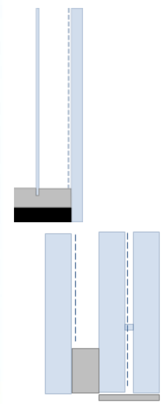
U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Window-Wall Integrated Panel



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OAK RIDGE
National Laboratory

Project Summary

Timeline:

Start date: 10/1/2018

Planned end date: 9/30/2021

Key Milestones

1. Design the window receptors for the wall panel; 6/30/2019
2. Print a set of window receptors for the wall panel that allow for streamlined field installation; 9/30/2019
3. Print an optimized set of window receptors for the wall panel that allow for streamlined field installation; 3/31/2020

Budget:

Total Project $ to Date:

- DOE: $267K
- Cost Share: $149K

Total Project $:

- DOE: $1,000K (Plus-up: $1,500K)
- Cost Share: 409K

Key Partners:

ORNL	Pella
Sto	ADL
S. Wall	

Project Outcome:

Develop better integrated **window-wall panel** and perform **field validation** of the highly insulated windows, factory-installed in a **pre-fabricated** wall panels and brought to a **building site** as integral modular units, **ready to be assembled** into the full building envelope sections. The choice of highly insulated windows will be made based on the **trade-off** between energy performance, cost and ease of installation. The selection will be made between vacuum insulated glazing (**VIG**), hybrid VIG configuration with a **third low-e pane of glass** and between-glass shading (shading located between VIG and third pane of glass) and **thin glass triple glazing.**

Team


Charlie Curcija


Christian Kohler


Robert Hart


Howdy Goudey


Luis Fernandes

Dr. Charlie Curcija is PI in LBNL's Building Technologies (BT) Department. He is a heat transfer expert and is leading research in thermal and optical performance of windows and shading systems. Charlie has over 35 years of experience in the energy performance of buildings, building facades, windows and shading systems. **Christian Kohler** is BT Department Head. His expertise is in window and envelope heat transfer, related software development and sensors and controls. **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. **Howdy Goudey** is the manager of the IR Thermal Lab, with extensive experience in the measurement of heat transfer. He is working on the characterization of highly insulating glazing and windows and insulating materials. **Dr. Luis Fernandes** has experience in both daylighting and heat transfer performance of windows. He is contributing to the measurements and method development for highly insulating materials.


Mahabir Bhandari


Simon Pallin

ORNL team is led by **Dr. Mahabir Bhandari**, R&D staff with expertise in thermal and whole building energy modeling, **Dr. Simon Palin** is R&D staff with expertise in moisture and durability analysis.

Challenge

- Building construction is **highly fragmented process**, which is particularly true for building envelope construction
- Walls are normally built **on site** with rough opening for windows and doors
- Openings are often **inconsistently dimensioned** and framed with excessive amount of **framing elements** creating **thermal bridges** and additional pathways for **air infiltration** and water penetration
- Windows are often installed in rough openings without regard for full installation instructions from manufacturers and due to **inconsistent dimensioning of openings**
- Window installation is **labor intensive** and therefore expensive process
- **Factory-installed** windows, coupled with proper window opening construction **reduces overall labor** and can be done **consistently** by workers that are trained specifically for this purpose
- Window opening design that reduces or **eliminates thermal bridging** and provides **good air sealing** and **protection from water penetration** is possible when the window-wall interface is designed with this purpose in mind
- Highly insulated windows with integrated dynamic shading have potential for **net zero energy** performance and will better match insulating value of the wall

Approach

- Develop an integrated design of **panelized insulated wall** and **highly-insulating, (dynamic) windows**
  - Design wall panel receptacles for consistent and effective window installation in the field. Use **3D printing** to enable rapid prototyping
  - Explore alternative to field installation by investigating issues connected to **transportation** of fully assembled window-wall sections
  - **Measure i**ntegrated assembly in a **laboratory** for moisture, air and thermal performance
  - **Model** thermal and moisture performance and **compare to measured data**
- Demonstrate window-wall assembly in an **outdoor testbed** and **validate** window-wall energy performance. Verify that air and water tightness are at least 50% better than industry standard
  - Install integrated assembly into the test bed and perform **extended testing t**o confirm **air**, **moisture** and **thermal** performance
  - Observe state of the assembly after the testing is completed and comment on the **prospects of overall durability**
- **Document** findings and recommend ways to reduce cost and increase productivity of façade fabrication and installation in the field**. Disseminate findings.**

