better, & last longer

What do we achieve?



Window Retrofit Opportunities

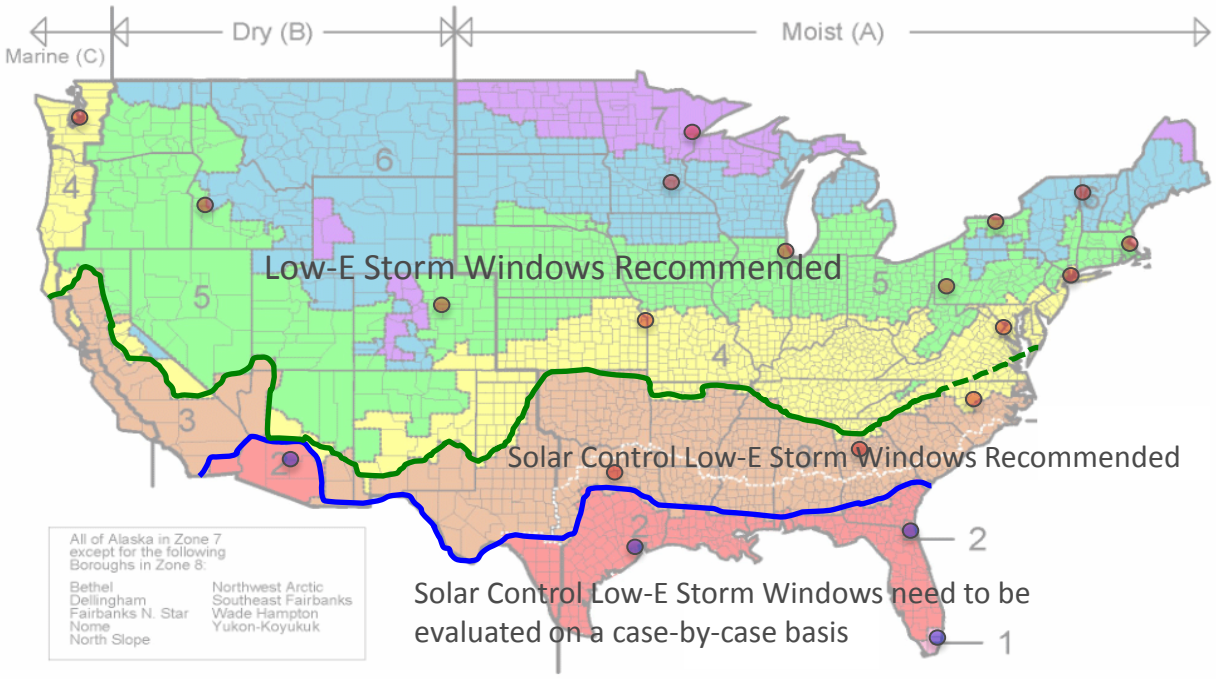


- 19 billion ft^2 of existing windows, ~40% with single pane glass
- ~47 million homes with single glazing, another ~46 million with double pane clear[1]

[1]Cort (2013) and DOE-EIA

Cost Effective Window Retrofits

- Using conservative assumptions, low-E storm windows are found to always be cost-effective when installed **over single-pane windows** and **double-pane (clear) metal-framed windows** in climate zones 4–8[1].



Over 30% of windows are **single-pane** in climate regions 4 though 8![2]

[1]Culp et. al, 2014
[2]DOE-EIA 2009

The New Look of Low-E Storms: Inside and Out

- 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

Tom Culp, Owner, Birch Point Consulting, LLC

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.

Low-E Storm Window Development Storm Window Development

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.

Market Transformation

- Working with weatherization, energy-efficiency, and labeling programs to have benefits recognized.

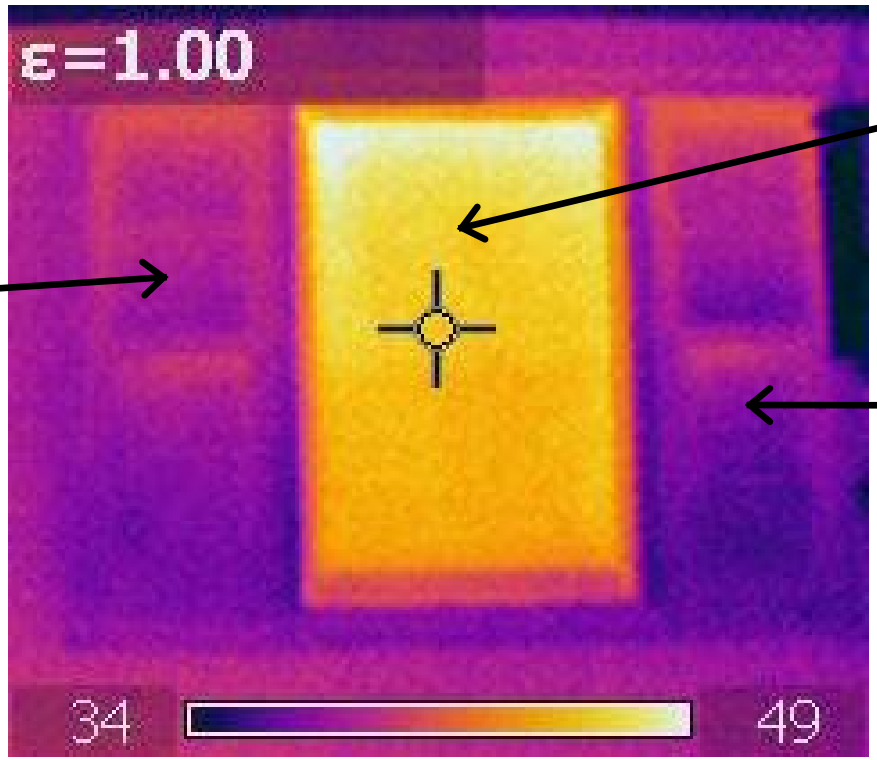
Low-E Storm Windows: Concept

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:



Original single pane window

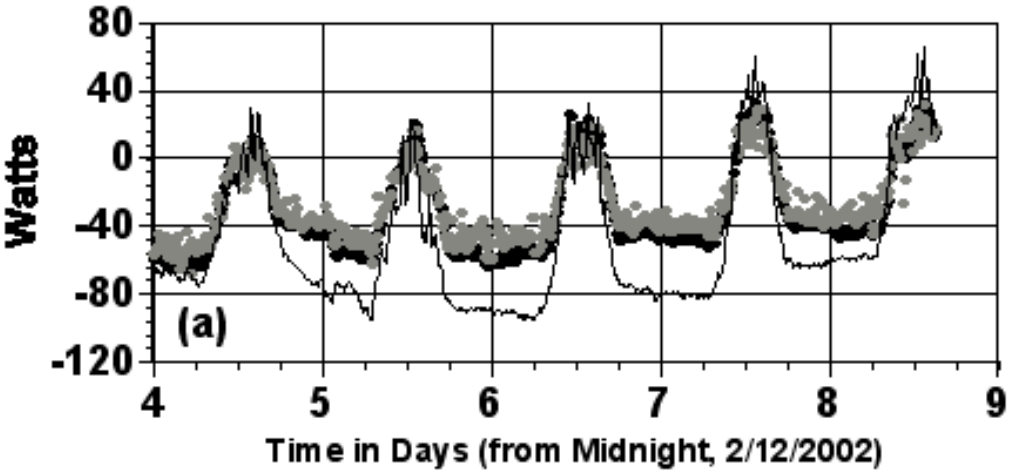
With Low-E Storm Window

With Low-E Storm Window

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

Initial Testing

- 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]

