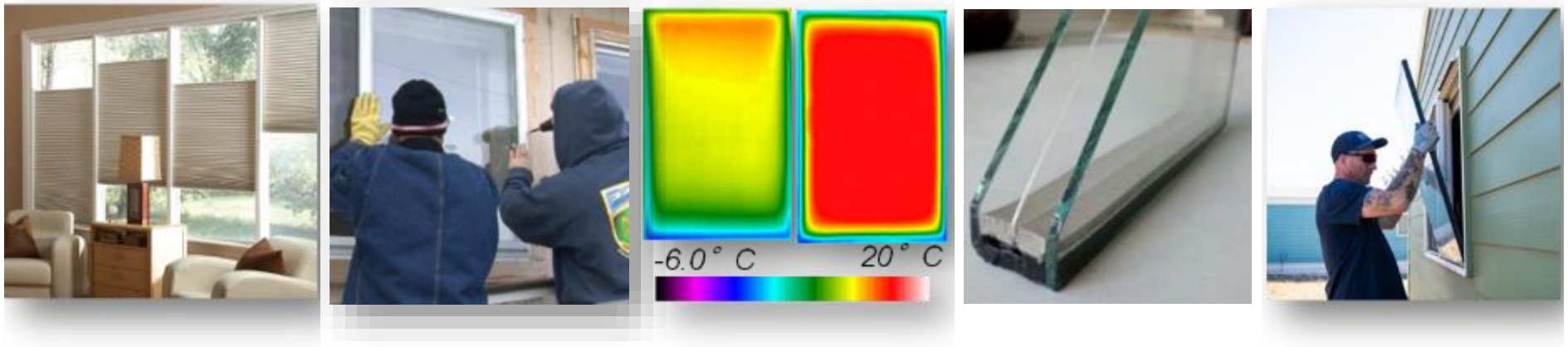
Field Validation and Market Transformation of High-R Windows and Window Attachments



Pacific Northwest National Laboratory
In collaboration with Berkeley Lab and ORNL
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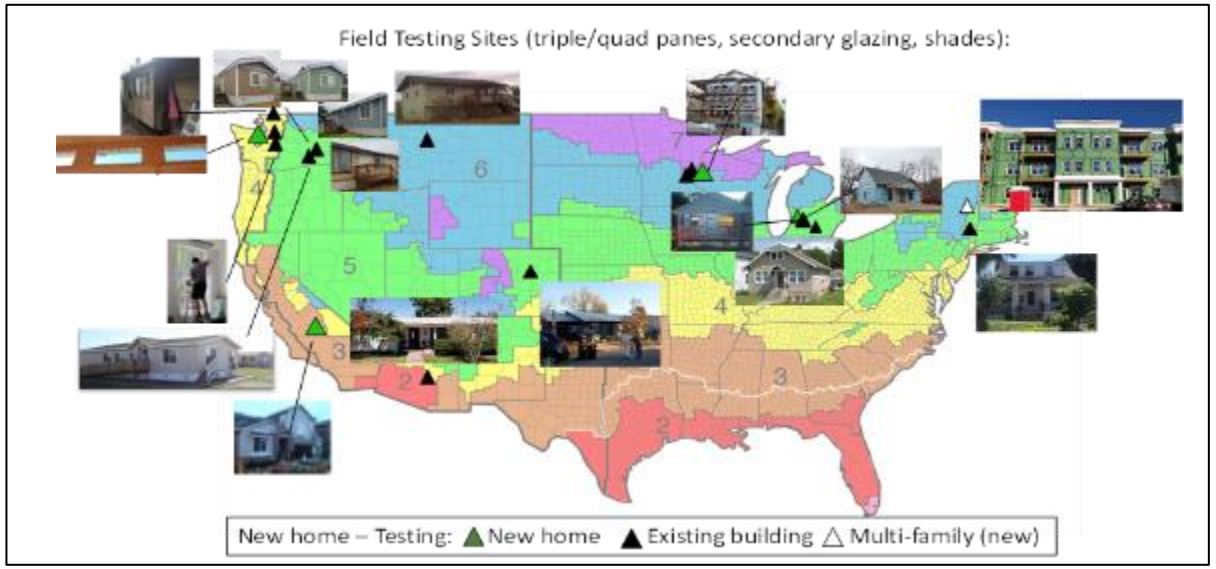
WBS 1.2.2.66

Project Summary

Objective and Outcome:

- Identify key barriers to the low-cost development of high-R windows and window attachments
- Validate the performance and system interactions of the latest generation of windows and attachments.
- Conduct Field Studies
- Analyze and extrapolate results to other climate zones.
- Use the research and outcomes from field-validation studies to initiate and support a utility-focused campaign on high-performance windows.



Team and Partners:

PNNL
Katie Cort, PM
Patti Gunderson, PI

Partners
Hunter Douglas
Center for Energy and Environment
Efficiency Solutions
University of Minnesota
Birch Point Consulting
Northwest Energy Efficiency Alliance

Stats:

Performance Period: FY19–FY23

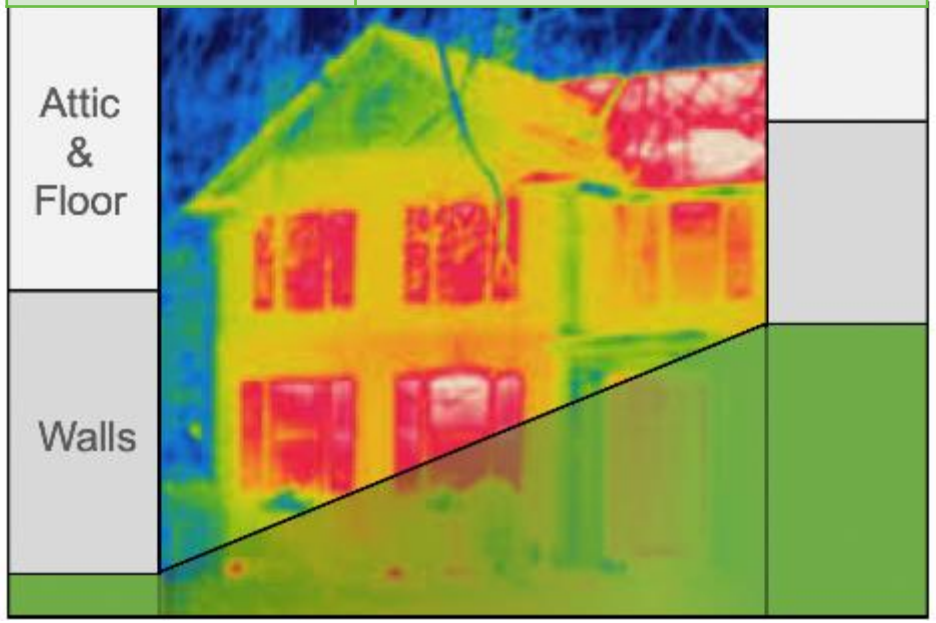
DOE FY23 Budget: $350k, Official Cost Share: $0k