Project Plan

Task 1: Development of panelized continuous insulated wall with standardized openings and connectors for windows

- Design panelized continuous insulated wall with standardized openings for windows & standardized connectors/brackets for window installation & connection to DC power
- Design opening trim to meet thermal break, air and water resistance requirements

Task 2: Development of a window suited for installation in a panel wall

- Select suitable window for the integrated window-wall panel and design necessary modifications/improvements so that it can be installed in newly designed wall opening/trim package.
- Design receiving brackets for installation into the wall brackets

Task 3 (plus-up task): Development of a panel integrated energy efficiency sensor package

Task 4: Integration of components into the panelized wall-window system

- Experiment with the designed components and iterate, as required to achieve the most effective design

Task 5: Fabrication of prototype units

- The fabricator (Southern Wall) will construct prototype walls
- Window manufacturer (Pella) will provide window units for integration.

Project Plan – Continued

Task 6: Lab testing

- Section of wall, including window will be tested in HAM chamber for moisture performance and in thermal chambers (hot box and IR) for thermal performance

Task 7: Field installation and validation

- Transport the prototype to the field validation site (testbed) and install into the testbed opening
- Perform measurements for a 3 month period
- Perform EnergyPlus modeling for testbed climate (calibration) and also for all typical climate zones
- Document and report measurement and modeling results

Task 8: Techno-economic analysis

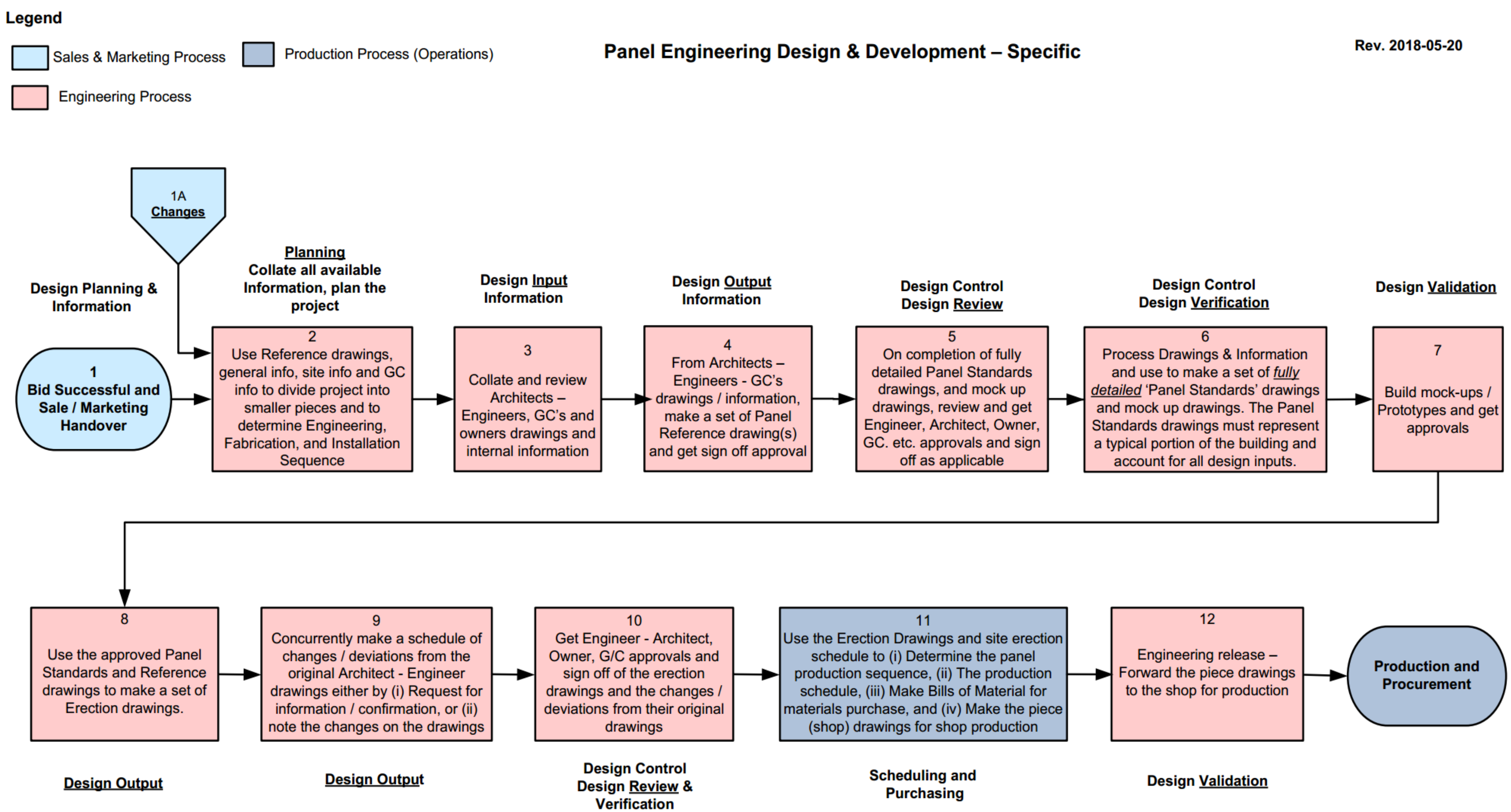
- Performe on a component basis (i.e., cost of component materials and their fabrication) and extend to the cost of the integrated assemblies and overall production process

