GEB Technical Report Series: Windows and Opaque Envelope

Building Technologies Office

June 16, 2020

RFIs Open Now for Windows, Opaque Building Envelope RDOs

- DOE's Building Technologies Office (BTO) has issued 2 RFIs to solicit feedback on its draft Research & Development Opportunities (RDO) reports for Windows and Opaque Building Envelope.
- Response deadline is July 20, 2020
- Download the RDOs and RFIs from https://eere-exchange.energy.gov

- Respond to the Opaque Building Envelope RFI on EERE Exchange
- Respond to the Windows RFI on EERE Exchange
- Learn more about the RDO reports and RFIs

Webinar Agenda

I. **GEB Overview**
   - Monica Neukomm, Senior Policy Advisor
     - Building Technologies Office

II. **GEB Windows and Opaque Envelope Report**
   - Chioke Harris, Research Engineer
     - National Renewable Energy Laboratory (NREL)

III. **Dynamic Solar Control**
   - Christian Kohler
     - Lawrence Berkeley National Laboratory (LBNL)

IV. **Dynamic Technologies for Opaque Envelopes**
   - Diana Hun
     - Oak Ridge National Laboratory (ORNL)

V. **Q&A Session**
   - Monica Neukomm, Senior Policy Advisor
     - Building Technologies Office





GEB Technical Report Webinar Series

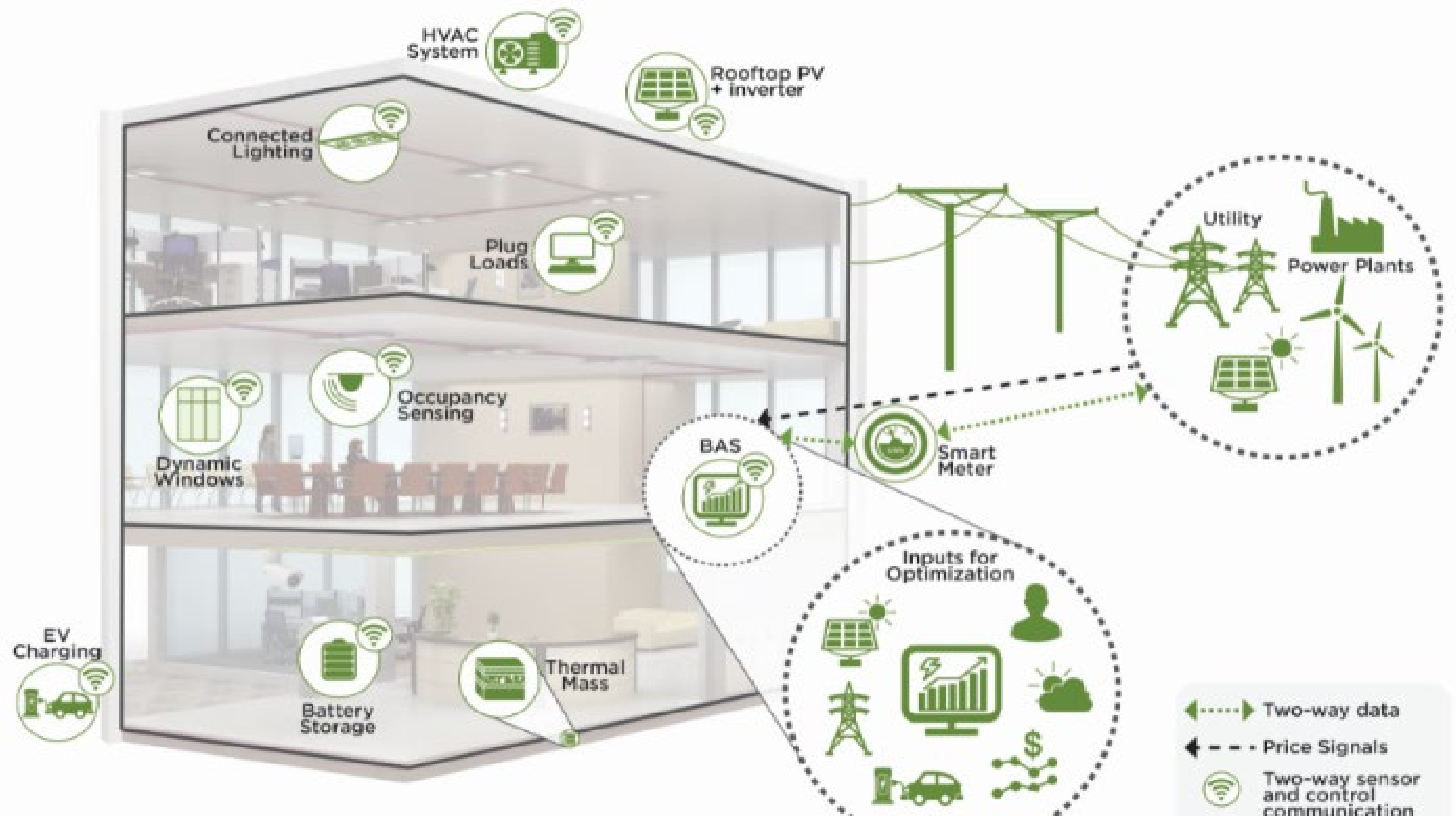
Topic	Date	Time
Whole-building Control, Sensing, Modeling & Analytics	May 19	2:00pm - 3:30pm ET
Lighting & Electronics	May 26	2:00pm - 3:00pm ET
Heating, Ventilation & Air Conditioning (HVAC)	June 2	2:00pm - 3:30pm ET
Water Heating & Appliances	June 9	2:00pm - 3:00pm ET
Envelope & Windows	June 16	2:00pm - 3:30pm ET
Integration - Building Equipment	June 23	2:00pm - 3:00pm ET
Integration –Distributed Energy Resources (DERs)	June 30	2:00pm - 3:00pm ET

