Innovative Window and Retrofit Solutions

Lawrence Berkeley National Laboratory
Robert Hart, Eng/Env Technology Researcher III
510.486.4244 rghart@lbl.gov
WBS 3.5.5.31, 3.5.5.19

Project Summary

Objective and outcome

Address the most pressing technical and market barriers impeding the advancement of high-performance fenestration systems. This work helps maintain an active pipeline of innovative materials for windows and shading systems, enabling continued improvements in their energy, resilience, and comfort performance.

Team and Partners

LBNL: Robert Hart, Charlie Curcija, Howdy Goudey, Christian Kohler, Jacob Jonsson, Lili Yu, Yuan Gao, Anothai Thanachareonkit, Taoning Wang

Partners: CEC, PNNL, NREL, ORNL, Andersen, Marvin, Alpen HPP, Pella, Michigan Tech, University of Sydney, Stephen Selkowitz, NFRC, AERC, ADL Ventures, and more

Stats

Performance Period: 10/01/19 – 9/30/23

DOE budget (FY23): $1,200k, Cost Share:

Milestone 1: Designs and industry collaboration on Thin Triple high volume manufacturing.

Milestone 2: Interior/Exterior Window Attachment Characterization.

Milestone 3: Codes and Standards incl Energy Star V7 work.

LBNL Windows Group

Robert Hart
25 minutes

Innovative Window and Retrofit Solutions

- Hi-R (Thin-Triple, VIG)
- Attachments
- Decarbonization
- Codes and Standards
- Field Demonstrations
- Hi-R window and Wall Panel

Charlie Curcija
15 minutes

Foundational, Industry Enabling Support for Windows Energy Performance

- Software (WINDOW, THERM, AERCalc, IGDB/CGDB)
- Optical Facilities
- Thermal Facilities

Luis Fernandes
20 minutes

Advanced Fenestration Controls for Resilient and Decarbonized Buildings
Community Engagement for Market Impact and Justice

- Dynamic Facades
- Disadvantaged Communities
- Maintaining an Innovation Pipeline
- Increasing Uptake in Commercial Buildings

Problem

44 million Single-Pane Homes* (35%)

Total windows: **2.4B stock**

29M retrofit/year

24M new construction/year

4M houses get windows/year

Floor Area: **97B** SF

139M SF window retrofit per year

284M SF new construction

2.4 million Single-Pane Commercial Buildings (40%)

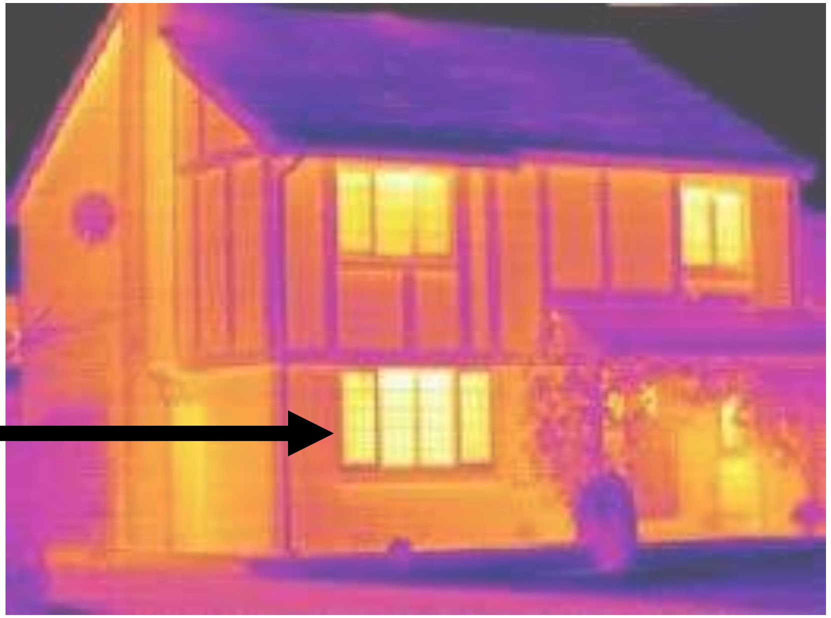
2020 RECS and 2018 CBECS data
* Many homes in cold climates have clear storm windows

Problem

Windows are far behind!

Windows	
Area:	8%
Heat loss:	47%

$45 Billon per year
400 MMT CO_2



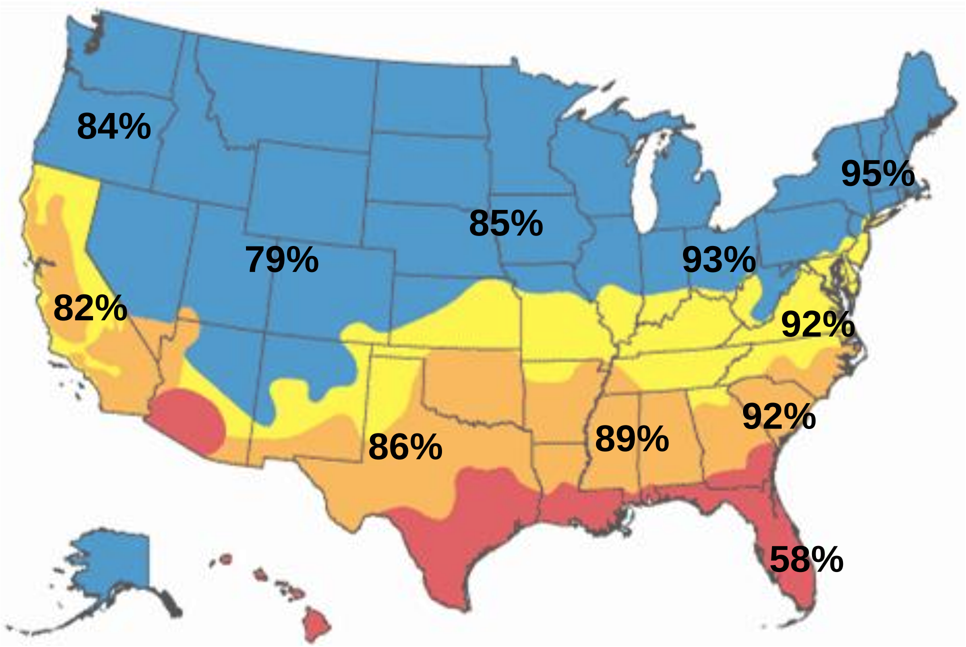
IECC 2021	R-60 Ceilings
	R-20 Walls
	R-3.3 Windows

	Roof	Walls	Floor
Area	25%	42%	25%
Heat loss	9%	31%	13%

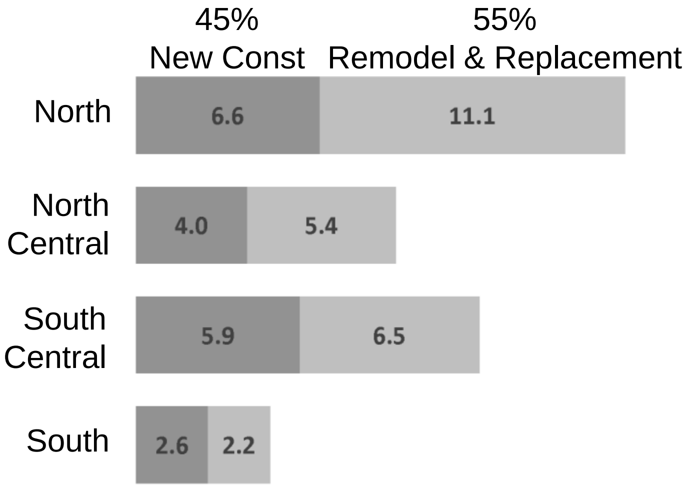
*Heat loss is defined as the overall average heat transmission of a gross area of the exterior building envelope in BTU/hr at Minneapolis 99% design day conditions.
**Thermal performance is the consolidated layer as calculated in the DOE residential prototype for IECC 2021 climate zone 6A.