Task 9: Final report

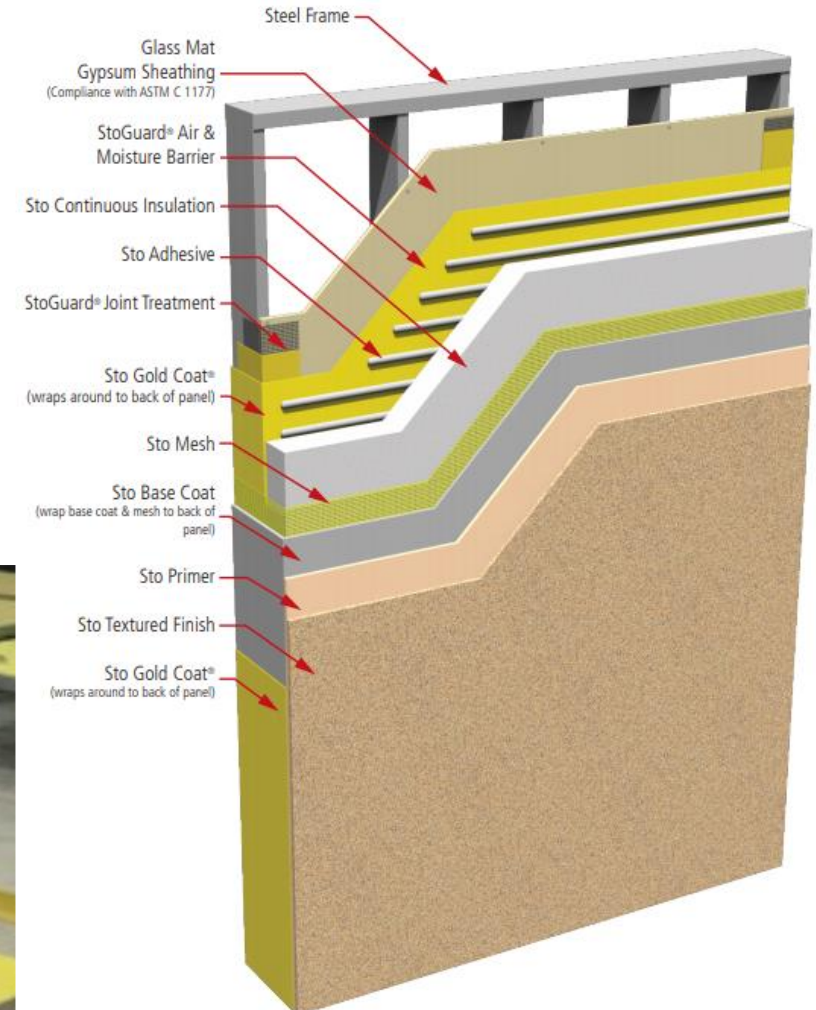
Task 10: External validation and dissemination

- Technical Advisory Group (TAG)
- Partner manufacturers (Sto and Pella)
- Conferences and industry gatherings

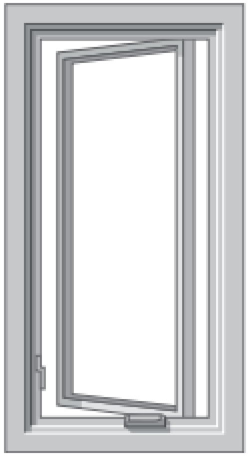
Wall Panel Design and Development Process