GEB Technical Report Series Overview

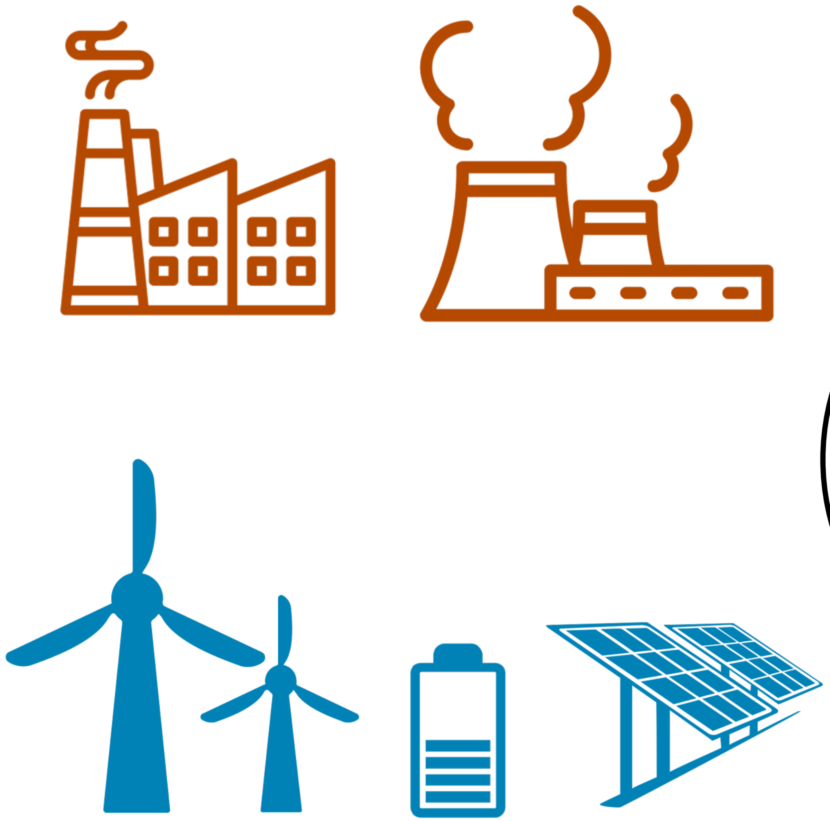
The GEB Technical Report Series outlines key demand flexibility opportunities across BTO's R&D portfolio:
https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings

Technical Report Series

- Overview of Research Challenges
- Heating, Ventilation, & Air Conditioning (HVAC); Water Heating; and Appliances
- Lighting & Electronics
- Building Envelope & Windows
- Sensors & Controls, Data Analytics, and Modeling