Industry Approach

Energy Star v6 Market share (86% overall)



52 million windows per year



Industry Approach

State adoption*	3		24		0		3		9		4	
	2006		2009		2012		2015		2018		2021	
Climate Zone	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC
1	1.20	0.40	1.20	0.30	NR	0.25	NR	0.25	NR	0.25	NR	0.25
2	0.75	0.40	0.65	0.30	0.40	0.25	0.40	0.25	0.40	0.25	0.40	0.25
3	0.65	0.40	0.50	0.30	0.35	0.25	0.35	0.25	0.32	0.25	0.30	0.25
4 except Marine	0.40	NR	0.35	NR	0.32	0.40	0.32	0.40	0.32	0.40	0.30	0.40
5 and Marine 4	0.35	NR	0.35	NR	0.32	NR	0.32	NR	0.30	NR	0.30	0.40
6	0.35	NR	0.35	NR	0.32	NR	0.32	NR	0.30	NR	0.30	NR
7 & 8	0.35	NR	0.35	NR	0.32	NR	0.32	NR	0.30	NR	0.30	NR

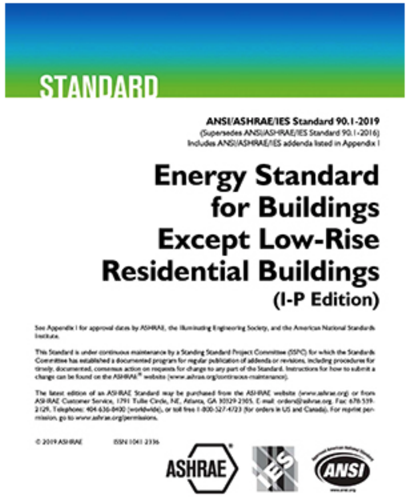
*www.energycodes.gov/state-portal

Climate Zone	V5 - 2009		V6 - 2015	
	U-factor	SHGC	U-factor	SHGC
South	≤0.60	≤0.27	≤0.40	≤0.25
South-Central	≤0.35	≤0.30	≤0.30	≤0.25
North-Central	≤0.32	≤0.40	≤0.30	≤0.40
North*	≤0.30	NR	≤0.27	NR

**See ENERGY STAR specifications for North trade-offs

Codes have caught up

Industry Approach



STANDARD

ANSI/ASHRAE/IES Standard 90.1-2019
(Supersedes ANSI/ASHRAE/IES Standard 90.1-2016)
Includes ANSI/ASHRAE/IES addenda listed in Appendix I

Energy Standard for Buildings Except Low-Rise Residential Buildings
(I-P Edition)

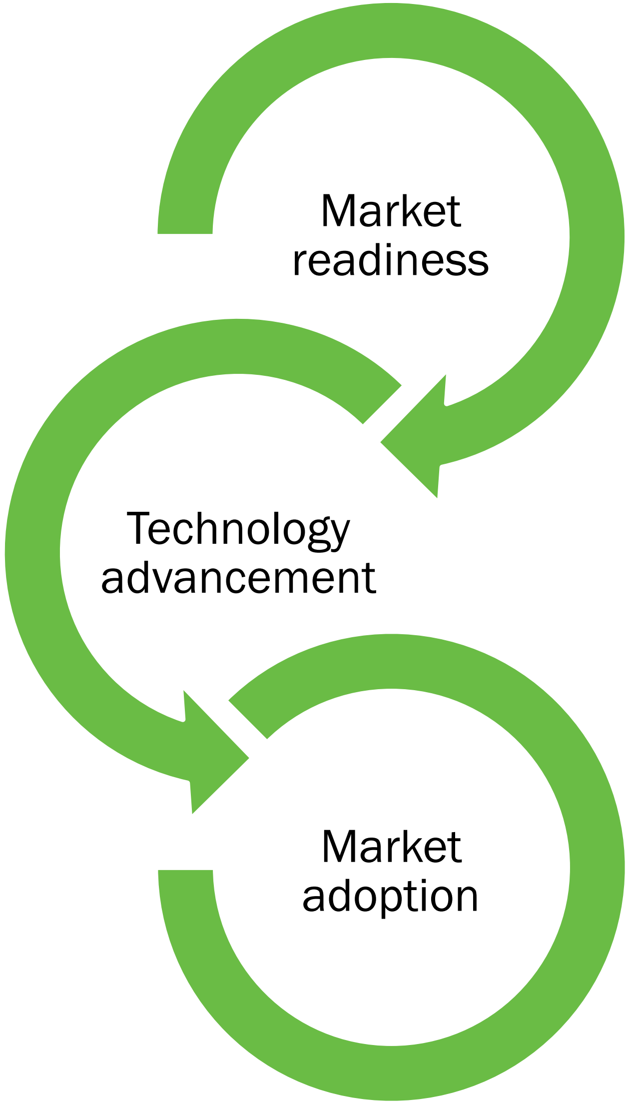
State adoption*	4		4		9		18		5	
	2007		2010		2013		2016		2019	
Climate Zone	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC
1	NM: 1.20 M: 1.20	0.25	NM: 1.20 M: 1.20	0.25	NM: 0.50 M-FX: 0.57 M-OP: 0.65	0.25	NM: 0.50 M-FX: 0.57 M-OP: 0.65	0.25	FX: 0.50 OP: 0.62	FX: 0.23 OP: 0.21
2	NM: 0.75 M: 0.70	0.25	NM: 0.75 M: 0.70	0.25	NM: 0.40 M-FX: 0.57 M-OP: 0.65	0.25	NM: 0.37 M-FX: 0.54 M-OP: 0.65	0.25	FX: 0.45 OP: 0.60	FX: 0.25 OP: 0.23
3	NM: 0.65 M: 0.60	0.25	NM: 0.65 M: 0.60	0.25	NM: 0.35 M-FX: 0.50 M-OP: 0.60	0.25	NM: 0.33 M-FX: 0.45 M-OP: 0.60	0.25	FX: 0.42 OP: 0.54	FX: 0.25 OP: 0.23
4	NM: 0.40 M: 0.50	0.40	NM: 0.40 M: 0.50	0.40	NM: 0.35 M-FX: 0.42 M-OP: 0.50	0.40	NM: 0.31 M-FX: 0.58 M-OP: 0.46	0.36	FX: 0.36 OP: 0.45	FX: 0.36 OP: 0.33
5	NM: 0.35 M: 0.45	0.40	NM: 0.35 M: 0.45	0.40	NM: 0.32 M-FX: 0.42 M-OP: 0.50	0.40	NM: 0.31 M-FX: 0.38 M-OP: 0.46	0.38	FX: 0.36 OP: 0.45	FX: 0.38 OP: 0.33
6	NM: 0.35 M: 0.45	0.40	NM: 0.35 M: 0.45	0.40	NM: 0.32 M-FX: 0.42 M-OP: 0.50	0.40	NM: 0.30 M-FX: 0.36 M-OP: 0.45	0.40	FX: 0.34 OP: 0.42	FX: 0.38 OP: 0.34
7	NM: 0.35 M: 0.40	0.45	NM: 0.35 M: 0.40	0.45	NM: 0.32 M-FX: 0.38 M-OP: 0.40	0.45	NM: 0.28 M-FX: 0.33 M-OP: 0.40	0.45	FX: 0.29 OP: 0.36	FX: 0.40 OP: 0.36
8	NM: 0.35 M: 0.40	0.45	NM: 0.35 M: 0.40	0.45	NM: 0.32 M-FX: 0.38 M-OP: 0.40	0.45	NM: 0.25 M-FX: 0.29 M-OP: 0.35	0.45	FX: 0.26 OP: 0.32	FX: 0.40 OP: 0.36