Wall Panel Design and Fabrication

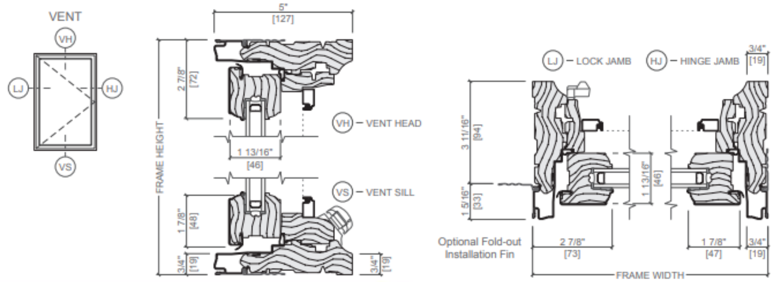


Window Design and Performance



CASEMENT

UNIT SECTIONS
Aluminum-Clad Exterior

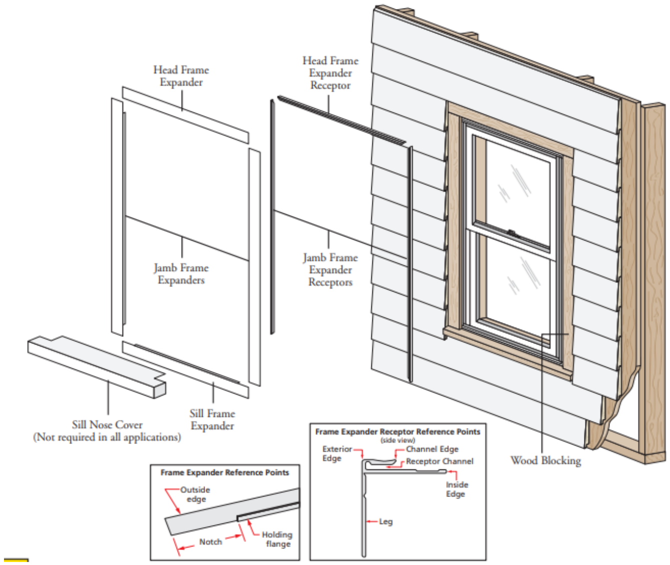


GLAZING PERFORMANCE - TOTAL UNIT
Wood Exterior
Vent Awning and Large Awning Triple-Pane Glass

Glazing Thickness	Type of Glazing	NFRC Certified Product #	Glass (mm)			Gap Fill	Performance Values 1				Shaded Areas Meet ENERGY STAR® Performance Criteria in Zones Shown							
											U. S.				Canada 2			
											Zone				ER	Zone		
			Ext.	Mid	Int.		U-Factor	SHGC	VLT	CR	N	NC	SC	S		1	2	3
VENT																		
1"	Advanced Low-E IG	PEL-N-40-07700-00001	3	3	3	argon	0.21	0.23	0.42	72					27			
	with grilles-between-the-glass	PEL-N-40-07978-00001					0.21	0.21	0.38	72					26			
	with integral grilles	PEL-N-40-07987-00001					0.21	0.21	0.38	72					26			
1"	Advanced Low-E IG	PEL-N-40-07706-00001	3	3	3	Krypton	0.17	0.23	0.42	76					31			
	with grilles-between-the-glass	PEL-N-40-07984-00001					0.18	0.21	0.38	76					30			
	with integral grilles	PEL-N-40-07993-00001					0.18	0.21	0.38	76					30			
1"	SunDefense™ Low-E IG	PEL-N-40-07701-00001	3	3	3	argon	0.21	0.17	0.39	72					24			
	with grilles-between-the-glass	PEL-N-40-07979-00001					0.21	0.16	0.35	72					23			
	with integral grilles	PEL-N-40-07988-00001					0.21	0.16	0.35	72					23			
1"	SunDefense™ Low-E IG	PEL-N-40-07707-00001	3	3	3	Krypton	0.17	0.17	0.39	77					27			
	with grilles-between-the-glass	PEL-N-40-07985-00001					0.17	0.16	0.35	77					27			
	with integral grilles	PEL-N-40-07994-00001					0.17	0.16	0.35	77					27			
1"	NaturalSun Low-E IG	PEL-N-40-07699-00001	3	3	3	argon	0.21	0.39	0.48	71					36			
	with grilles-between-the-glass	PEL-N-40-07977-00001					0.21	0.35	0.43	71					34			
	with integral grilles	PEL-N-40-07986-00001					0.21	0.35	0.43	71					34			
1"	NaturalSun Low-E IG	PEL-N-40-07705-00001	3	3	3	Krypton	0.18	0.39	0.48	76					40			
	with grilles-between-the-glass	PEL-N-40-07983-00001					0.18	0.35	0.43	76					38			
	with integral grilles	PEL-N-40-07992-00001					0.18	0.35	0.43	76					38			
HIGH ALTITUDE GLAZING																		
1"	Advanced Low-E IG	PEL-N-40-07703-00001	3	3	3	air	0.24	0.24	0.42	67					23			
	with grilles-between-the-glass	PEL-N-40-07981-00001					0.24	0.22	0.38	67					22			
	with integral grilles	PEL-N-40-07990-00001					0.24	0.22	0.38	67					22			
1"	SunDefense Low-E IG	PEL-N-40-07704-00001	3	3	3	air	0.24	0.18	0.39	68					20			
	with grilles-between-the-glass	PEL-N-40-07982-00001					0.24	0.16	0.35	68					19			
	with integral grilles	PEL-N-40-07991-00001					0.24	0.16	0.35	68					19			
1"	NaturalSun Low-E IG	PEL-N-40-07702-00001	3	3	3	air	0.24	0.39	0.48	67					33			
	with grilles-between-the-glass	PEL-N-40-07980-00001					0.24	0.35	0.43	67					30			
	with integral grilles	PEL-N-40-07989-00001					0.24	0.35	0.43	67					30			