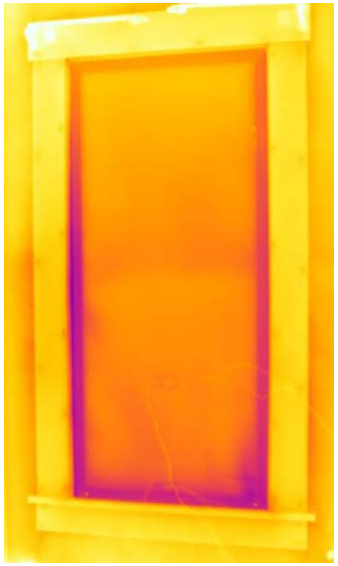


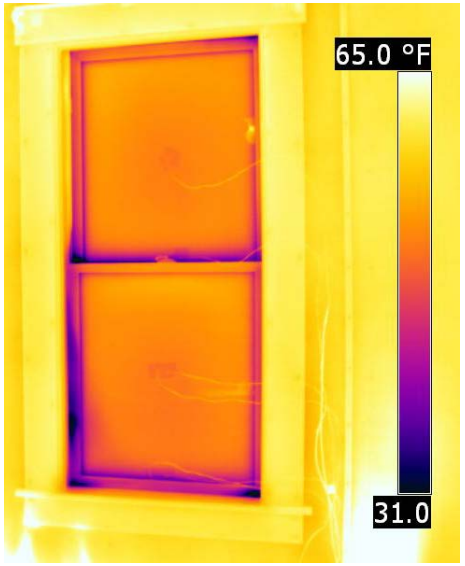
[1] Klems, 2003

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

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

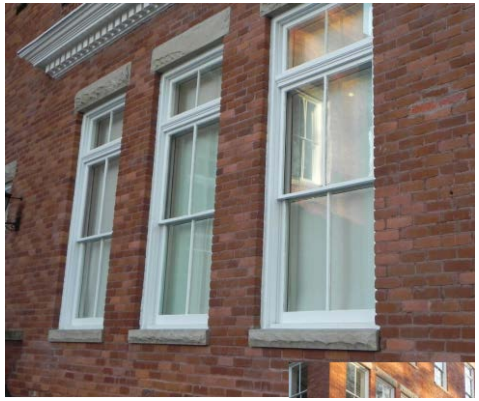
Demonstration Case Studies

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

Real World Examples



Photos courtesy of QUANTAPANEL

Success Stories - 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

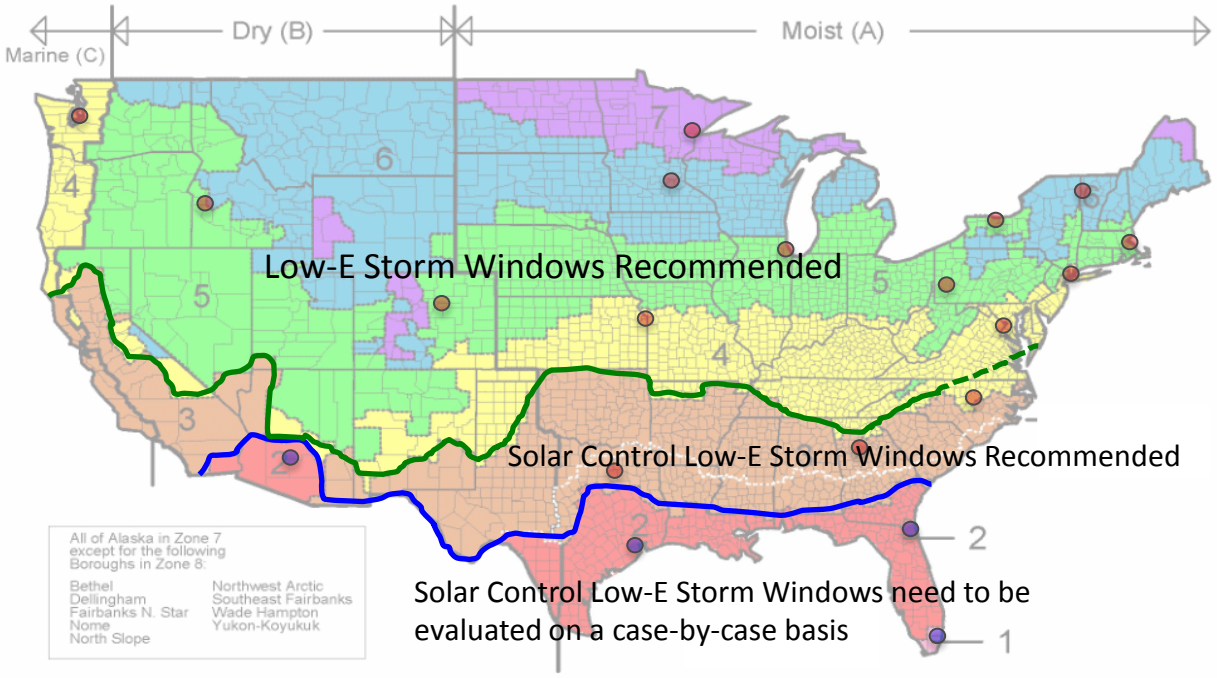
SIR = Savings-to-Investment Ratio. Must be > 1 to qualify.

[1] Zalis et al, 2010

Success Stories - Weatherization

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

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



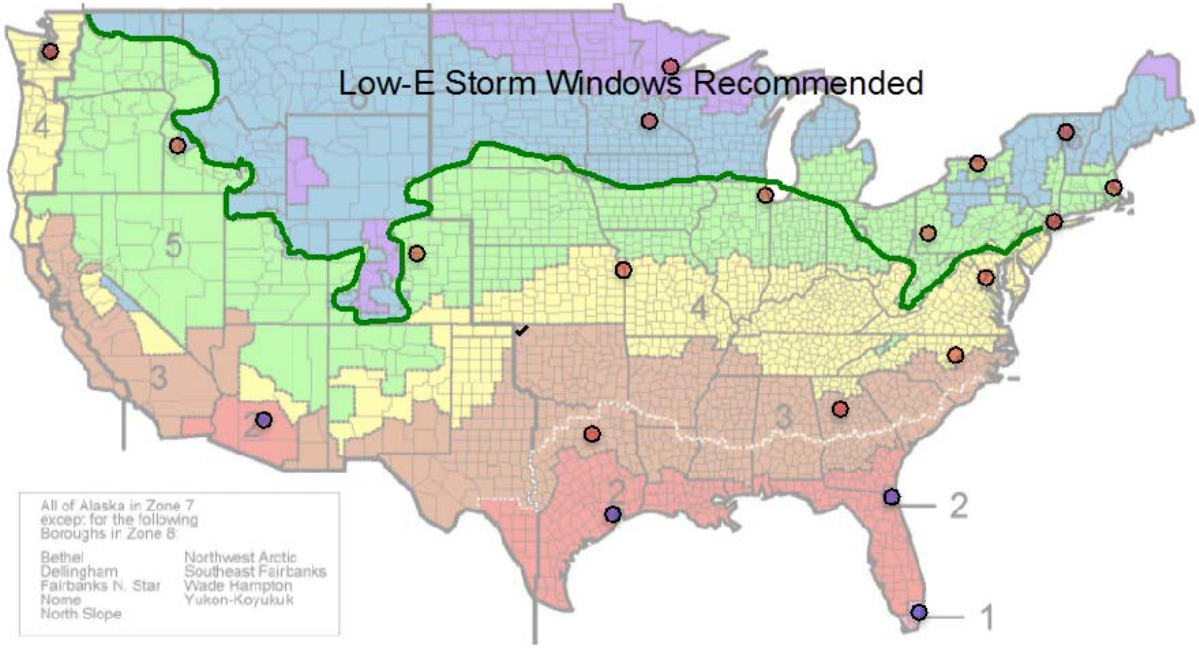
Cost effective in climate zones 3-8 with SIR 1.2 – 3.2