NM: Non-metal
M: Metal

FX: Fixed
OP: Operable

*www.energycodes.gov/state-portal

Our Approach



Prime market with actionable climate specific consumer recommendations and products, manufacturer support

Identify and support the development of the most potentially impactful new technologies

Manufacturing at scale, Demonstrations, and advancing codes and standards

Harris, Chioke. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. United States. https://doi.org/10.2172/1866581

Alignment and Impact

Increase building energy efficiency

Reduce primary energy use associated with windows by 70% in residential and 90% in commercial buildings by 2050, compared to baseline

Accelerate building electrification

Enhance electrification effort with up to 50% reduced HVAC system sizing, 30% reduced back-up sizing, enhanced comfort, and building resilience

Transform the grid edge at buildings

Reduce winter and summer peak electric loads associated with windows by greater than 50%

Prioritize equity, affordability, and resilience

Focus research on window technologies with potential for incremental costs to consumers below 5.6 $\$/\text{ft}^2$ in residential and 11.9 $\$/\text{ft}^2$ at scale

Demonstrate benefits of high-performance technologies in low-income and disadvantaged communities

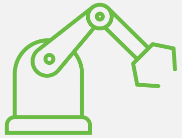
Harris, Chioke. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. United States. https://doi.org/10.2172/1866581

Alignment and Impact

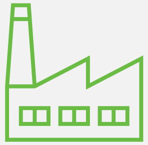
Building Sector	Performance [hr-ft^2-F/BTU]	Installed Premium [$/ft^2 window area]	Primary Energy Savings [Quads]	
			2030	2050
Residential	R6 - R13 (U .17 – U .08)	1.8 – 5.6	1.28	1.07
Commercial	R6 – R10 (U .17 – U .10)	3.9 – 11.9	0.93	0.72

Success

Technology advancement



Manufacturing at scale

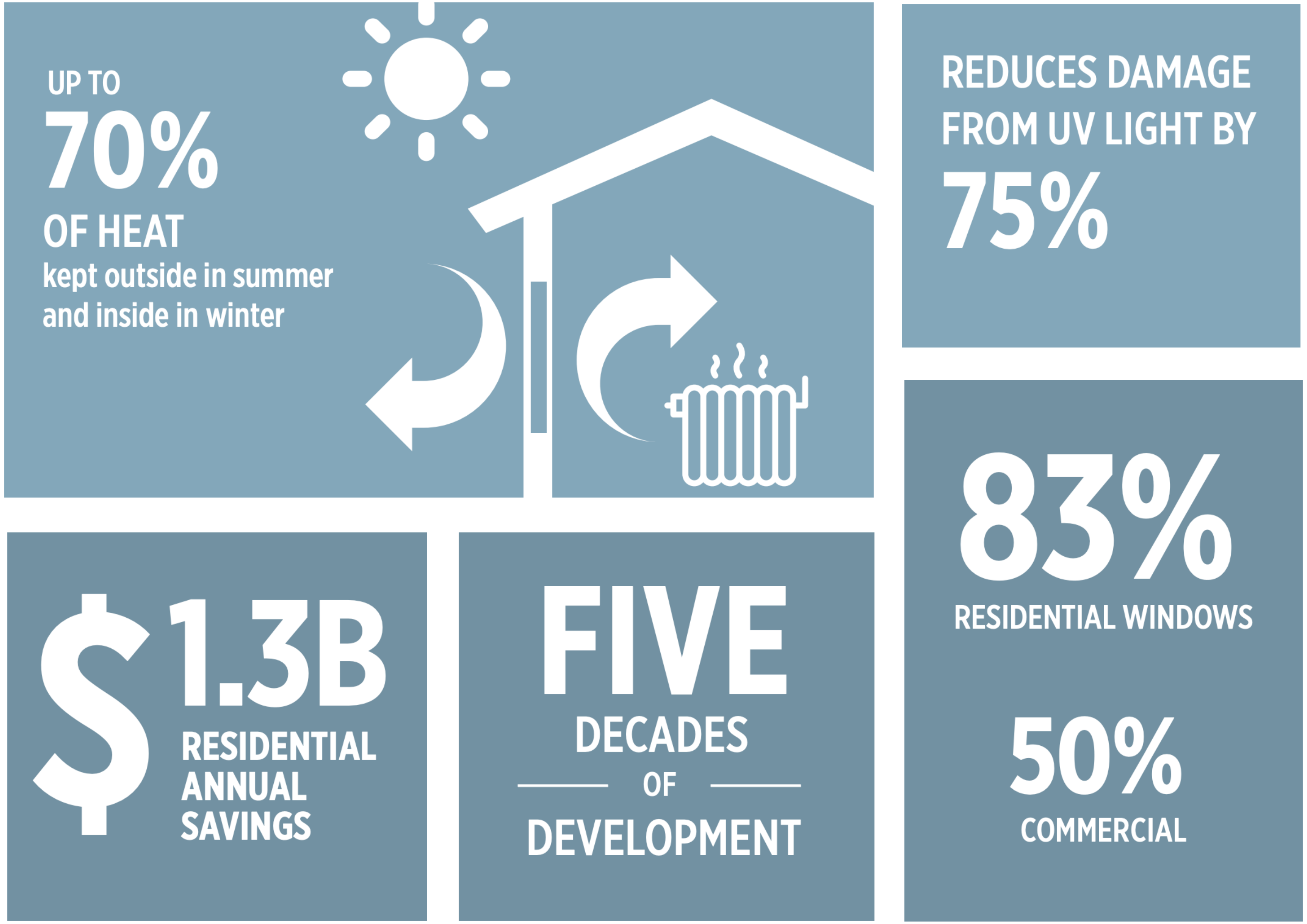


Market adoption

Harris, Chioke. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. United States. https://doi.org/10.2172/1866581