3D Printing of Integration Components

Oak Ridge National Laboratory



Fused Deposition Modeling

Uses a heated nozzle to melt and deposit a thin lament of thermoplastic material into a two-dimensional pattern.

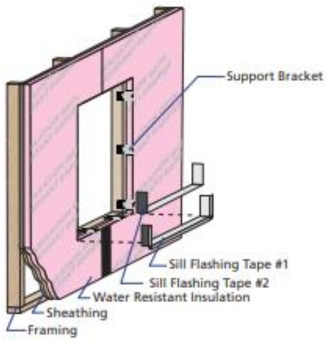
Equipment: Stratasys, 3D Systems, Afinia, Solidoodle

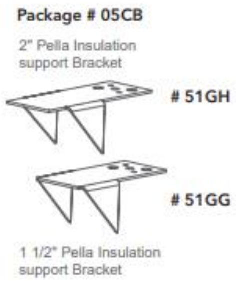
Multi-head Photopolymer

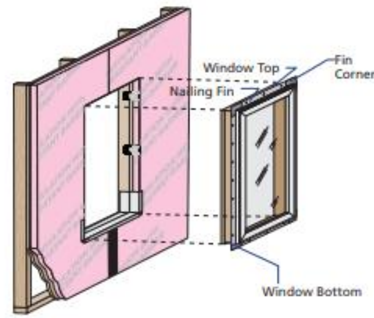
Inkjet print heads are used to jet liquid photopolymers onto a build platform. The material is immediately cured by UV lamps and solidified which allows to build layers on top of each other.

Equipment: Stratasys/Objet

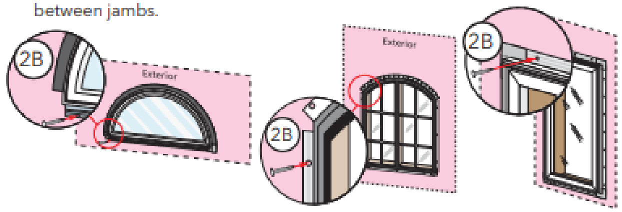
Integration Process Design and Documentation



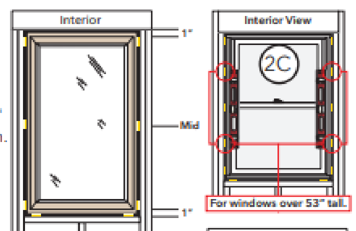




A. **Insert the window into the opening** on the sill spacers. Center the window between jambs.

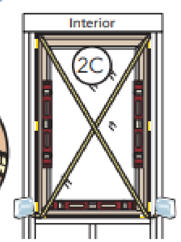


B. **Drive two fasteners,** one near each end of the top nailing fin. (Longer fasteners required, see the nail fin anchor instructions at the end of this booklet.)