Milestone 1: Present field study findings at NFRC meeting

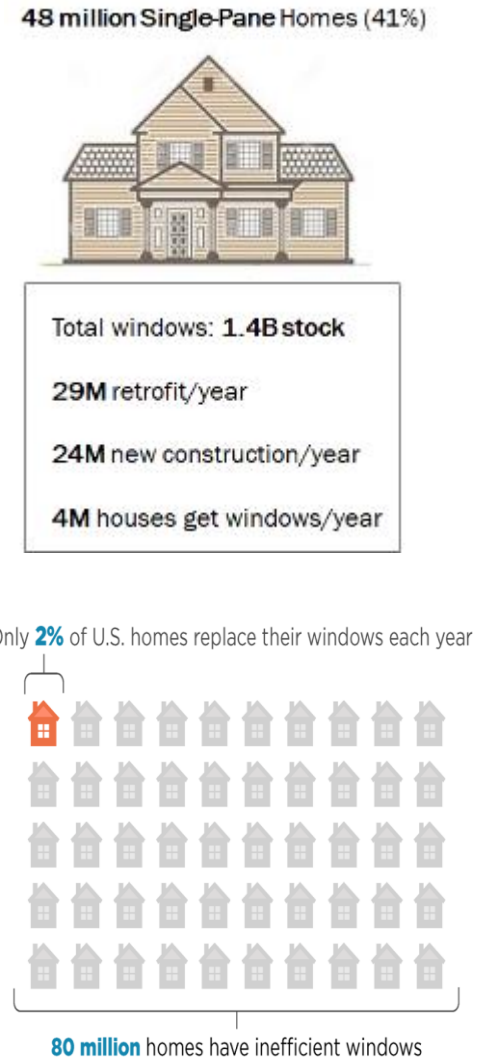
Milestone 2: Report status and findings of all field testing, demonstrations, case studies, and program development efforts

Problem

Current Strategy: New Homes	
IECC 2021	R-60 Ceilings
	R-20 Walls
	R-3.3 Windows



7% Area **Windows** **48% Heat Transfer**



Current Strategy: Existing Homes (118 million hh)
~ 2% of windows replaced each year
~ 2 million storm windows sold (~30% low-e)
~ 200 million interior window attachment shipments per year (4% insulated shades)

*Apte, J., Arasteh, D., Huang, Y.J. (2003) Future Advanced Windows for Zero-Energy Homes. ASHTRAE Transactions. LBNL-51913

**Based on 2,000 sf 2-story house, IECC 2015

Alignment with EERE/BTO Goals

Envelope EE First

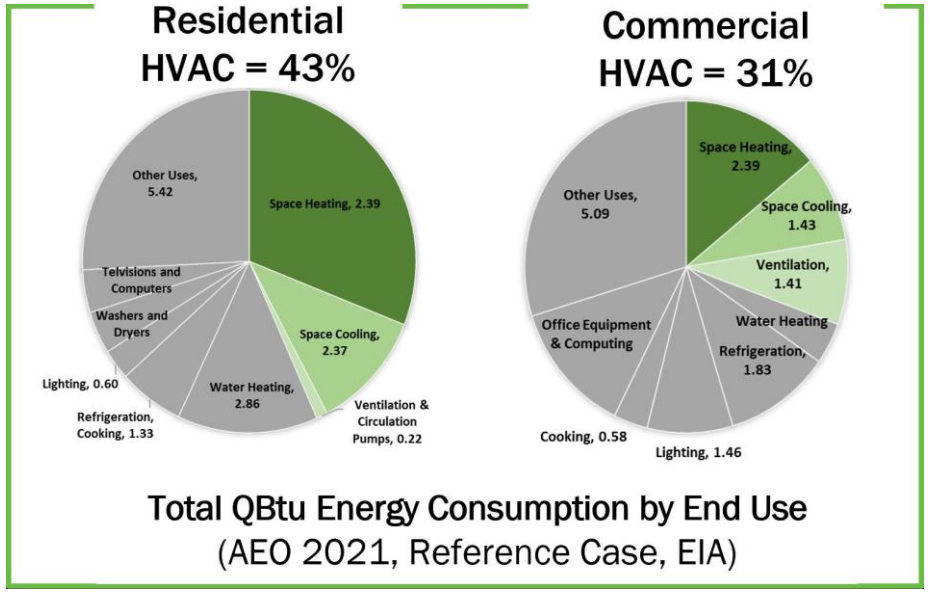
- ✓ **Impactful:** Carbon savings on day one with commercially available products and wide reach (new and existing)
- ✓ **Grid/HP-Friendly:** Reduces peak loads and facilitates renewable/clean power
- ✓ **Cost-Effective:** Provide long-term, persistent energy savings, benefits, and increase building value
- ✓ **Resilient:** Shelter-in-place protection against extreme climatic events
- ✓ **Occupant Benefits:** Added comfort, improved health and acoustics

Grid — HP

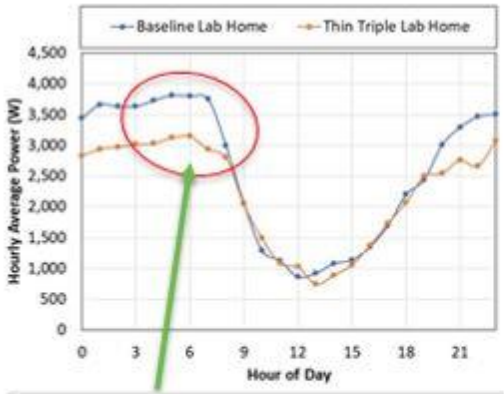
Impact

Thermal losses/gains through the window account for ~25% of building HVAC consumption. To meet carbon reduction goals, we need to improve window performance for new and existing buildings to help achieve