Barriers and Risk

Can we **repeat** the **market adoption** success of double low-e?



https://windows.lbl.gov/sites/default/files/low%20e%20windows.pdf

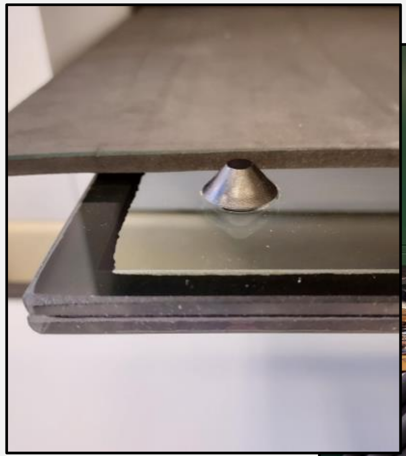
Progress and Future Work: Vacuum Glazing technical Support

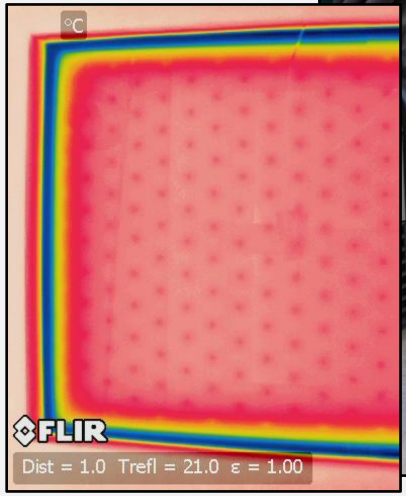
Market readiness

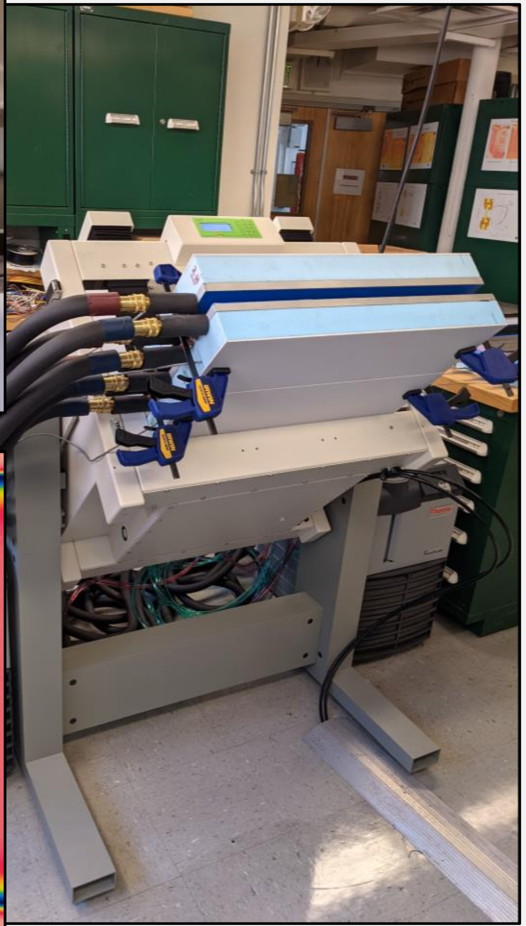
Technical support to development of VIG measurement and rating standards

- Test methodology (VIG and hybrid)
  - Interface layers
  - Spatial distribution
  - Asymmetric heat flow
- Simulation algorithms supporting all pillar geometries
- International collaboration

- FY23+
  - Implementing algorithms
  - Standard development
  - VIG Stakeholder forum