[1] Culp, et. al. 2014

Success Stories - Weatherization

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

Over double-pane wood or vinyl-framed windows:



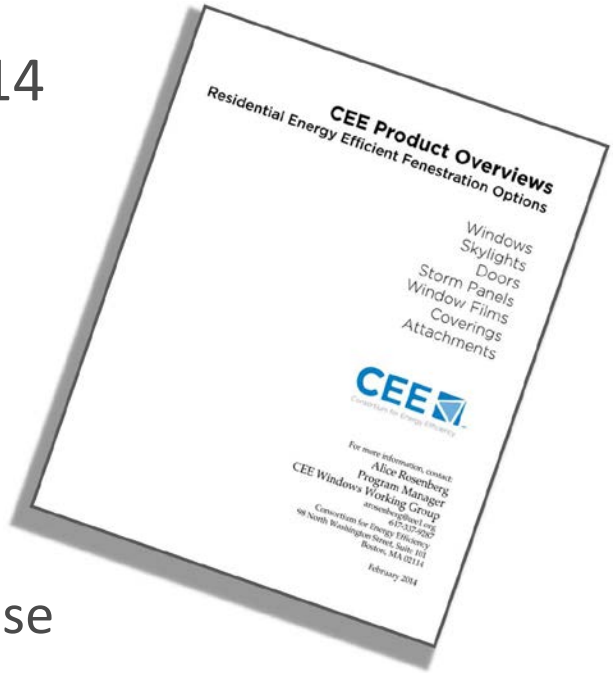
Cost effective in climate zones 6-8 and eastern part of zone 5 with SIR 1.1 – 1.9.

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

[1] Culp, et. al., 2014

Success Stories – 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



Code Compliance

- 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.

Looking to the Future

- Low-e storm windows integrated in FEDS model (supports most Federal building energy audits)
- Supporting DOE's Certification and Rating Attachment for Fenestration Technologies (CRAFT) 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.

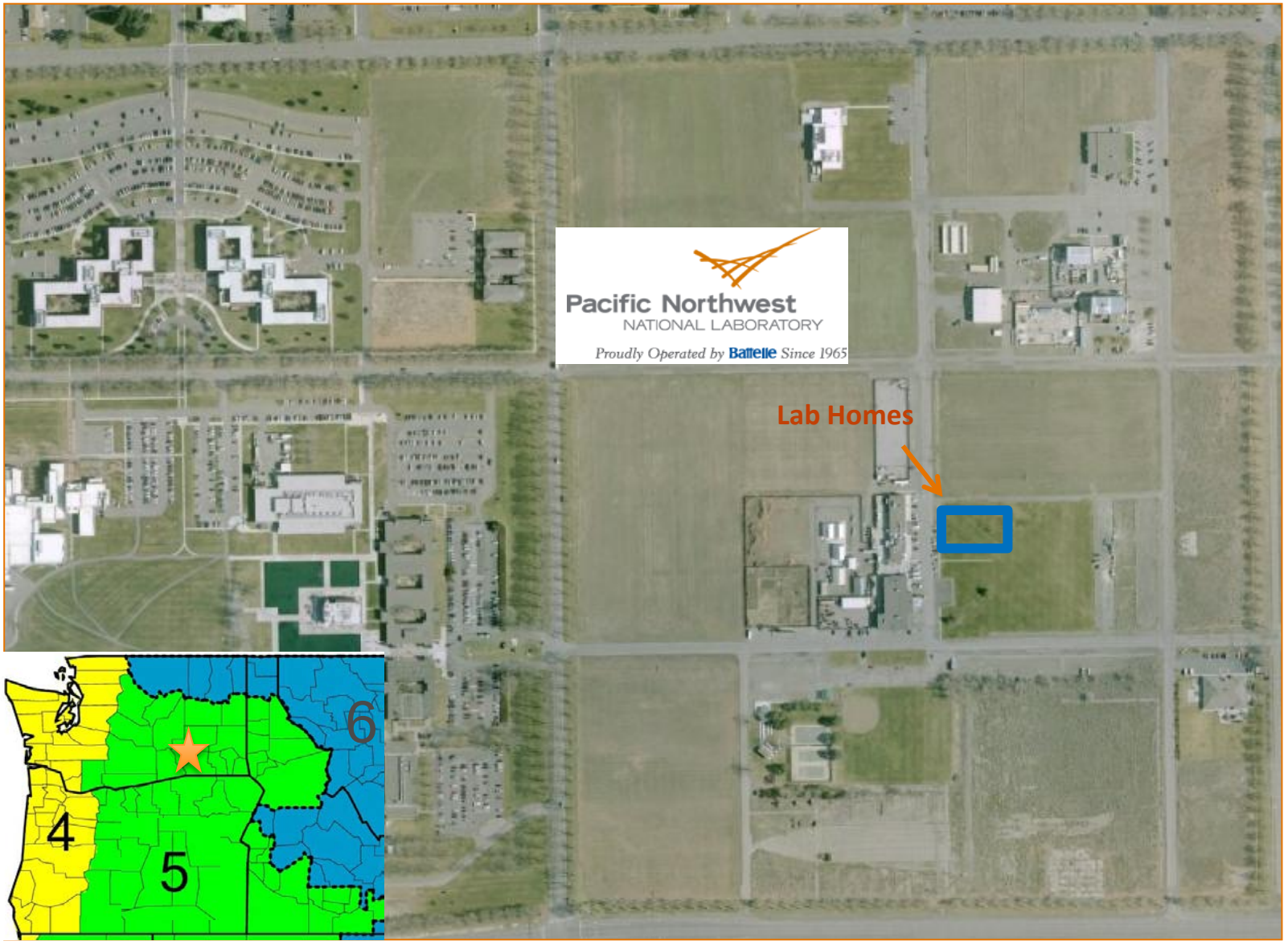
Sarah Widder, Engineer, Pacific Northwest National Laboratory