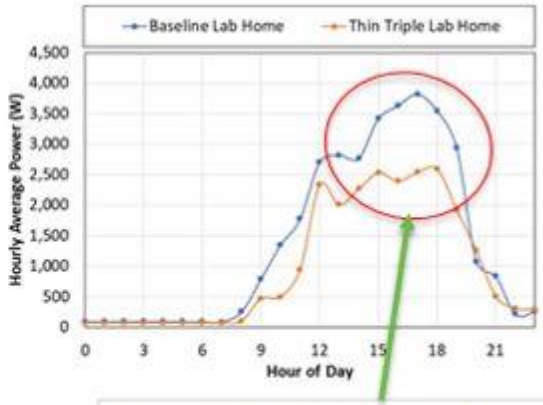
- Energy and Peak Load Reductions
- HVAC Electrification
- Energy Equity and Resilience Goals



Total QBtu Energy Consumption by End Use
(AEO 2021, Reference Case, EIA)



Reduced early morning heating needs when heat pumps require auxiliary heat



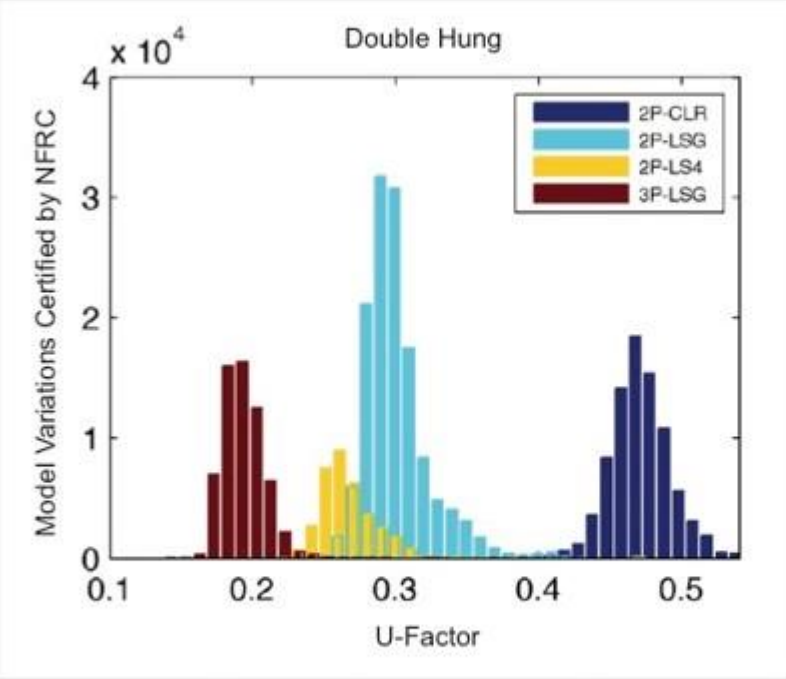
Reduces afternoon and early evening cooling load, coincident with system peak

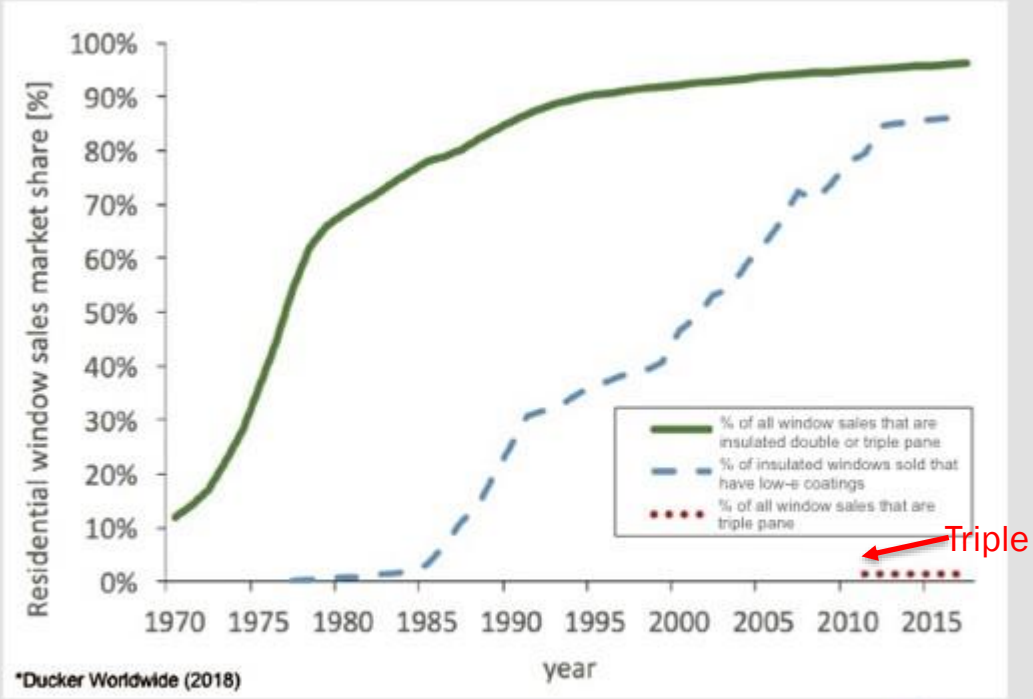
Technical Potential Savings of High-R Window Solutions in Residential Sector = 2.3 Q Annual Energy (Heating: 1.30 Q Cooling: .94 Q). Reduces year-round HVAC.