GEB is about enabling buildings to provide flexibility in energy use and grid operation



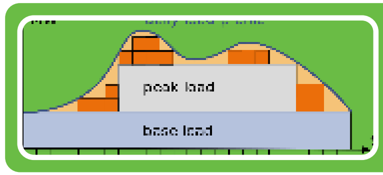
~75% of electricity generation is used in buildings

Supply

Demand

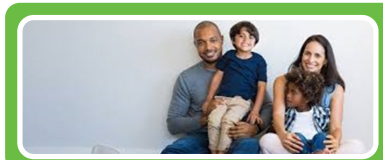
Potential Benefits of Flexible Building Loads

✓ Energy affordability



✓ Improved reliability & resiliency

✓ Reduced grid congestion



✓ Enhanced services

✓ Environmental benefits

✓ Customer choice

Key Characteristics of GEBs

A GEB is an energy-efficient building that uses smart technologies and on-site DERs to provide demand flexibility while co-optimizing for energy cost, grid services, and occupant needs and preferences, in a continuous and integrated way.

EFFICIENT

Persistent low energy use minimizes demand on grid resources and infrastructure

CONNECTED

Two-way communication with flexible technologies, the grid, and occupants

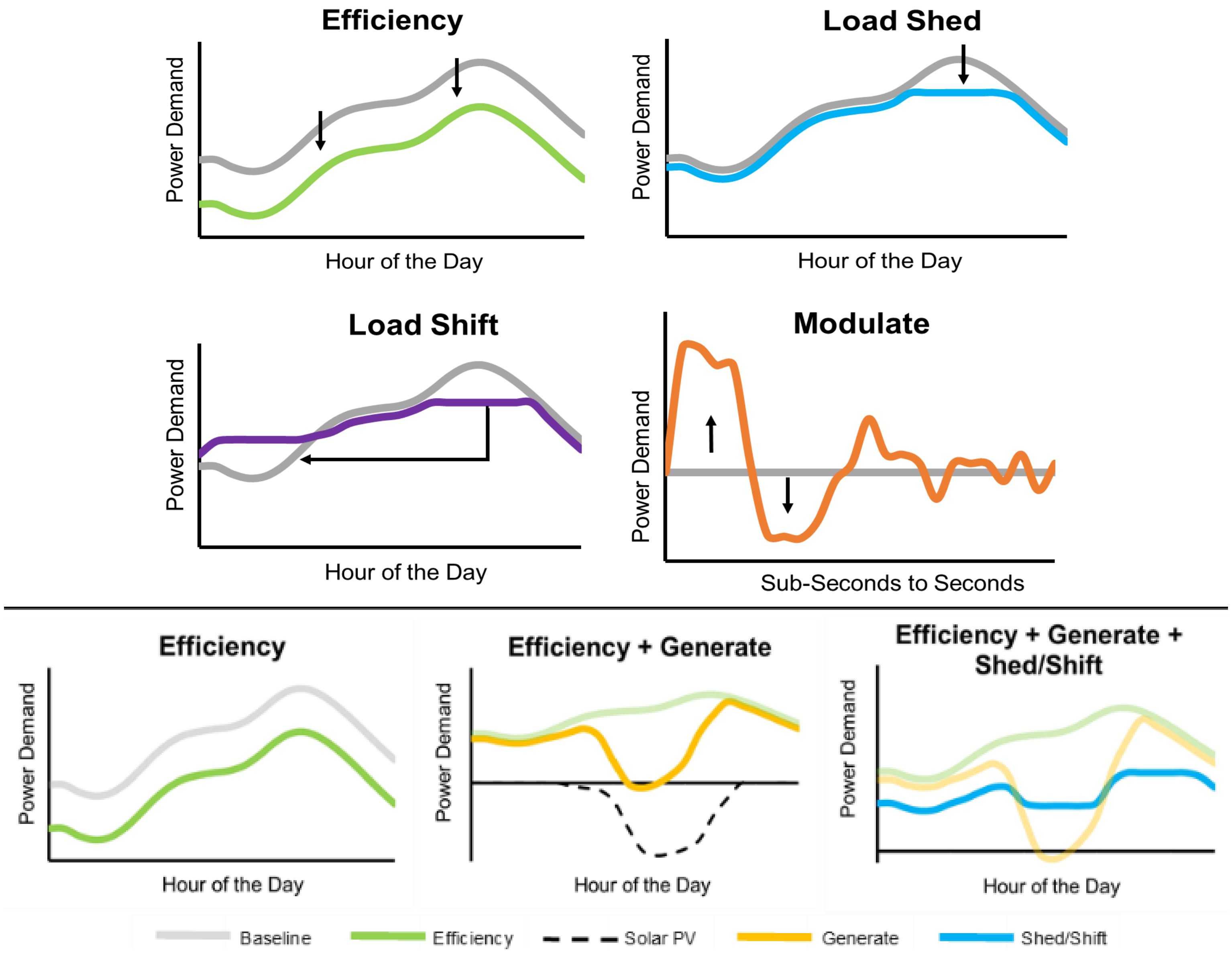