Sarah Widder focuses on the application of technology, standards, and regulations to meet sustainable design, energy efficiency, and greenhouse gas management goals. Some of her current projects involve researching cost-effective solutions for improving energy-efficiency in residential buildings with DOE's Building America Program and evaluating new energy efficiency technologies, such as low-E storm windows, in PNNL's side-by-side Lab Homes.

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

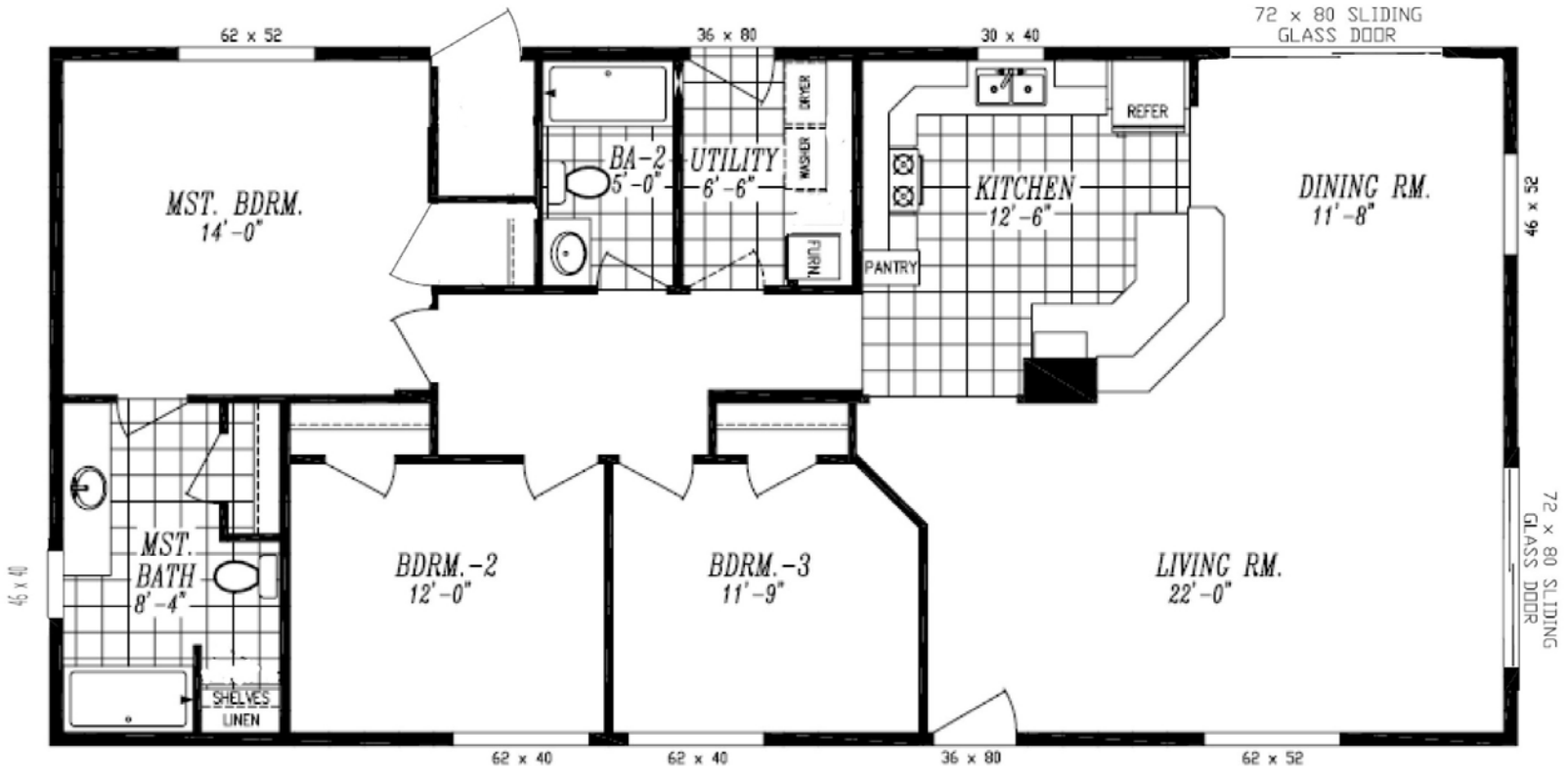


Lab Homes Characteristics

- 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

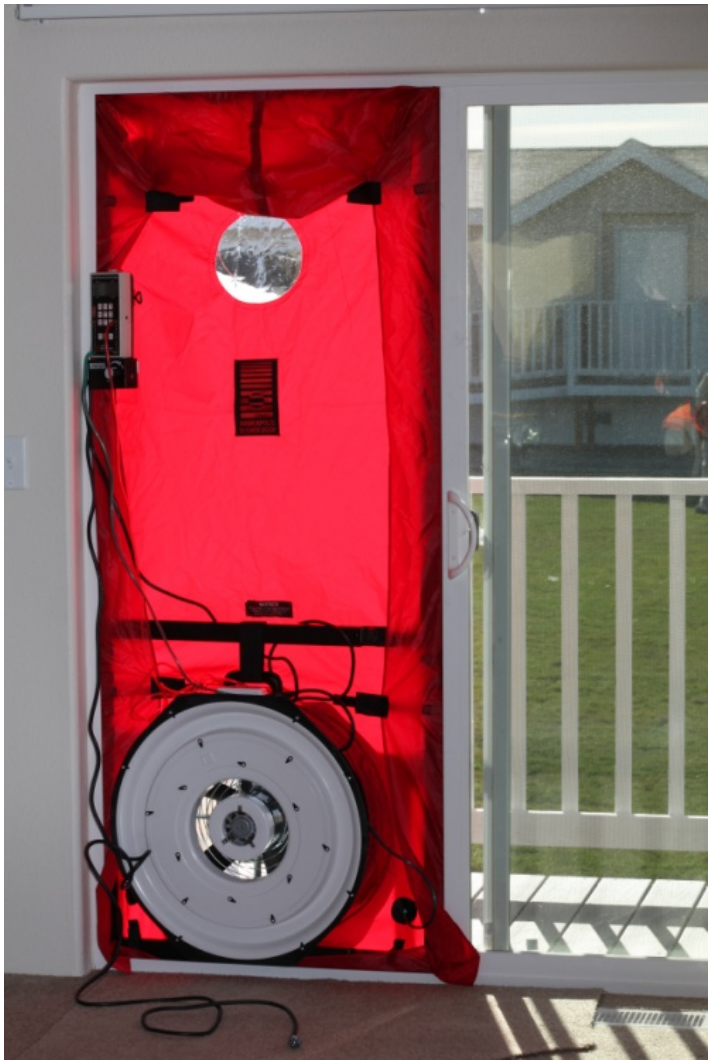


Metering and Monitoring

- 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



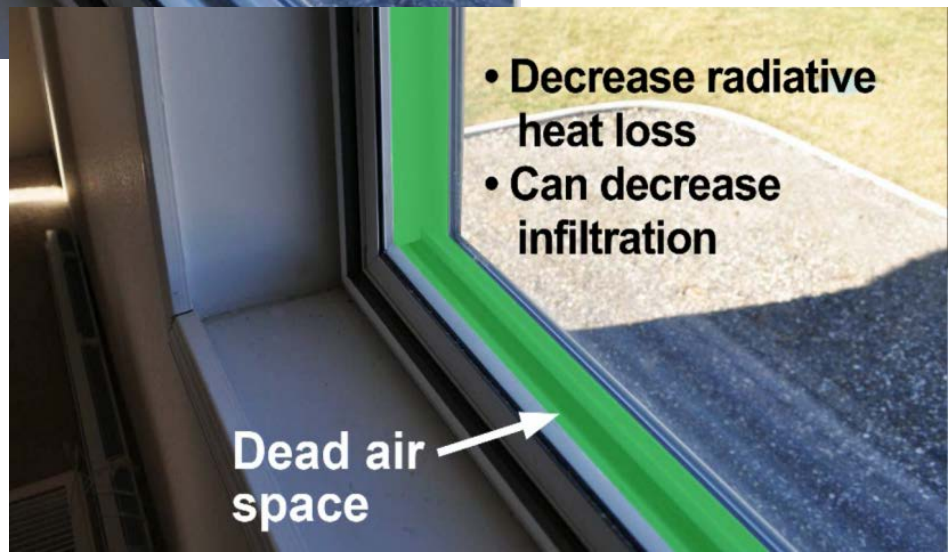
Window Characteristics

- 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.