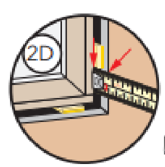


C. **Plumb and square the window** using shims at the locations shown. Adjust shims to plumb and square the window. Keep shims 1/2" short of window frame depth.

NOTE: DO NOT shim above the window. Additional shims are required at screw locations for large units and combinations. See the anchor schedule at the end of this booklet.



D. **Check the window placement** by measuring from the interior surface of the window frame or jamb extension to the interior surface of the wall for consistency. If the dimensions are not equal, confirm the fins are folded fully to 90° (if applicable).



Refer to the nail fin installation preparation section at the beginning of this booklet.

A. **Inspect the joints of the water resistant exterior insulation.** The insulation must be fastened and sealed according to the insulation manufacturer's instructions. Pella Corporation assumes no responsibility for the design, quality or durability of the exterior insulation system or its joints.
Taped joints intersecting with the bottom or sides of the opening must have tape installed before beginning window installation.

B. **Insert the Rough Opening Support Brackets** by pressing the support bracket into the edge of the insulation panel. Insure that the bracket is tight against the wall system's sheathing or rough opening framing. **Support brackets are required at each shim location**:
- Sill: 1/2" from each bottom corner.
- Jambs: Refer to Step 2C.

Place additional support brackets at each mullion or interlocker.
Refer to the anchor schedule at the end of the booklet for all additional shim and support bracket locations that are required for larger windows and combinations.
For vinyl windows, add support brackets so maximum spacing is 18" along the sill.
NOTE: No support brackets are required above the window.

C. **Fasten the support bracket to the rough opening framing.**
- For wood framing, use either two roofing nails or two #6 or #8 screws with minimum 1-1/2" embedment. Stagger the fasteners.
- For light gauge steel framing, use one #10 or two #8 self-drilling / tapping screws.
- For concrete or masonry, use one 3/16" masonry screw with 1-1/4" minimum embedment.

D. **Cut 6" pieces of flashing tape and apply tape over each support bracket,** covering each bracket completely.

E. **Cut 2 pieces of flashing tape 12"** longer than the opening width.

F. **Apply sill flashing tape #1** at the sill extending 2" to the exterior and 6" up each jamb.

G. **Cut 1" wide tabs** at each corner by tearing the foil 1/2" each way from corner.

H. **Apply sill flashing tape #2** overlapping tape #1 by 1" minimum.

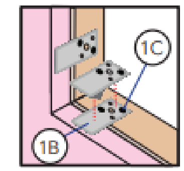
I. **Cut 4 pieces of flashing tape** equal to the height of the opening.

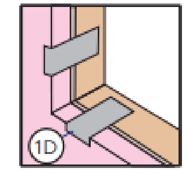
J. **Apply one piece on each jamb** extending 2" onto the surface of the insulating panel.

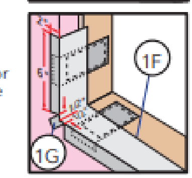
K. **Apply a second piece on each jamb** overlapping the first piece by 1". Press tape down firmly.

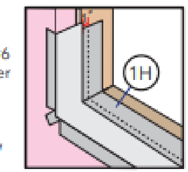
L. **Install and level sill shims.** Place 1" wide x 1/4" to 3/8" thick shims onto each rough opening support bracket on the sill. Keep shims back 1/2" from interior face of the window.

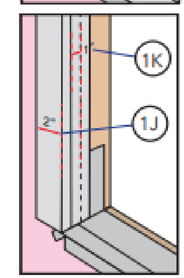
M. **Use flashing tape to attach shims** to prevent movement after they are level.
NOTE: Improper placement of shims may result in bowing the bottom of the window.