- Summer cooling peak, duck curve and grid impacts
- Winter peak heating, resistance electric heating
- Improves thermal comfort, passive resilience, condensation issues and outdoor noise (including noise from new outdoor HP units) (2018 LBNL)

Approach: How Problem is being Addressed Today

Current State of Windows





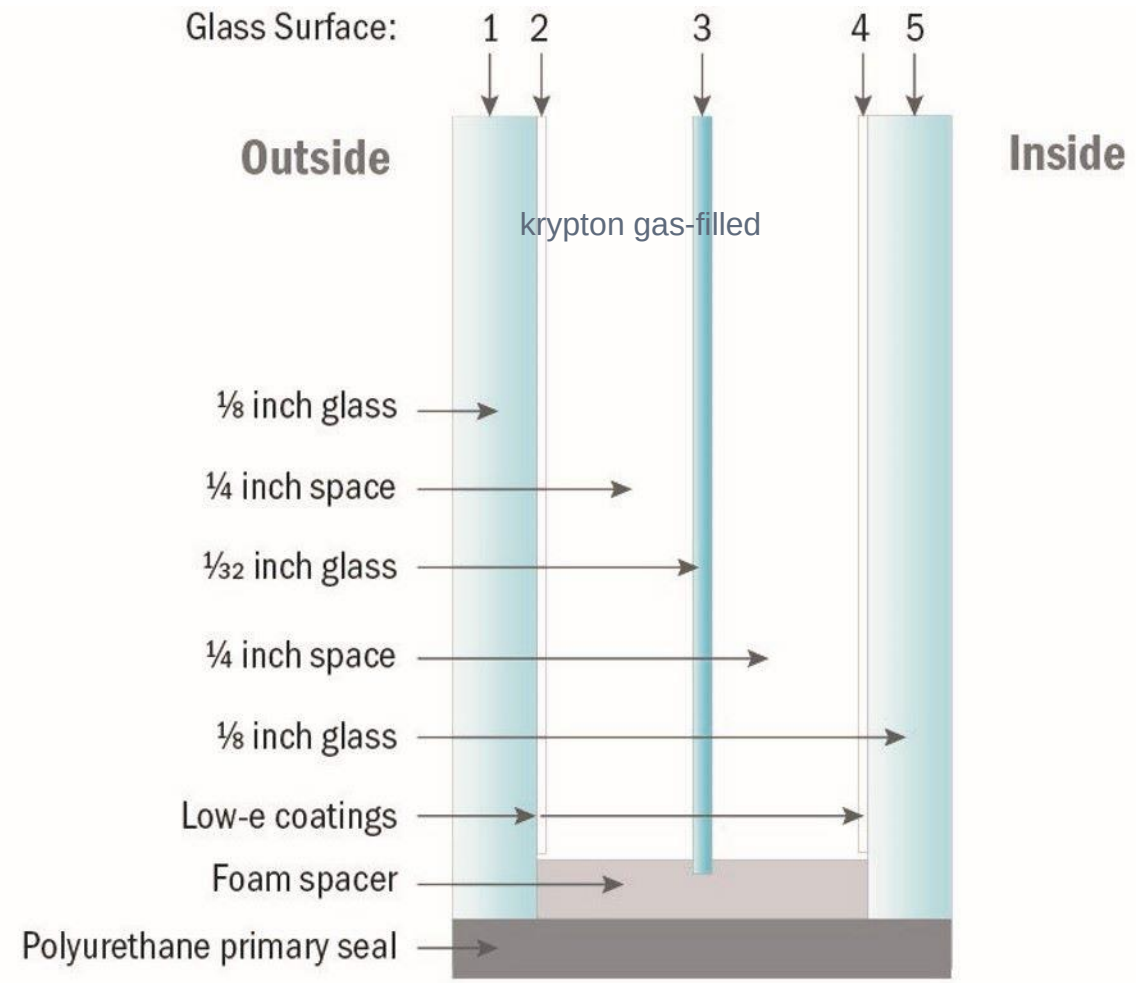
Of all double-hung window model variations certified by the NFRC, 11% are triple-pane models, but triple-pane windows constitute only 1% of total U.S. window sales! A drop-in replacement transformed the market from clear glass to low-e. Can a drop-in thin-triple transform the market from double-pane to triple-pane?

Approach: Supply Push – Demand Pull Strategy

Supply Push, Led by Berkeley Lab

- Leading **R&D** for advanced window solutions
- Work with manufacturers to drive development of “drop-in” replacement **thin triple-pane** insulated glass unit (IGU) and other advanced systems
- Develop **modeling software** that reflects advanced window performance for primary windows and window attachments
- Support the **development** and algorithms for **ratings and labels**
- Advocate for manufacturer **adoption** of of **energy ratings and labels**