How Low-e Storms Save Energy



Materials Needed

Caulking Gun

Caulk

Putty Knife

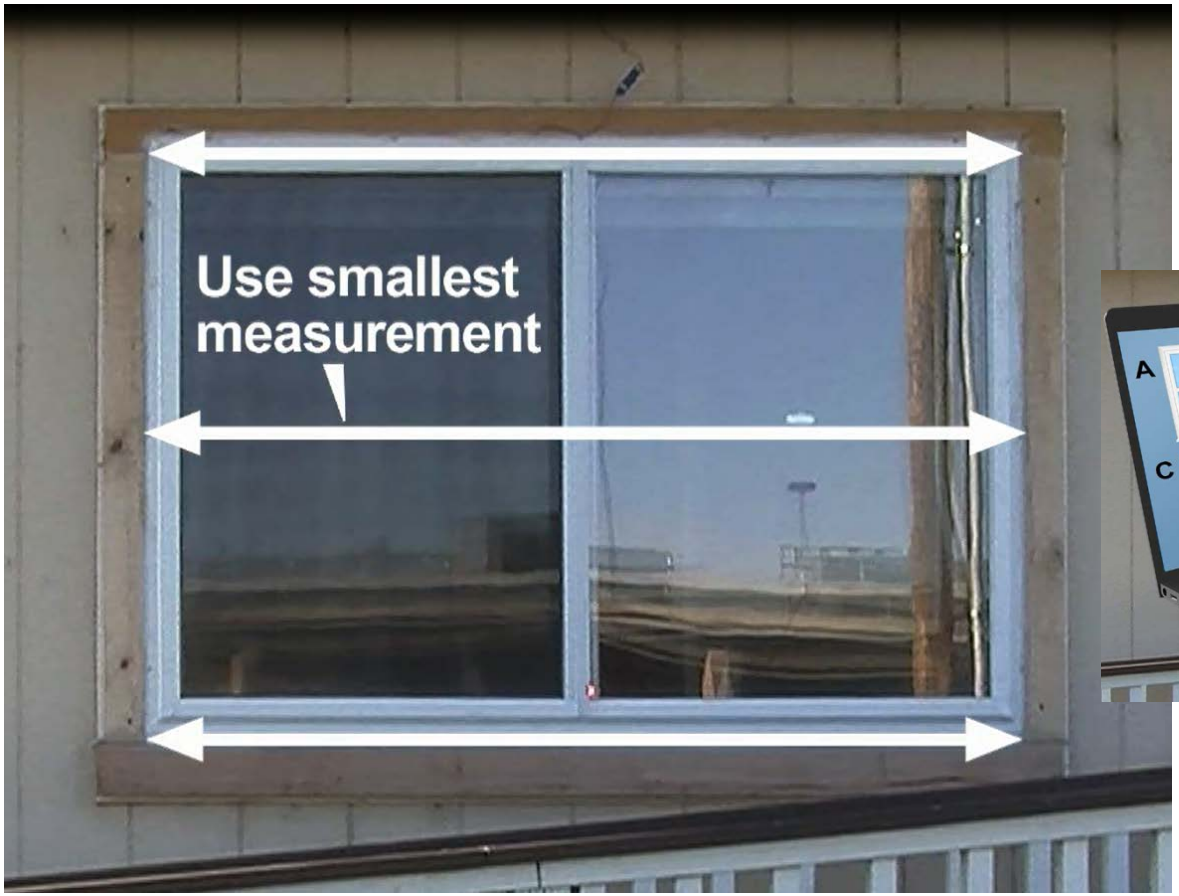
Putty Knife

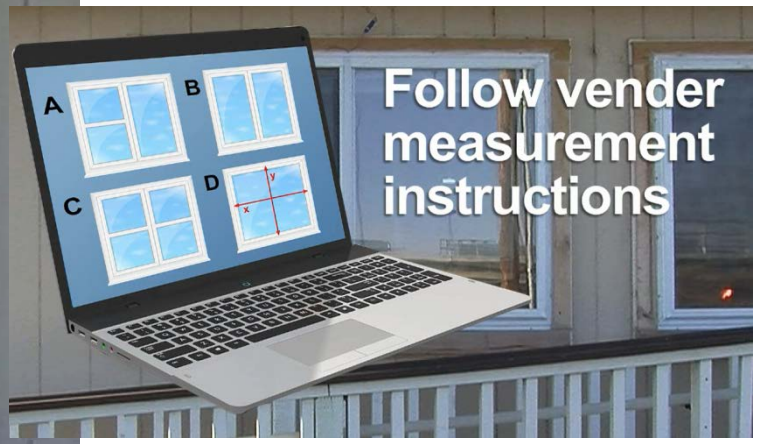
Screw Driver

Measuring Tape

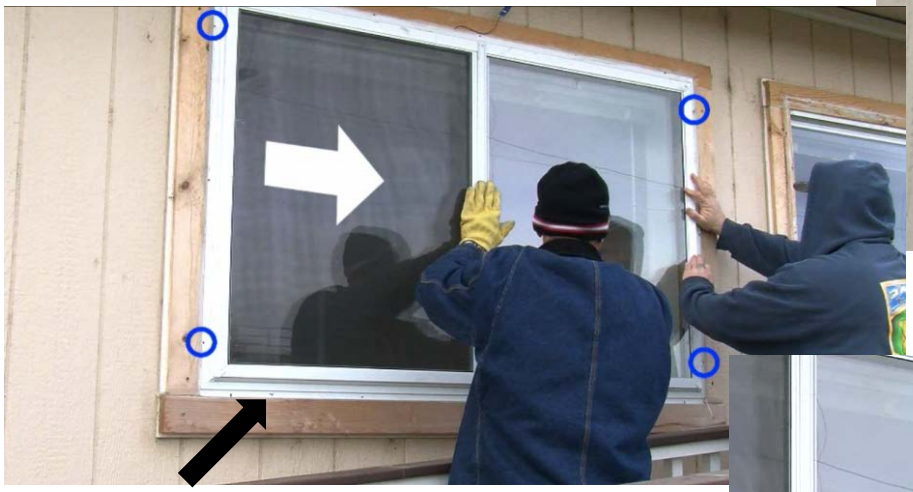
Step 1: Measuring

Measure, Measure, Measure





External Installation



Weep Holes

Permanent Year-Round Installation

Interior Installation

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/

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.