SMART

Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences

FLEXIBLE

Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use

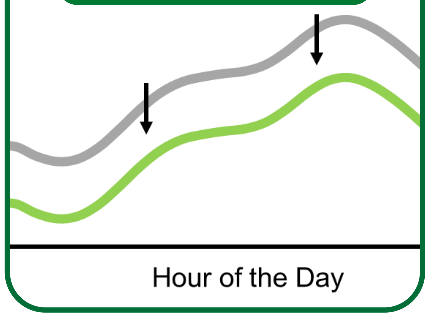
Demand Management Provided by GEB



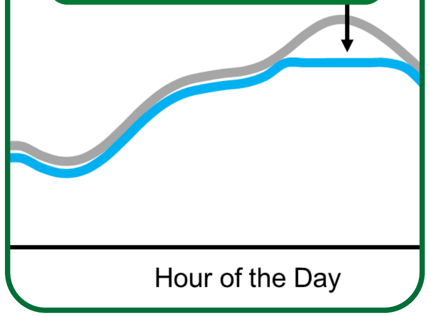
Mapping Flexibility Modes and Grid Services

Buildings can provide grid services through 4 demand management modes.

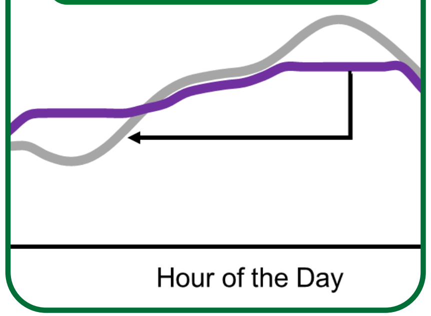
Efficiency



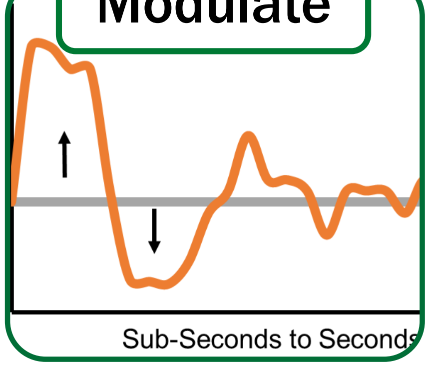
Load Shed



Load Shift



Modulate



	Efficiency	Load Shed	Load Shift	Modulate
Grid Services Provided	• Generation: Energy & Capacity • Non-Wires Solutions	• Contingency Reserves • Generation: Energy & Capacity • Non-Wires Solutions	• Generation: Capacity • Non-Wires Solutions	• Frequency Regulation • Ramping
Examples	• Daylighting with sensors & controls	• Reduce plug loads	• Precool with T-stat; preheat water heater	• Rapid dimming of lighting