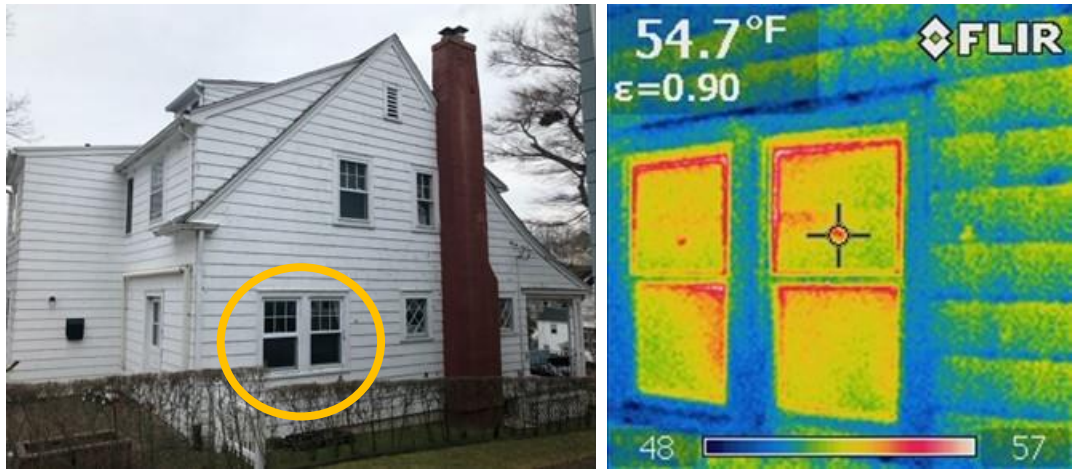
Thin Triple-Pane IGU



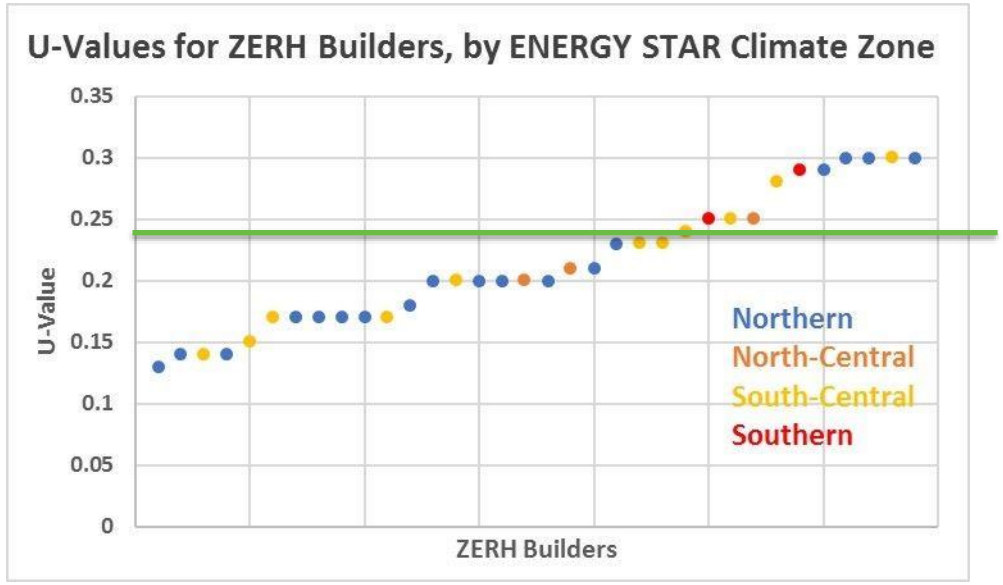
Approach: Supply Push – Demand Pull Strategy

Demand Pull, Led by PNNL

- Conduct **techno-economic market analysis** to inform field validation and market transformation efforts
- Develop experimental plan **and field protocol** tests to assess costs, validate benefits and trade-offs
- **Recruit strategic field study participants** and partnerships
- **Conduct field studies** and quantify these values for consumers, builders, and utilities
- Advocate for use of **energy ratings and labels** in energy efficiency programs

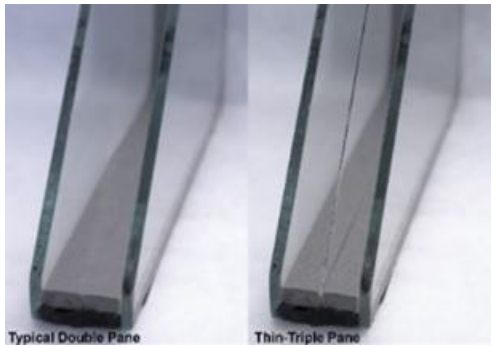


Single-Family Retrofit Home, Yonkers, NY

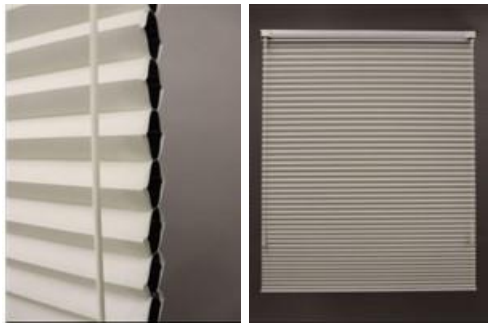


Approach: FY23 Project Goals

1. **Primary Windows: Thin Triple-Pane Window Field Validation Studies**
   a) Validate performance in terms of HVAC savings, peak demand savings, system trade-offs
   b) Validate co-benefits (comfort, acoustics), condensation reduction
   c) Validate “drop-in” feasibility with multiple double-pane brands
   d) Evaluate cost-effectiveness in new and retrofit applications

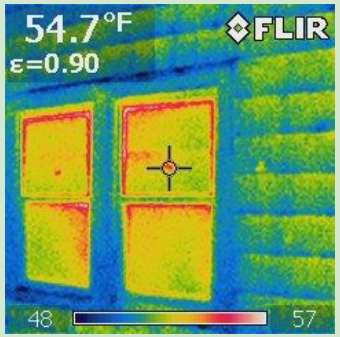


2. **Window Shades: Thermal and Moisture Performance Testing of Insulating Shading**
   a) Assess the factors affecting condensation potential of interior window surface with application of insulating shades
   b) Evaluate mitigation strategies to reduce potential of condensing moisture



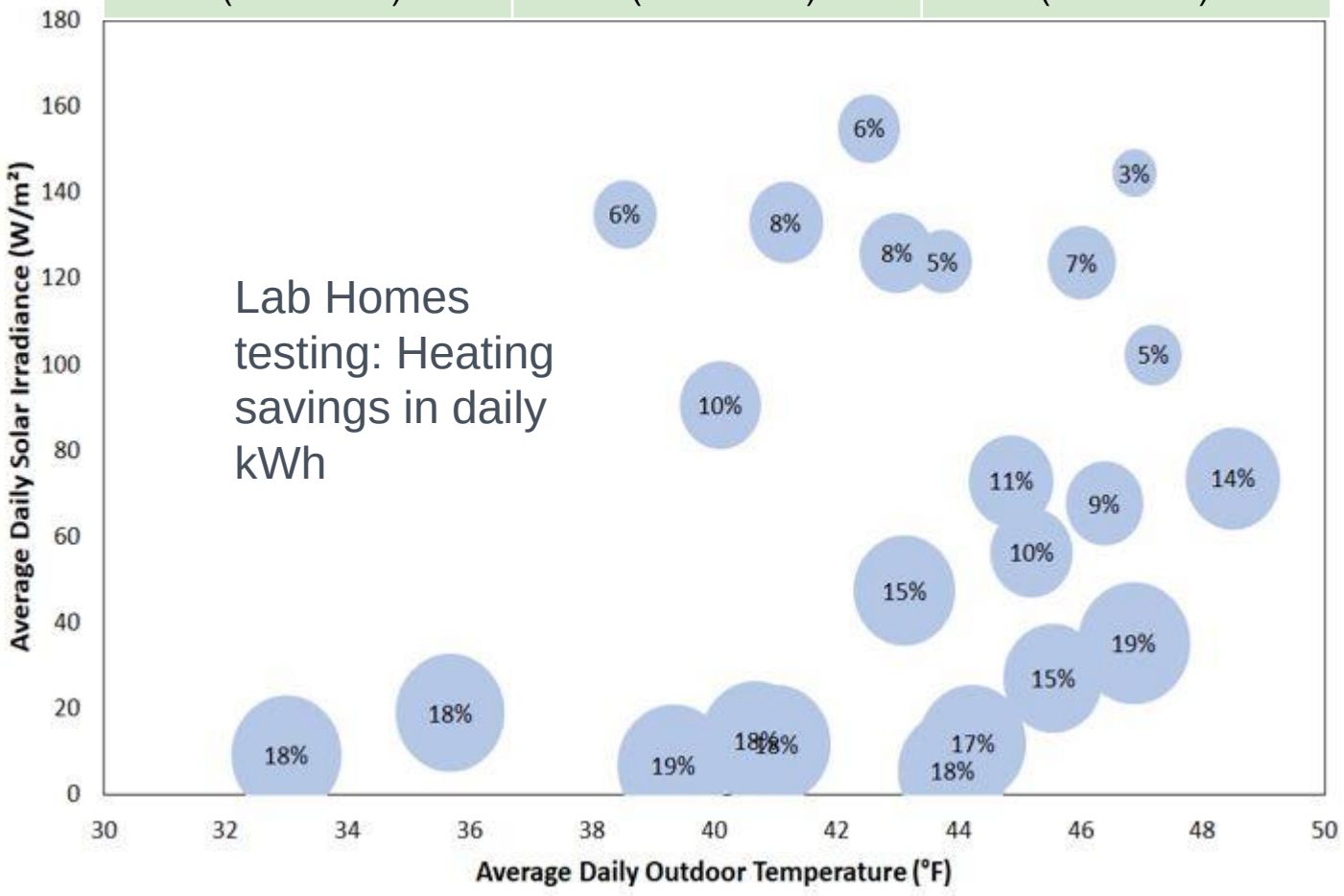
3. **Secondary Window Attachments: Minnesota Storm Window Replacement Pilot**
   a) Validate weatherization and thermal performance of new storm windows in Minneapolis
   b) Explore utility incentives and rebates
   c) Engage with key stakeholders to inform field validation