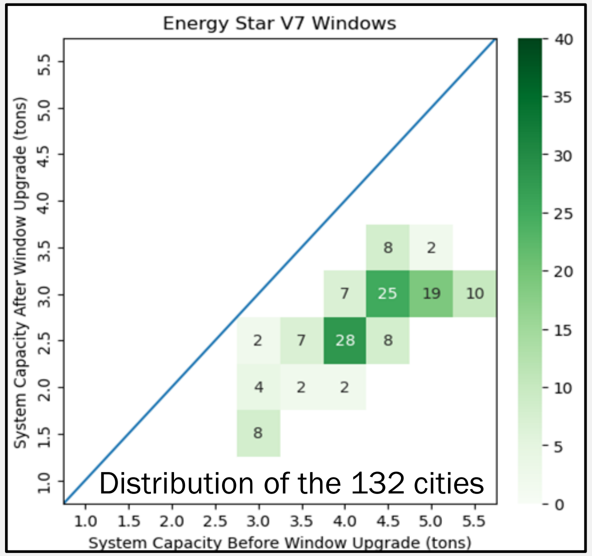




Commercial

Progress and Future Work: Enhancing HVAC Decarb Effort

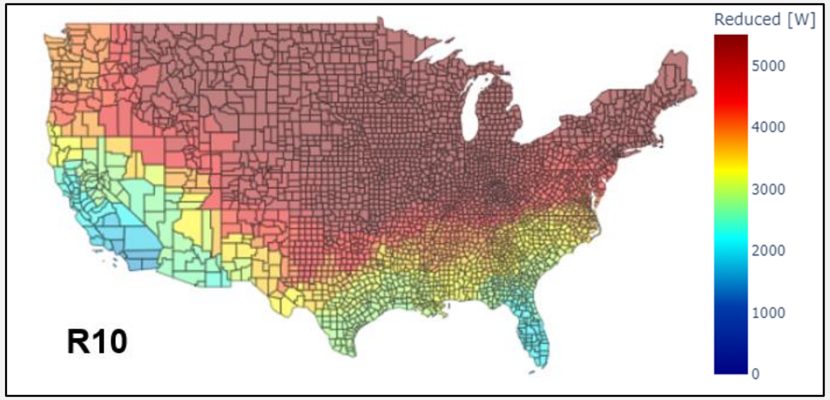
HP Sizing



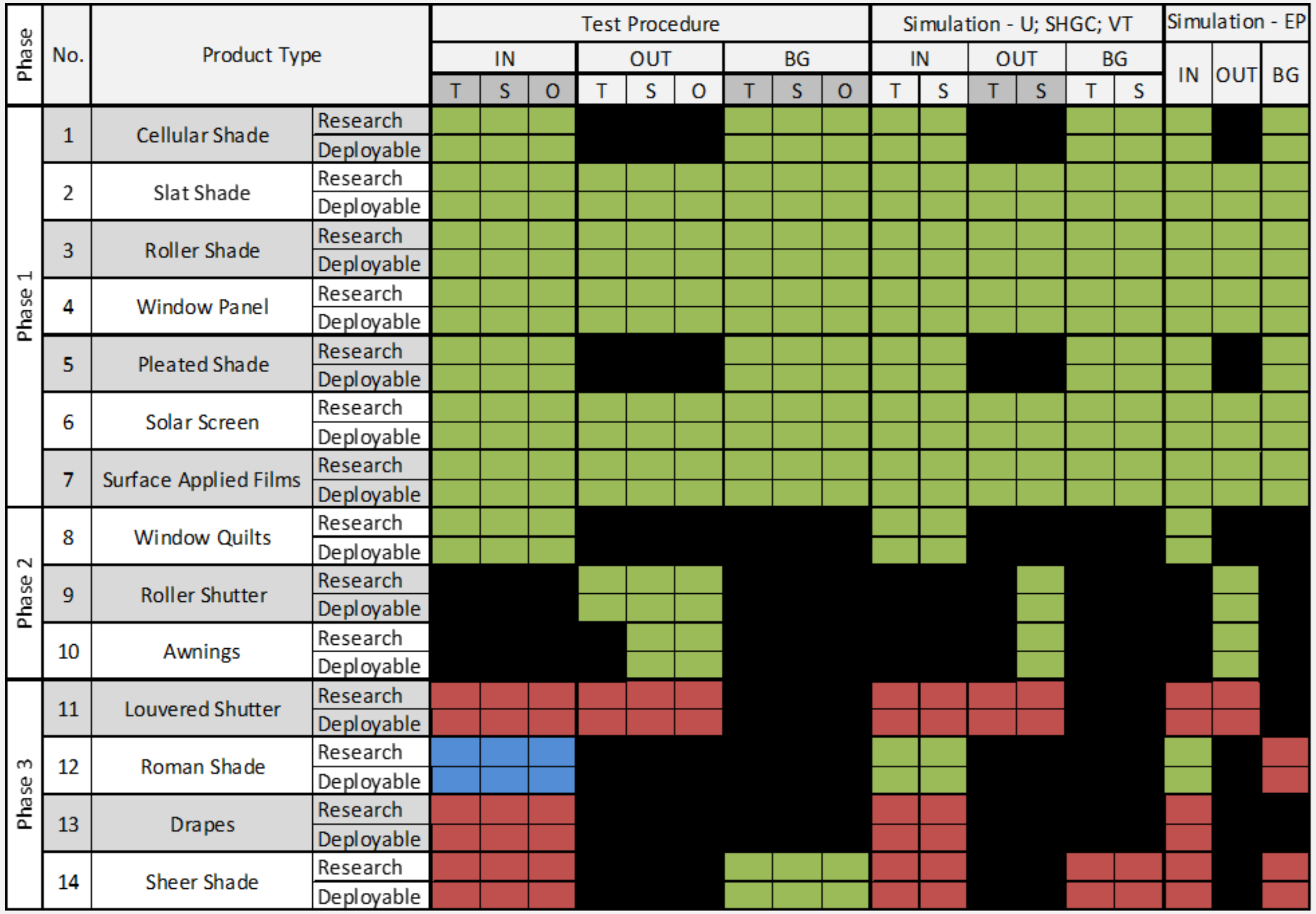
Quantify extent window upgrades can enhance HVAC decarbonization

- Affordability of electrification
  - Heat pump sizing (equipment cost)
  - Backup heating sizing (panel and service)
- Save HVAC electricity usage and utility costs
- Grid impacts (winter & summer peaks)
- Life cycle carbon of heat pumps

Backup heating reduction



Progress and Future Work: Support AERC Rating System

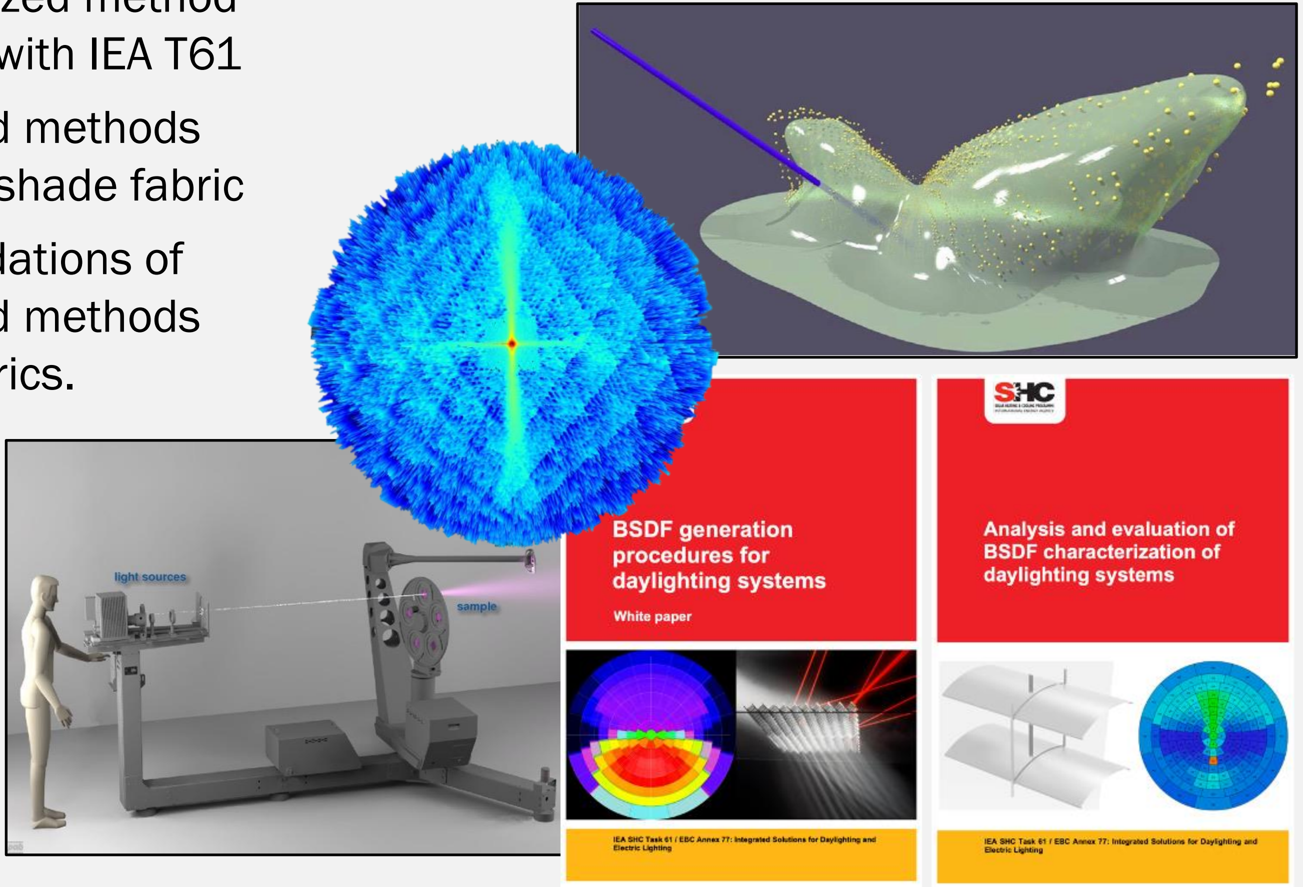


Attachment model development & validation with lab measurements and modeling comparisons

Progress and Future Work: Modeling Complex Fenestration

Market readiness

- Established generalized method of generating BSDF with IEA T61
- Developed simplified methods for modeling woven shade fabric
- Performed field validations of different models and methods using a range of fabrics.