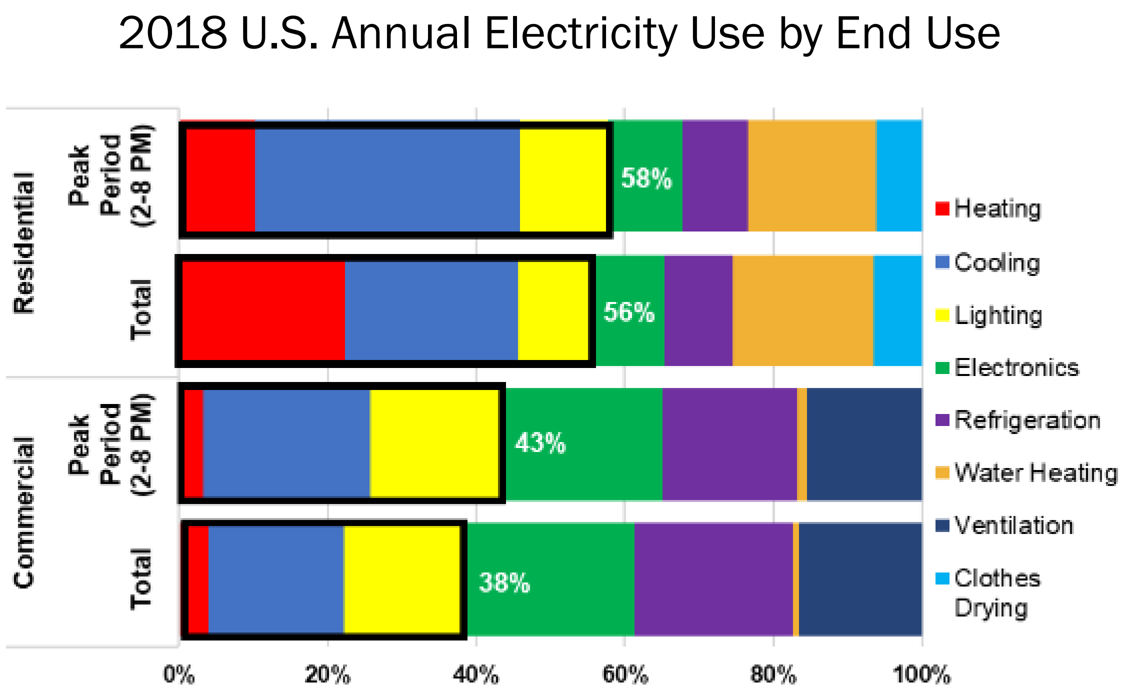
GEB Windows and Opaque Envelope Report

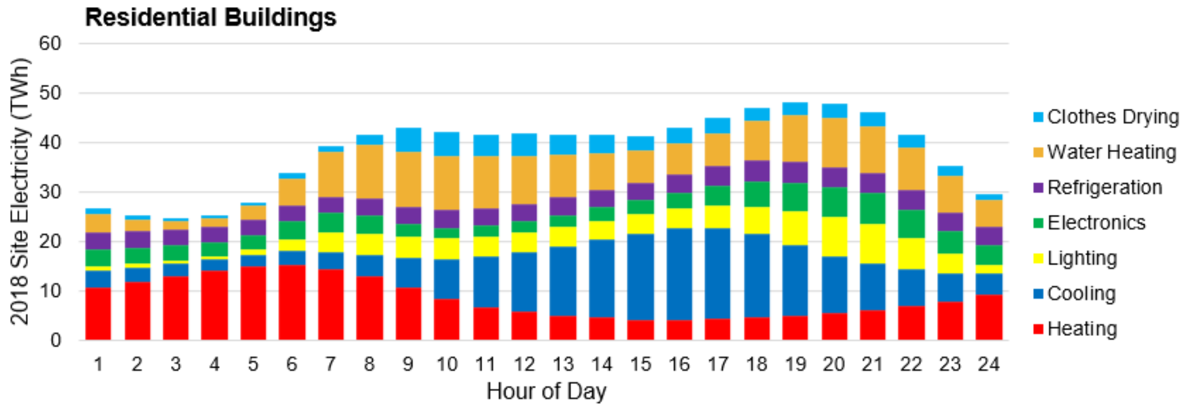
Chioke Harris
National Renewable Energy Laboratory