Approach: Field Testing Platforms

Field Testing Platforms/Projects	
Lab Homes (Whole Home Controlled Testing) • Thin Triple Panes • Secondary Glazing/Storm Windows • Insulating Shades • Connected Homes – Shade Automation • Exterior Shades	
Controlled Environmental Test Chambers • Moisture and Thermal Performance Insulating Shades	  
Occupied Home/Building Field Sites • Thin Triple Panes (and conventional) • Quadruple Panes • Exterior Storm Windows and Interior Insulating Window Panels	  

Progress: Thin Triple-Pane Performance Validation

Heating Savings	Cooling Savings	Annual Savings
12% (7.8 kWh)	28% (5.5 kWh)	19% (7.4kWh)

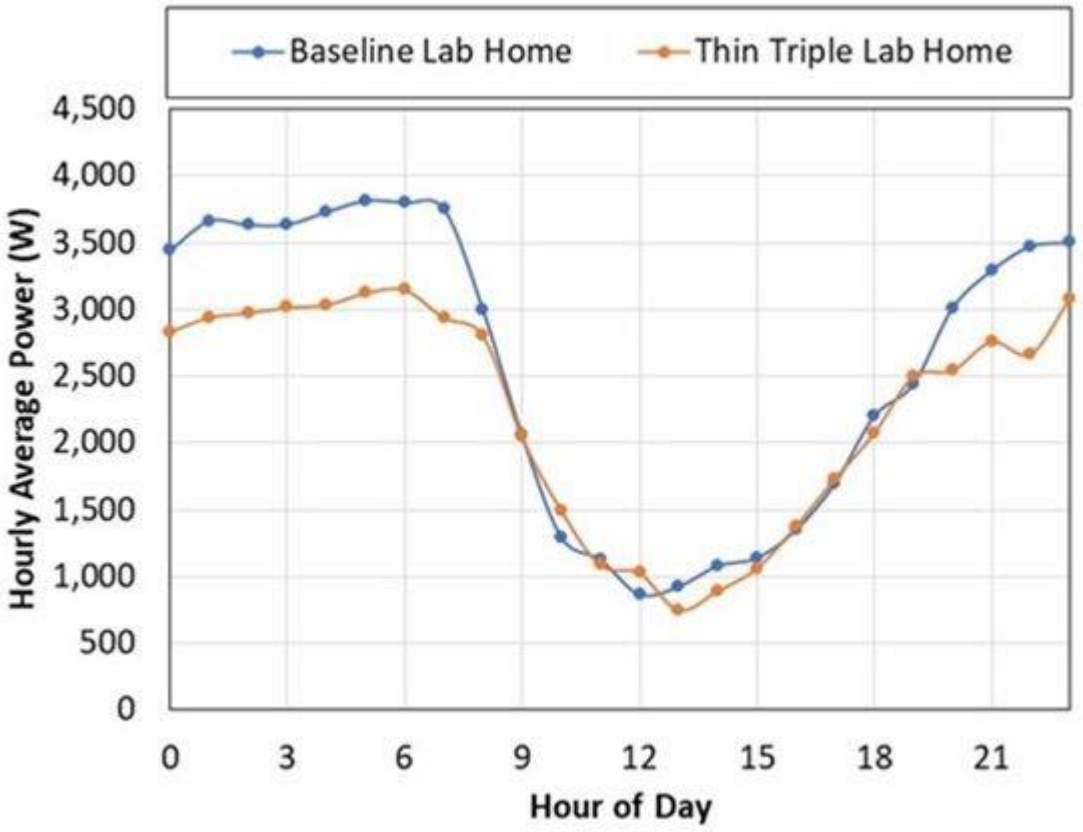


Thin Triples versus Double-Pane Clear

Progress: Load Shapes and Peak Savings

WINTER Average Peak Electrical Load Reduction:

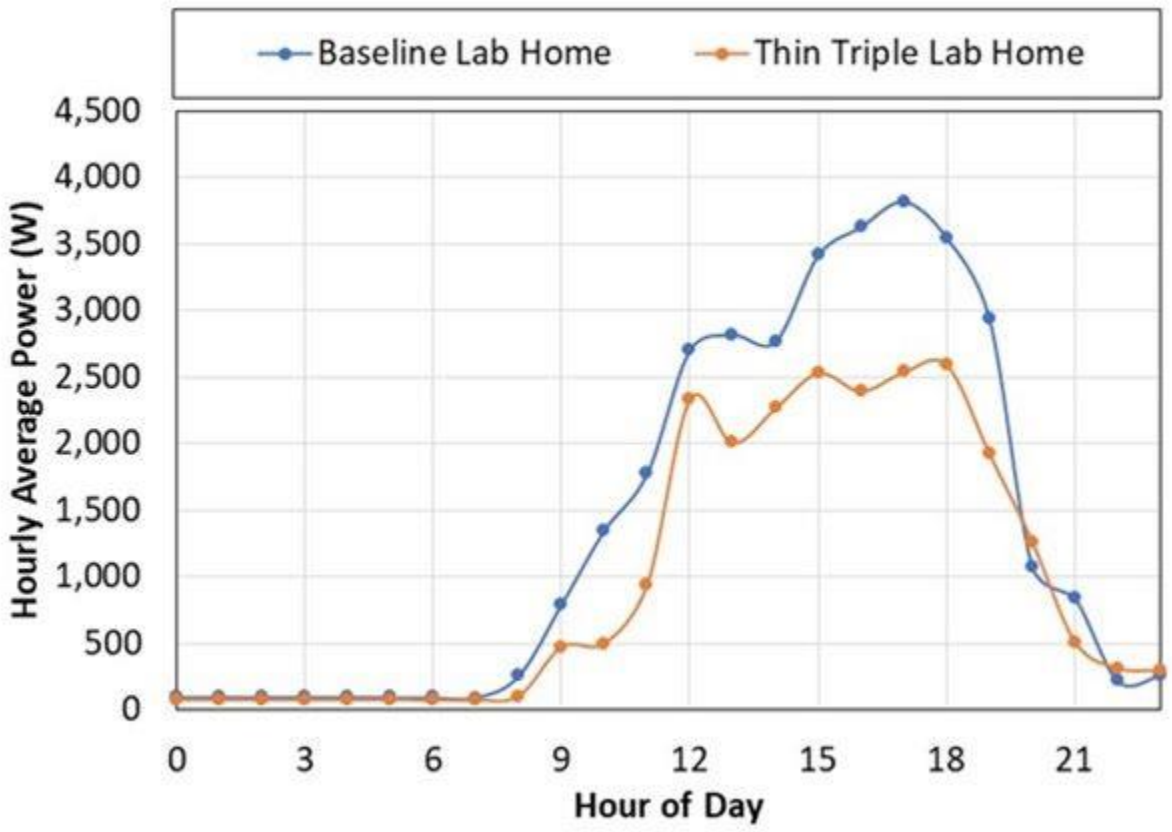
- 17% (650 Watts)



HVAC Load **Heating** Season

SUMMER Average Peak Electrical Load Reduction:

- 33% (1200 Watts)



HVAC Load **Cooling** Season

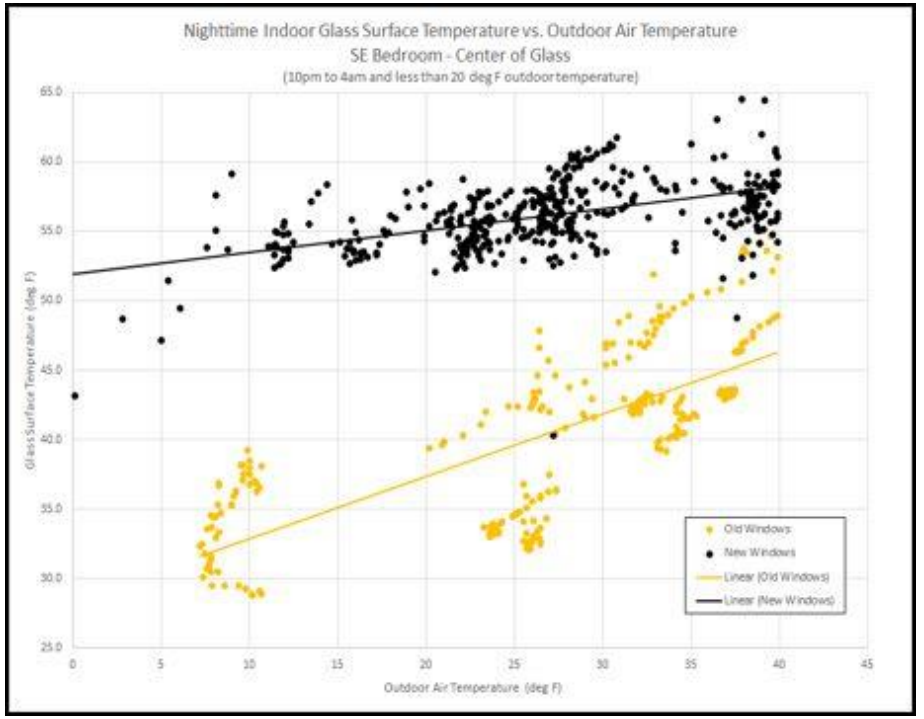
Progress:
Thermal Comfort and Other Co-Benefits from High-R Windows

Co-Benefits Validated in the Field:

- **Improved thermal comfort:** Warmer interior glass temperatures (in winter)
- **More even temperatures** throughout the home (all seasons)
- **Improved sound insulation:** Thin triple-pane windows reduced sound infiltration by ~10 dB relative to baseline double-pane windows
- **Reduced condensation potential** on interior window surface

Condensation and ice buildup on interior surface of Helena, MT home field site (double-pane window).

SE Bedroom10 p.m. to 4 a.m. and < 20° F $T_{(out)}$



Boulder, Colorado Retrofit
Nighttime Indoor c.o.g. Glass Surface Temperature vs. $T_{(out)}$
SE Bedroom

Progress: Thin Triple “Drop-in” Feasibility, Constructability, Cost-Effectiveness

New ENERGY STAR multi-family site in Rotterdam, NY

$6/s.f. incremental cost to install thin triples versus double panes

Paradigm vinyl double pane frames with thin triple IGU and Quanex foam spacer

Condensation Resistance rating increased from 45 to 65 with thin triples

Challenges, Lessons Learned, and Next Steps

Challenges and Lessons Learned

- COVID and residential field studies don't mix well
  - Added instrumentation and data collection complications
  - Supply chain delays and rising costs, including krypton costs
- Size and tempering limitations of thin glass may limit scale/demand in short term
- In addition to material costs, acquisition/search costs pose major barrier for broader uptake
- Non-energy co-benefits are marketable and important part of business case