Ward, Gregory J., et al. "Modeling specular transmission of complex fenestration systems with data-driven BSDFs." *Building and Environment* 196 (2021): 107774.
Wang, Taoning, et al. "Field validation of data-driven BSDF and peak extraction models for light-scattering fabric shades." *Energy and Buildings* 262 (2022): 112002.
Wang, Taoning, et al. "Field validation of isotropic analytical models for simulating fabric shades." *Building and Environment* (2023): 110223.

Progress and Future Work: Hi-R Window and Wall Panel

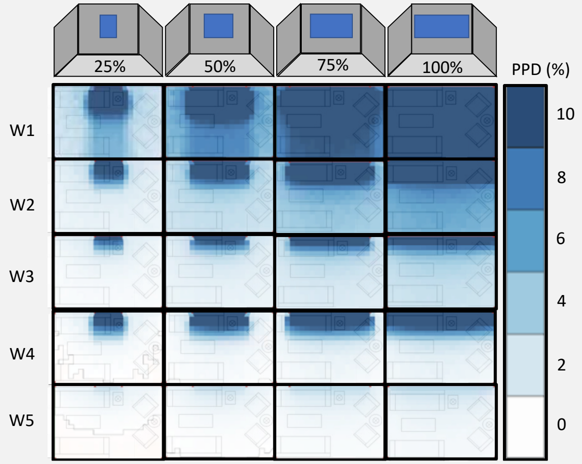
Technology Advancement

Create a receptor system to reduce thermal bridging and improve air leakage and water penetration

- **Reduced** overall **labor**
- **Consistent fabrication**
- Factory fabrication in a **controlled construction environment**
- **Safer construction** conditions
- Lower **labor and scheduling costs** and **reduced on site trade conflicts**

ADL VENTURES
KAPTURE PREFAB
Pella
BERKELEY LAB
OAK RIDGE National Laboratory
sto Building with conscience.

Progress and Future Work: Thin Glass Industry Support

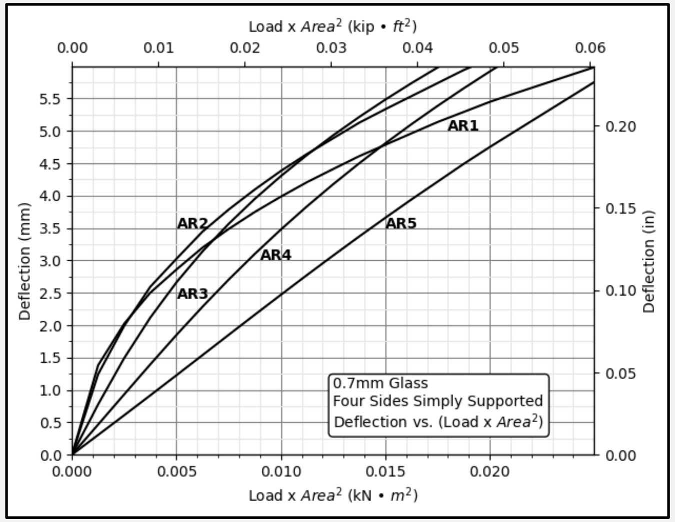


Demonstrate the business **case for comfort**

Hart, Robert, C. Curcija, S. Selkowitz. 2019. Determining the Value of Occupant Comfort from Highly Insulating Windows. Thermal Performance of the Exterior Envelopes of Whole Buildings XIV International Conference. Clearwater Beach, Fl.

Expansion of ASTM E1300 to 0.5mm*

- **Load resistance**
- Vertical deflection
- **Horizontal deflection**
- **Natural frequency**
- IGU Weight
- Safe handling limits



*Co-funded by California Energy Commission

Progress and Future Work: Thin Glass

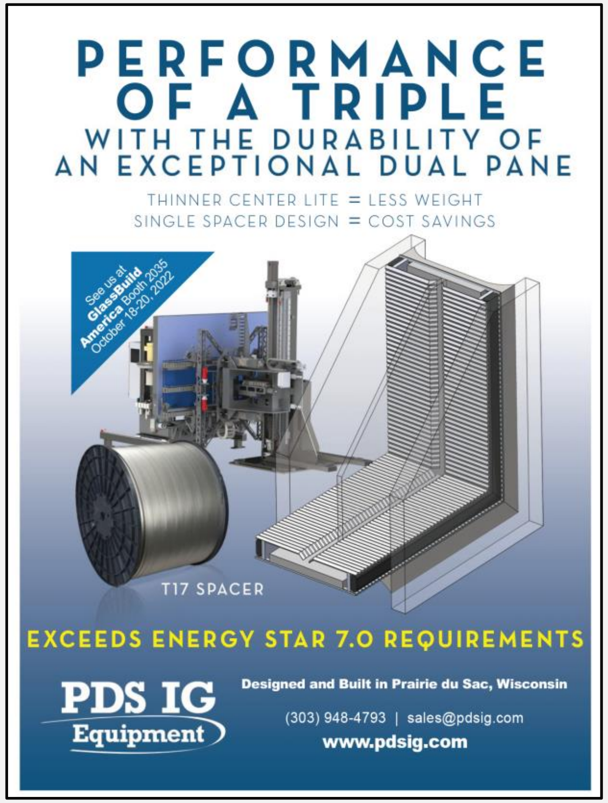
Building on 5+ years of effort including **comfort & energy analysis, design guidance** and **technology demonstrations**

More thin glass products entering the market

- Multiple manufacturers
- Multiple component suppliers
- Multiple equipment suppliers