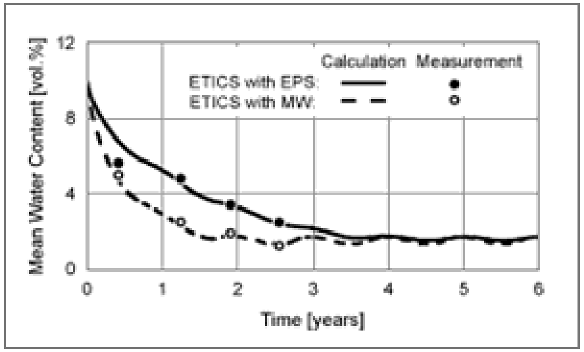


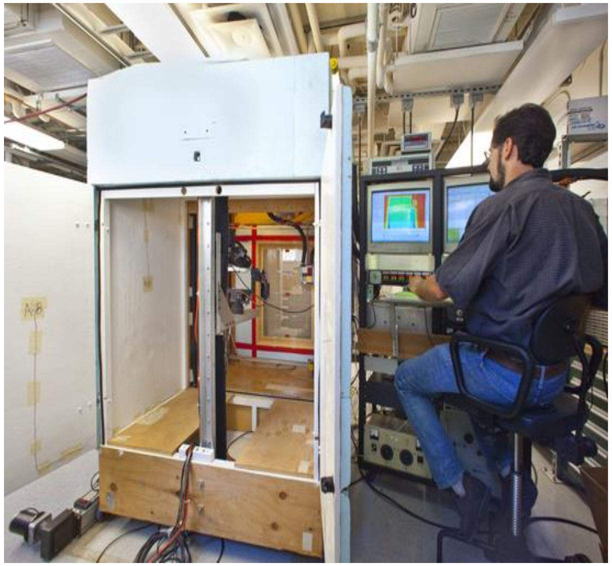


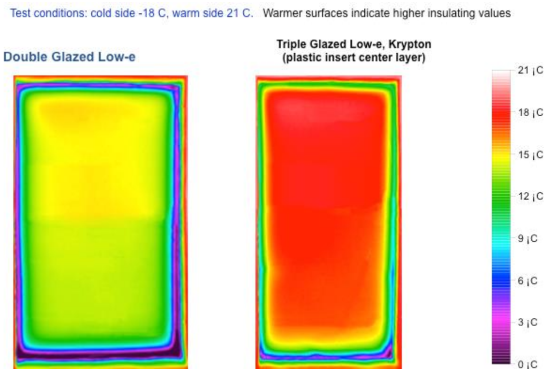
Site Installation and Integration Issues