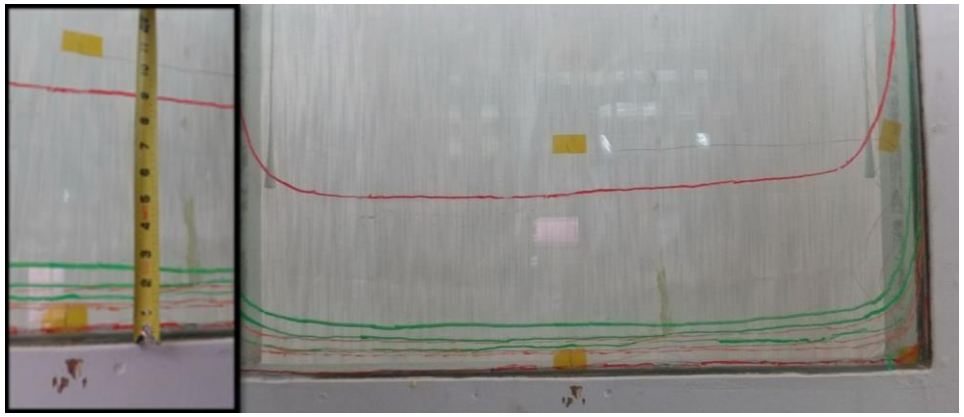
Next Steps Focus on Enabling Research for Market Transformation Efforts

- Partnership for Advanced Window Solutions (PAWS) -- PAWS aims to aggregate market demand, reduce product cost, and accelerate the adoption of advanced window solutions
- DOE Established Window ENERGY STAR Program, provides EPA support such as major effort on version 7 proposed recently, will move to triple pane in Northern Zone
- NFRC Window Selection Tool – Making it easier for consumers to find advanced window solutions
- Other DOE Rating Programs and Campaigns

Progress: Insulating Cellular Shades Thermal and Moisture Performance Testing

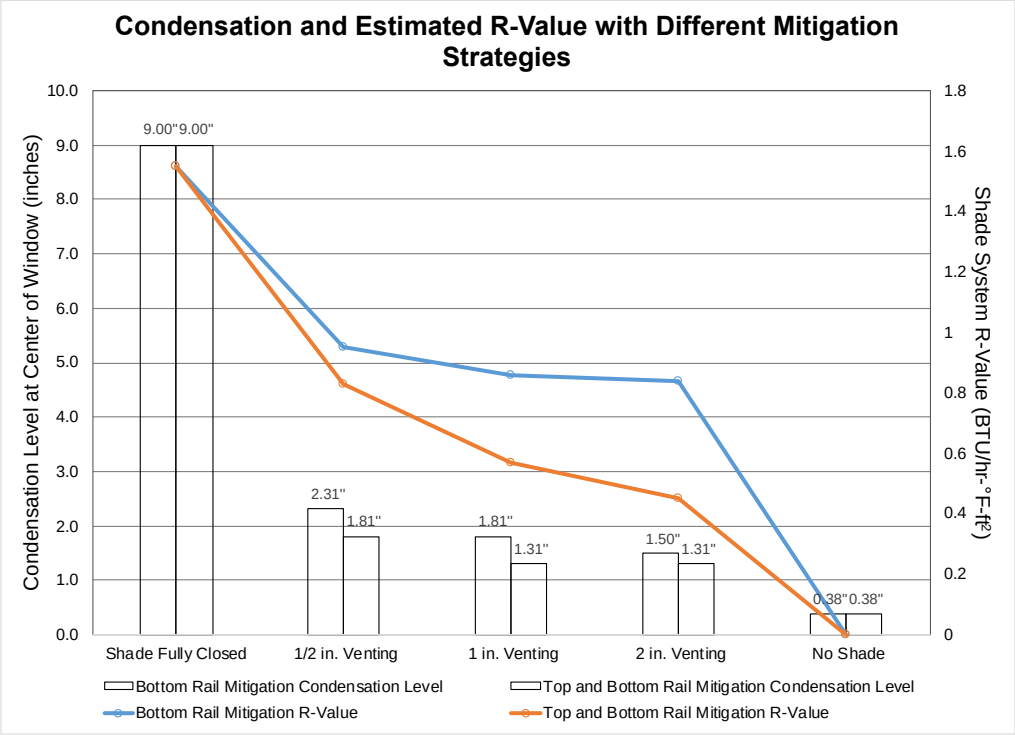
Problem and Context

- Insulating Shades
  - 5–25% Heating and Cooling savings demonstrated (ORNL and PNNL)
  - AERC energy ratings
- Utility Feedback
  - Cellular shades dismissed as EE measure due to increased potential for condensation buildup on window



R-value Controlled Test Chamber Testing (in partnership with Hunter Douglas and ORNL) to investigate factors influencing condensation buildup and strategies to mitigate effects

- Developing User Guidance with AERC based on study outcomes and recommendations:
  1. Open shades in the daytime during the heating seasons
  2. Open shade 0.5-inch from bottom rail when condensation accumulates
  3. Install better windows or attach insulating secondary glazing panels when condensation is chronic issue



Progress and Future Work: Minnesota Storm Window Replacement Pilot

DOE Low-e Storm Window Field Studies (Cold Climate)

Problem and Context

- Modern Low-e Storm Window as retrofit measure
  - Demonstrated HVAC savings = 10-30%
  - Cost-effective: Achieve savings similar to double-pane replacements at <1/3 cost
  - AERC energy ratings and ENERGY STAR available
- Minnesota Context
  - < 3% of homes have single-pane windows without storm windows
  - 30% of low-income households have single-pane windows with storm

Opportunity

- Cost-effectively replace old, leaky, clear-glass storm windows and achieve energy savings, added comfort for low-mid-income homes
- Validate weatherization performance -- air-leakage reduction from new storm windows
- Work with local utilities (XCel Energy, Nicor) and regional audit program to demonstrate performance meets program requirements

Progress

- Completing pre-inspections for all housing types
- Recruited manufacturers with AERC-rated products plus two local high-quality manufacturers

Future Work

- Complete installations and blower-door testing
- Document case studies, air leakage and other thermal comfort findings
- Work with local utilities to develop programs

Thank You

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REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	$376,746				$411,054							
Spent budget	$391,774				$171,640							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Report occupied field site findings - DRAFT	◆											
Report occupied field site findings - FINAL		◆										
Present final results from field validation studies			◆									
Report findings and status for all case studies				◆								
Current/Future Work												
Present findings of High R field studies - PPT					◆							
Report status and findings of all field studies - Q1						◆						
Report status and findings of all field studies - Q2							◆					
Report status and findings of all field studies - Q3								◆				
Report status and findings of all field studies - Q4									◆			

◆ Milestone/Deliverable (Originally Planned) use for missed

◆ Milestone/Deliverable (Actual) use when met on time

Team

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