FY23+: Safety glazing focus

- Stakeholder Technical Advisory Group
- Define laboratory test plan



Ad in Window and Door Magazine, October 2022

Progress and Future Work: Field Demonstrations

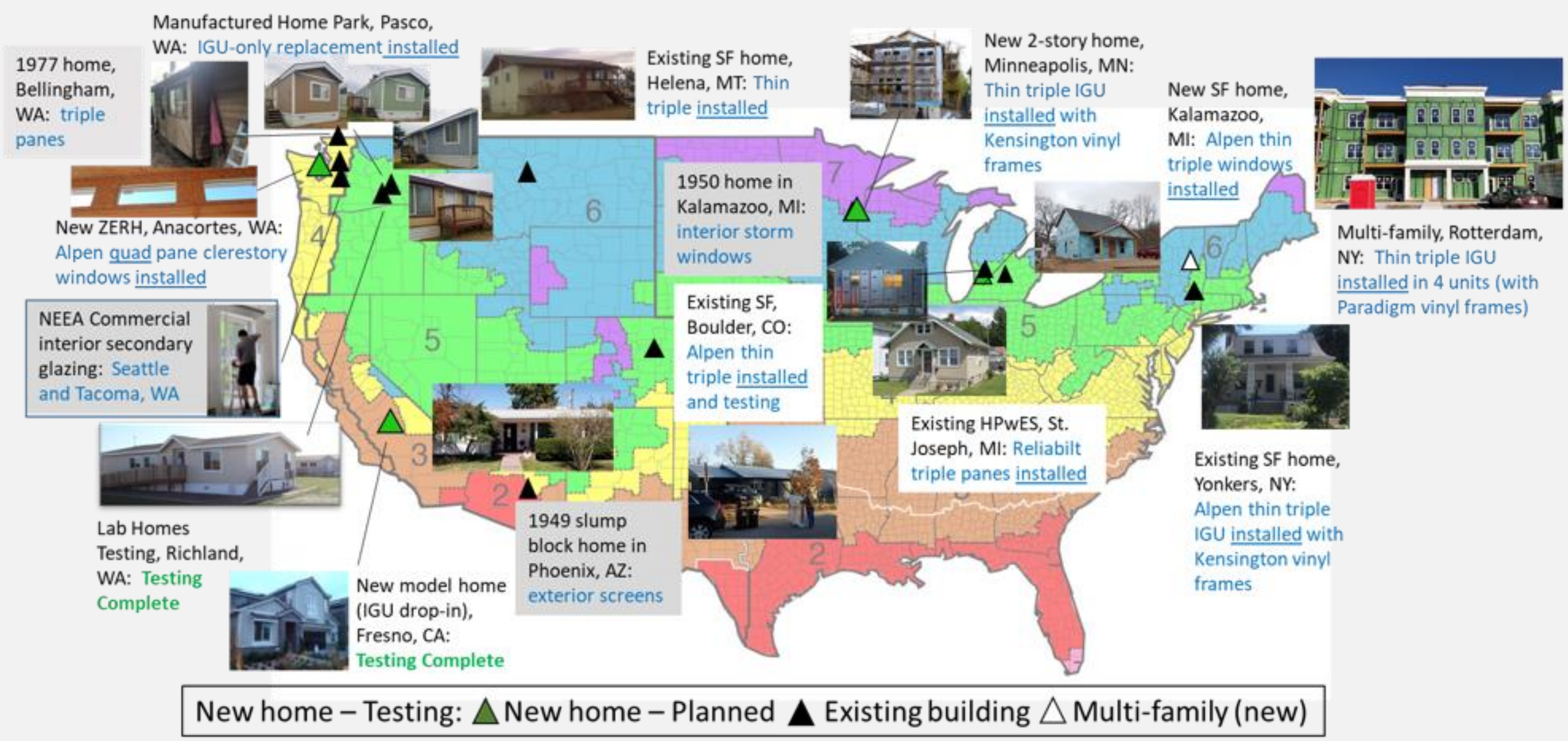


*Image courtesy of PNNL

Progress and Future Work: Codes and Standards

IECC
INTERNATIONAL ENERGY CONSERVATION CODE

Climate Zone	2015		2018		2021	
	U-factor	SHGC	U-factor	SHGC	U-factor	SHGC
1	NR	0.25	NR	0.25	NR	0.25
2	0.40	0.25	0.40	0.25	0.40	0.25
3	0.35	0.25	0.32	0.25	0.30	0.25
4 except Marine	0.32	0.40	0.32	0.40	0.30	0.40
5 and Marine 4	0.32	NR	0.30	NR	0.30	0.40
6	0.32	NR	0.30	NR	0.30	NR
7 & 8	0.32	NR	0.30	NR	0.30	NR

ENERGY STAR

Climate Zone	V6 - 2015		V7 - 2023	
	U-factor	SHGC	U-factor	SHGC
South	≤0.40	≤0.25	≤0.32	≤0.23
South-Central	≤0.30	≤0.25	≤0.28	≤0.23
North-Central	≤0.30	≤0.40	≤0.25	≤0.40
North*	≤0.27	NR	≤0.22	≥0.17

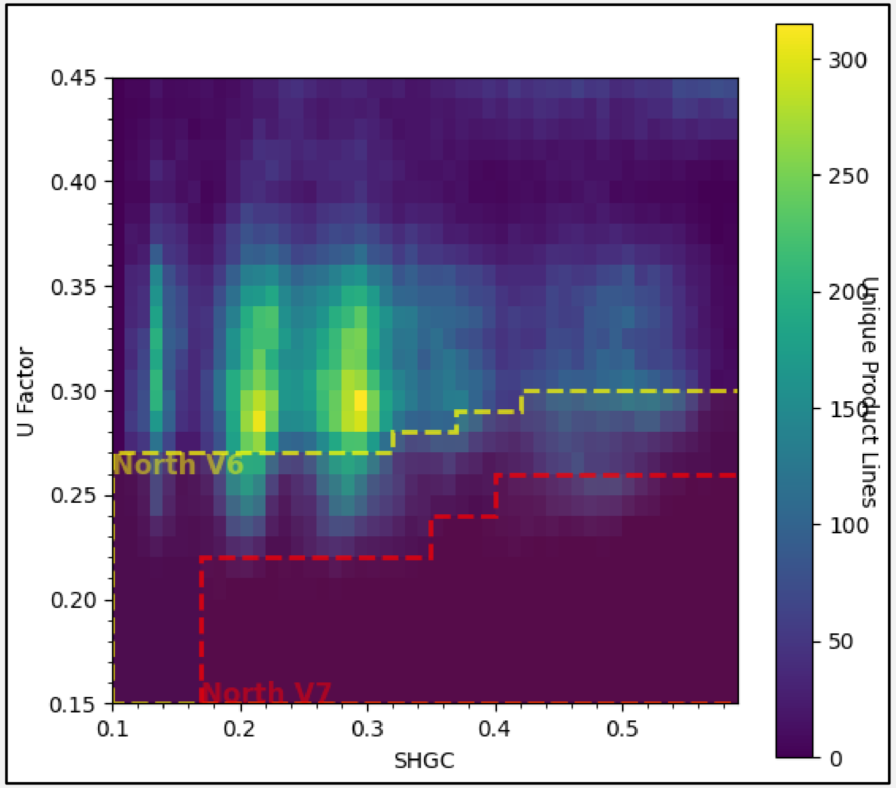
*See ENERGY STAR specifications for North trade-offs

Market Adoption

ENERGY STAR Most Efficient 2022
www.energystar.gov

U-factor
≤0.20

Progress and Future Work: Codes and Standards



Lead Partnership for Advanced Window Solutions (PAWS) Codes and Standards Working Group

Organized organization technical responses to **CA T24, NY Stretch, IECC,** and **Energy Star**