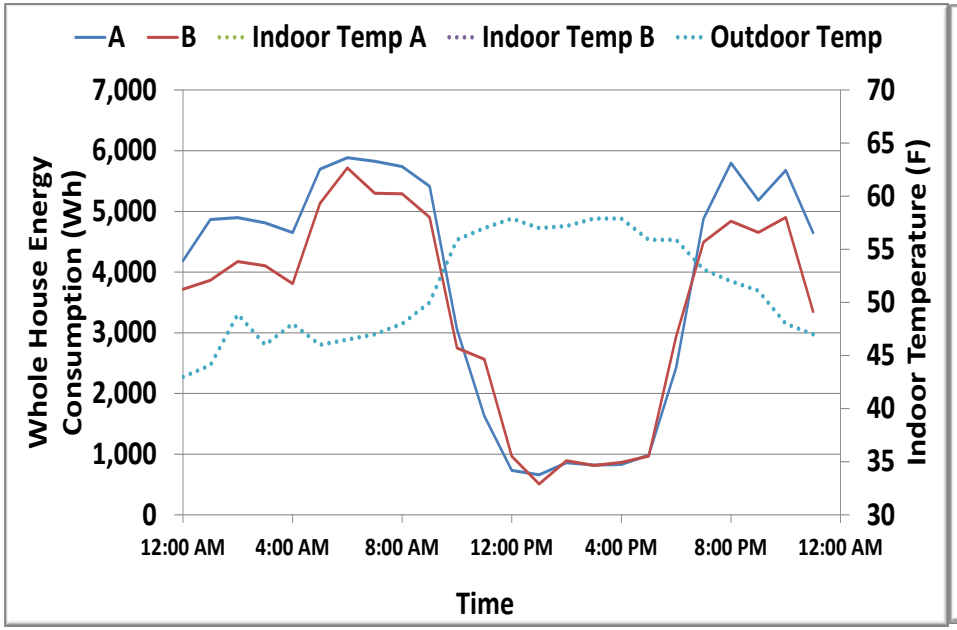
Air Leakage

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

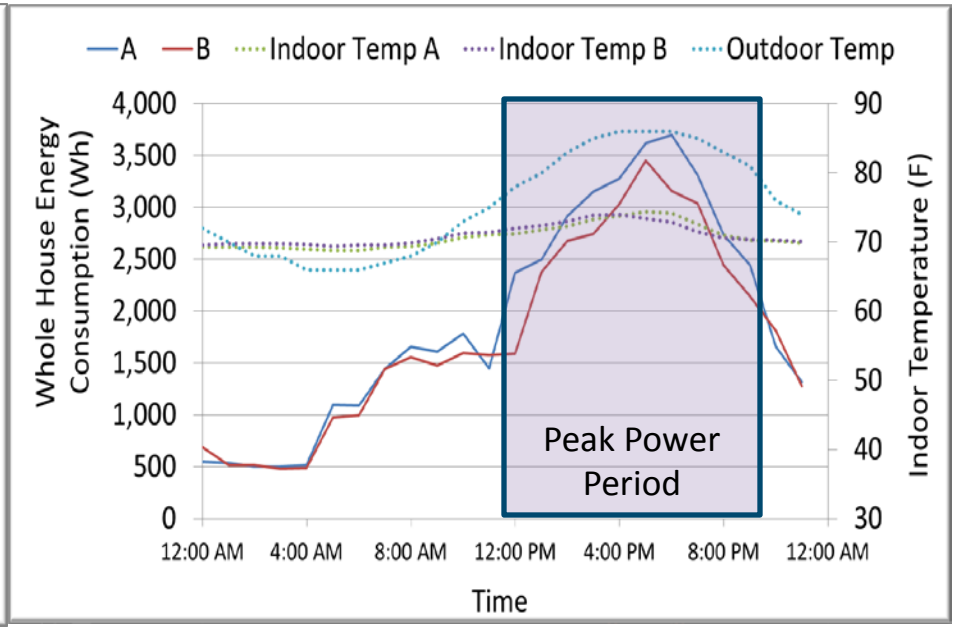
Lab Home	Primary Window	Storm Window	Bottom Edge of Storm Window	Average Value (cfm50)
A	**Closed*	*N/A*	*N/A*	*789.7 ± 25.7*
B	Closed	Closed	Unsealed	803.1 ± 29.3
B	Closed	Open	Unsealed	842.0 ± 31.4
B	Open	Closed	Unsealed	1,445.9 ± 58.9
B	Closed	Closed	Sealed	841.8 ± 41.9
B	Open	Closed	Sealed	1,316.3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

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Where can I find resources?

Building America Solution Center:

Proven Innovations from World-Class Research

… at Your Finger Tips

https://basc.energy.gov/

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

Time for Q&A

Field Implementation Success Stories

Tom Culp
Culp@birchpointconsulting.com

Lab-Home Study and Results

Sarah Widder
Sarah.widder@pnnl.gov

Low-E Storm Window Efforts at PNNL

Katie Cort
Katherine.cort@pnnl.gov

Thank You!

PDF copies of the presentations in this Webinar are available at:
http://energy.gov/eere/buildings/events/building-america-webinar-low-e-storms-next-big-thing-window-retrofits

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