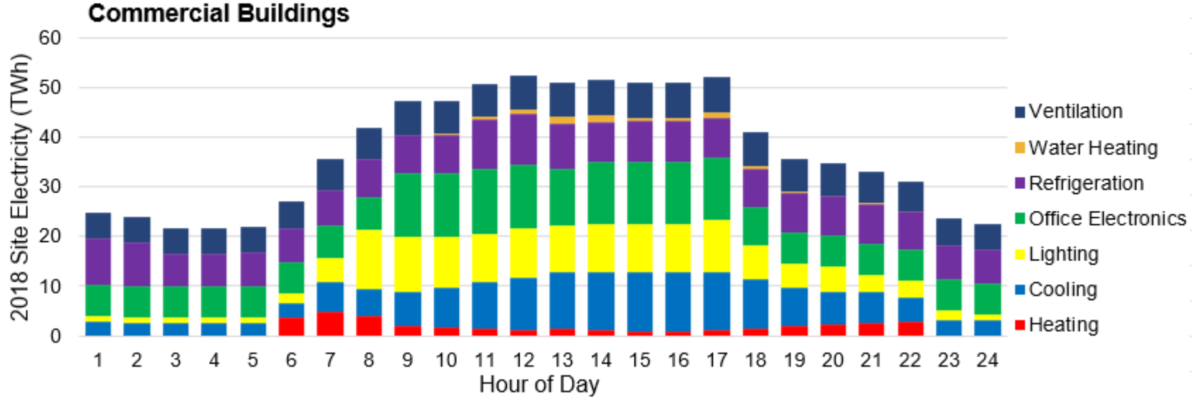
Report Objectives

- What window and opaque envelope technologies can provide grid services?
- Which technologies have the highest potential?
- What R&D is needed to overcome current challenges inhibiting their performance and/or adoption?

Building envelopes affect 47% of overall electricity use, 51% of peak demand



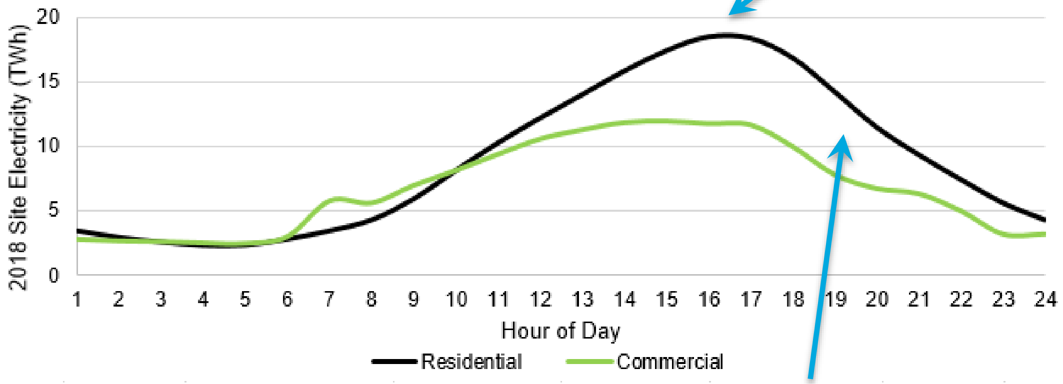




High-performance building envelopes can influence load shape

Electric Space Cooling

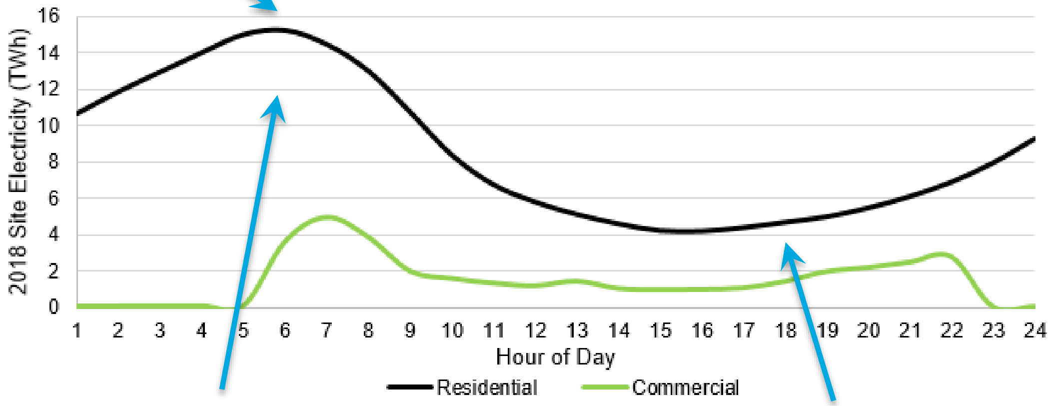
Substantial peak relative to trough, highlighting load shifting opportunity