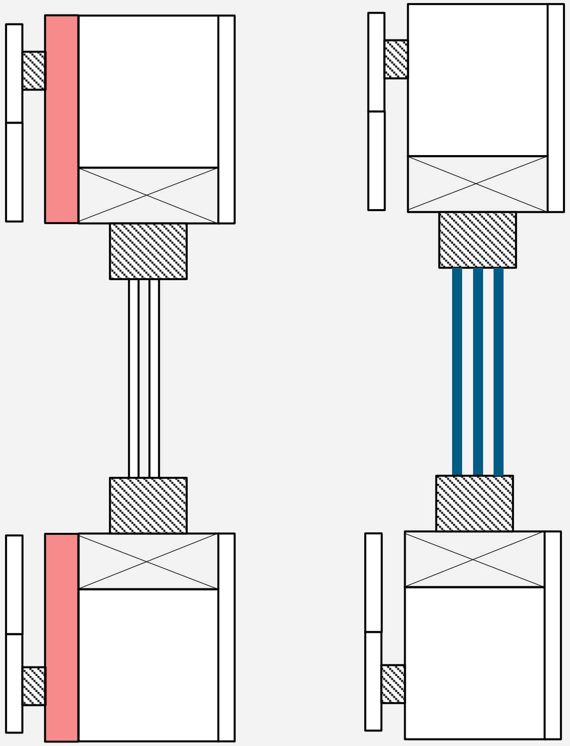
Technical Webinars for NFRC members on how to meet Energy Star v7

•Frames: https://www.youtube.com/watch?v=SXqoWMQjbMs

•IGUs: https://www.youtube.com/watch?v=_6z1u2_fGx0

Progress and Future Work: Codes and Standards

2021 IECC



Demonstrated window wall-trade-off works in CZ-3 and above!

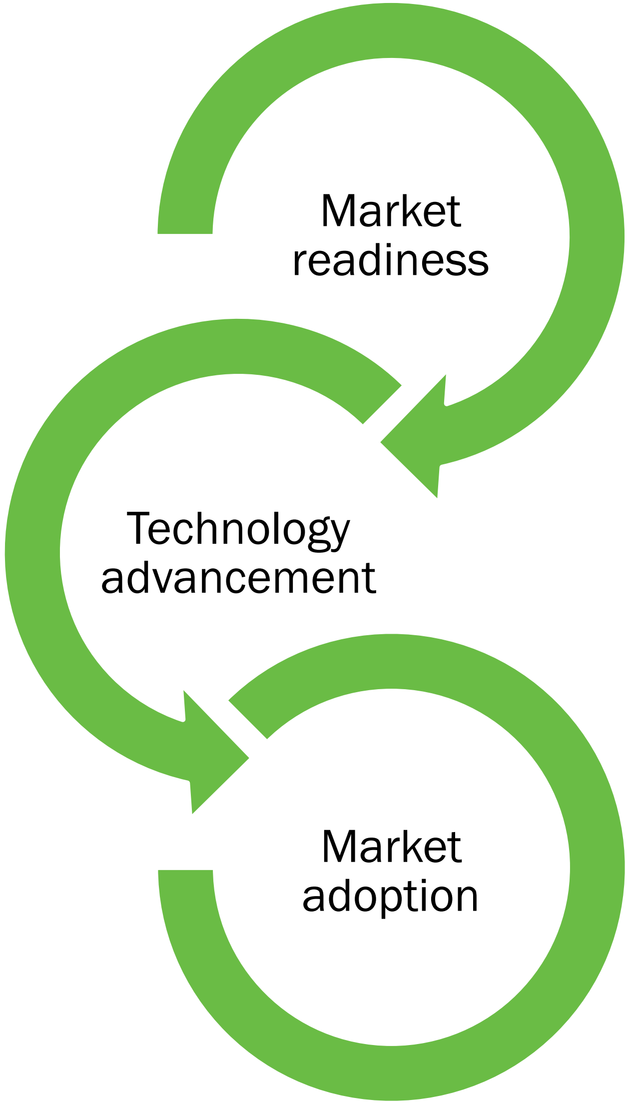
Cort, Katherine, Louie Edward; Hart, Robert. 2022. Using Triple-Pane Windows to Meet IECC Envelope Requirements. ASHRAE Journal 64 (3), 50-58

Prescriptive: R5 continuous insulation
or
Tradeoff: high performance windows

FY23+:

- Energy Star v7 focus
- Production homebuilders
- Retrofit programs (Utilities, etc.)

Approach Summary



Vacuum Glazing
HVAC Decarbonization
Attachment Energy Rating System support

Hi-R Window and Wall Panel
Vacuum Glazing
Thin-Glass

Vacuum Glazing
Thin-Glass
Codes and Standards

Harris, Chioke. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. United States. https://doi.org/10.2172/1866581

Thank You

Lawrence Berkeley National Laboratory
Robert Hart, Eng/Env Technology Researcher III
510.486.4244 rghart@lbl.gov
WBS 3.5.5.31, 3.5.5.19

REFERENCE SLIDES

Project Execution

	FY2020				FY2021				FY2022				FY2023			
Planned budget	2,132,986				2,289,317				1,740,855				1,889,799			
Spent budget	2,000,957				1,941,022				1,292,775				708,161*			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work																
Interior/Exterior Shades Characterization																
Attachments Software Updates																
AERC Support Technical Reports																
Attachments Field Study																
BSDF/CFS Work																
Energy Star																
Enhanced Window Collaborative Website Upgrade																
New Window Materials Review																
Thin-Triple Stakeholder/Industry Support																
VIG Measurments																
Current/Future Work																
Decarb																

Team

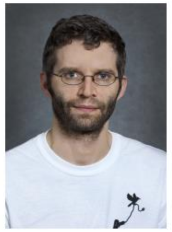

Charlie Ćurčija


Robin Mitchell


Stephen Czarnecki


Simon Vidanović


Christian Kohler


Jacob Jonsson


Robert Hart


Anothai Thanachareonkit


Taoning Wang


Daniel McQuillen

Dr. Charlie Curcija is principal investigator and project leader. He is a heat transfer expert and is leading research and software development in thermal and optical performance of windows and shading systems. Charlie has over 40 years of experience in the energy performance of buildings and fenestration.

Robin Mitchell is software development manager. Robin manages development of all windows software tools and provides active user support.

Stephen Czarnecki and **Simon Vidanovic** are software developers. They are working on all of windows software tools and APIs.

Christian Kohler is BT Department Head. His expertise is in window and envelope heat transfer, related software development and sensors and controls.

Dr. Jacob Jonsson is optical physicist and manager of the Optics Lab. Jacob is working on the development of methods and models for optical performance of glazing and shading systems

Robert Hart is a scientist with expertise in both modeling and measurements of heat transfer. He is actively involved in highly-insulating windows project and also contributes to the development of models and methods for shading systems.

Dr. Anothai Thanachareonkit is a researcher specializing in window and building envelope materials and systems, visual comfort, and building analysis

Taoning Wang is a scientist specializing in optical characterization of complex fenestration systems.

Daniel McQuillen is an independent software developer, specializing in e-learning and simulation applications. He is working as a subcontractor for the development of COMFEN, IGSDB, THERM and AERCalc.

LBNL's Windows group exists for over 45 years with a track record of accomplishment based on successful technology development and deployment, state-of-the-art measurements and software development. Staff have unique breadth and depth of expertise and a series of unique lab and field test facilities that provide state of the art performance feedback. DOE has designated LBNL's Windows group as a core DOE program.