Lab Testing

HAM Chamber for moisture & thermal performance measurements

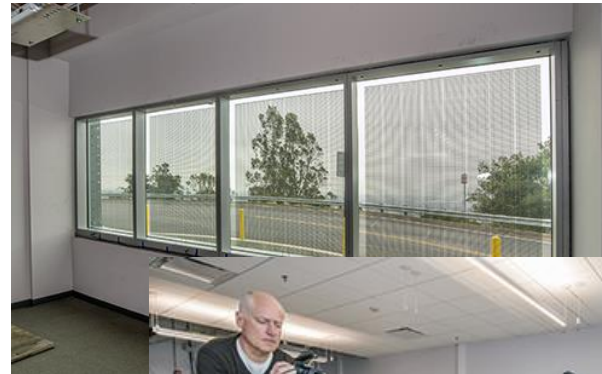


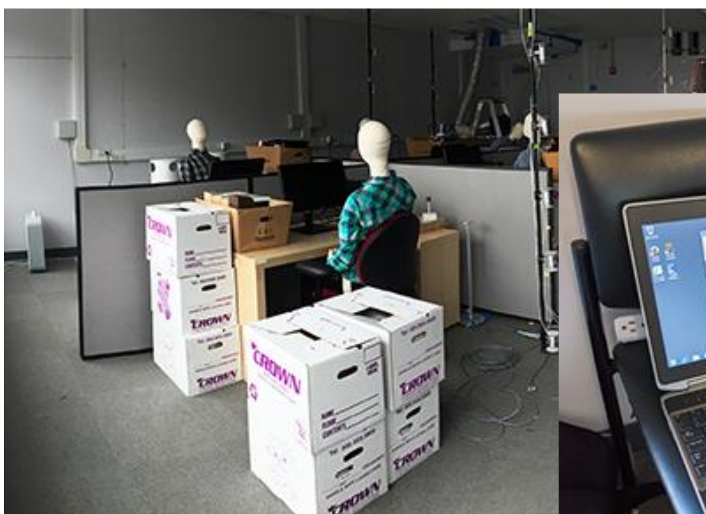


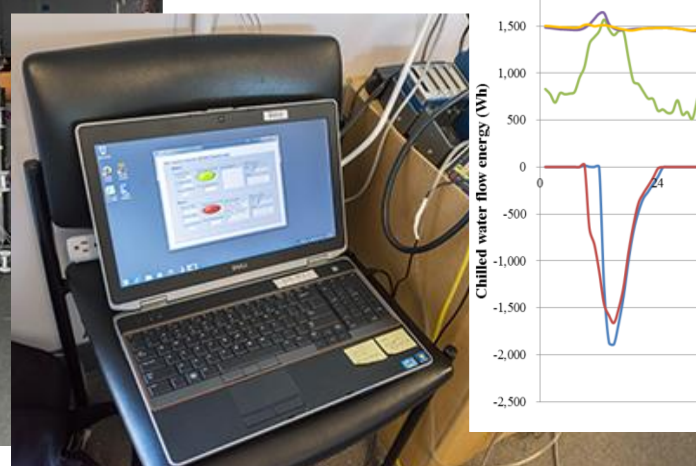


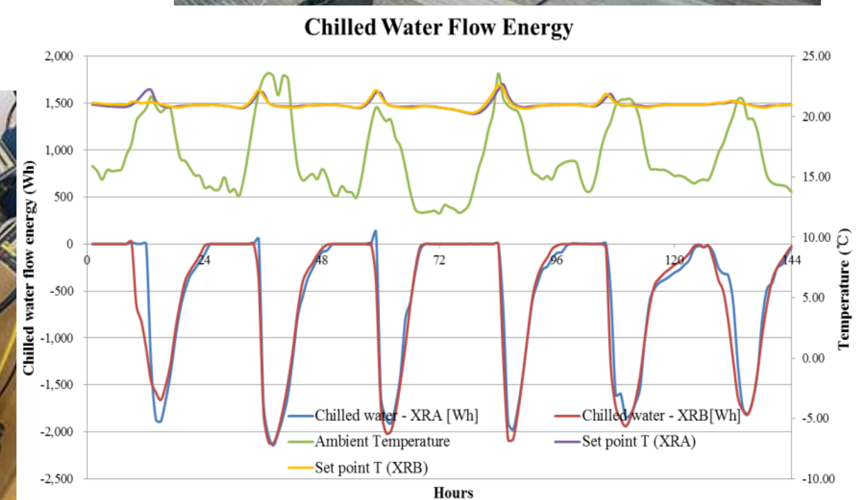
IR Thermography Apparatus

Field Testing – FLEXLAB at LBNL









Project Impacts

- **Windows (including transparent façade) and opaque envelope have the technical potential for net zero energy performance, which translates to approximately 11 quads per year, or $110 billion/year. This is equivalent to nearly 600 Mt of CO_2.**
  - Cooling impacts for windows: 1.4 quads / 66 Mt CO_2
  - Heating impacts for windows: 3.9 quads / 202 Mt CO_2
  - Cooling impacts for walls (including infiltration): 0.6 quads / 24 Mt CO_2
  - Heating impacts of walls (including infiltration): 6.5 quads / 345 Mt CO_2.
- **Installation of highly insulated, dynamic windows into the wall panel at the factory assures that integrated assembly performs better by reducing unwanted thermal bridges and pathways for air infiltration, while increasing durability and integrity of the construction.**
- **Integrated wall panel with window makes it more cost-effective to integrate sensors into the construction, which will be explored if plus-up funding is provided in years 2 & 3.**
- **Streamlined window-wall integration can lead to increased efficiency, labor reduction and overall cost reduction**

Remaining Project Work

- Complete design of panelized continuous wall with standardized openings and connectors for windows
- Complete design of a window with highly insulating glazing and installation components that will fit wall panelized receptors
- Print a set of window receptors for the wall panel that allow for streamlined field installation
- Design integration of components into the panelized wall-window system
- Fabricate prototype units to demonstrate t3echnology and to use for lab and field testing
- Perform lab testing for thermal, air infiltration and moisture performance
- Perform techno-economic analysis on a component and integration level
- Perform field testing to demonstrate integrated performance as installed in real building
- Write final report with detailed design and installation details
- Form technical advisory group (TAG) and disseminate results of design, measurements, and validation

Thank You

LBNL ORNL

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REFERENCE SLIDES

LBNL Project Budget

Project Budget: $1,000K for 3 years. Plus-up option: $1,500K
Variances: None
Cost to Date: $100K
Additional Funding: $409K cost share from industry partners

Budget History					
New		FY 2019 (current)		FY 2020 – FY2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
NA	NA	$334K	$149K	$666K	$260K

Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2018		Completed Work										
Projected End: 9/30/2020		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2019				FY2020				FY2021			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
NA												
Current/Future Work												
Design the window receptors for the wall panel												
Print a set of window receptors for the wall panel												
Print an optimized set of window receptors												
Moisture analysis of the completed design												
lab testing												
field validation results, Techno-Economic Analysis												