Notable elevated load after sundown

- A/C load growth continues in most regions
- Utility concern: continued peak load growth on hottest days summer

Electric Space Heating

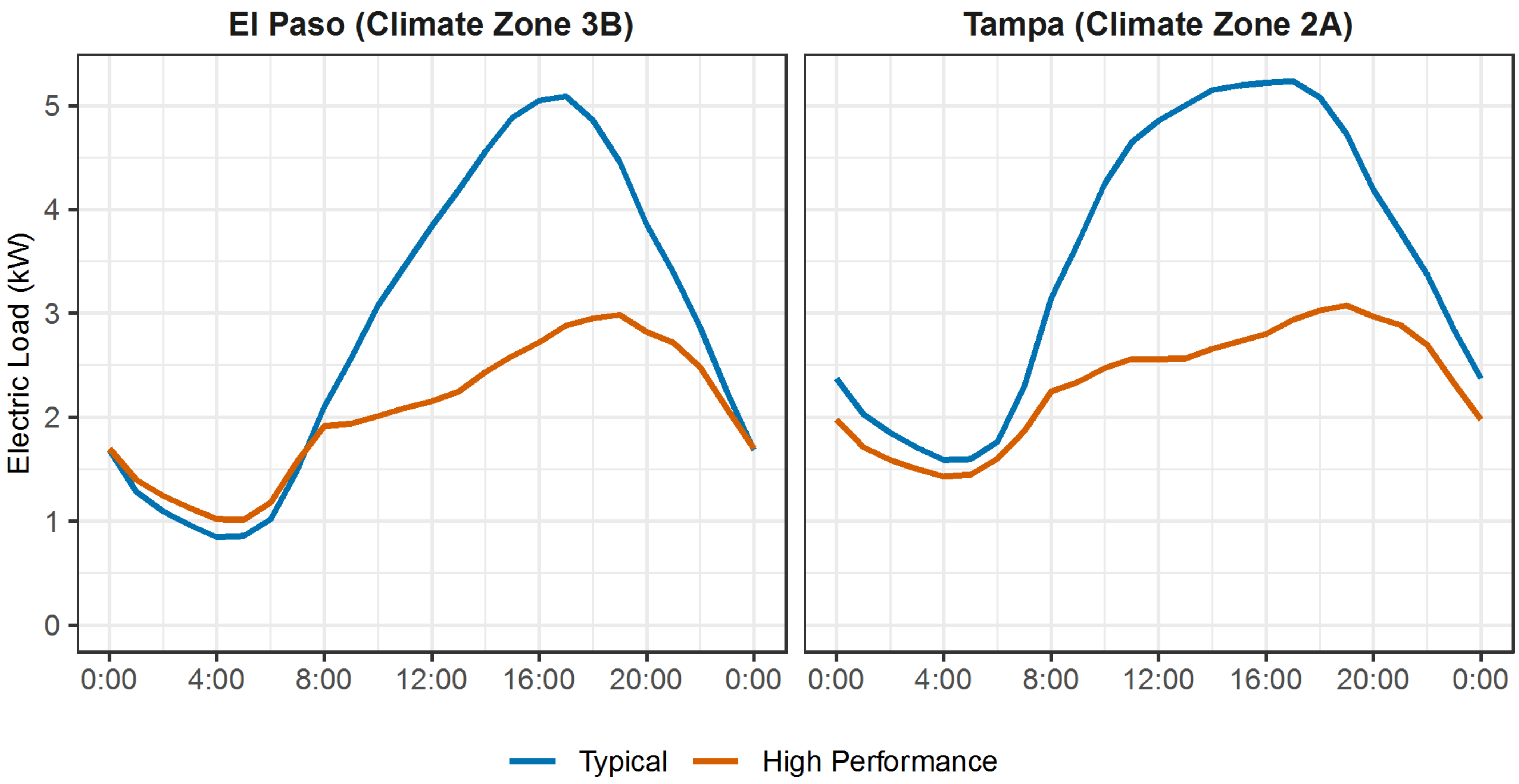


Early morning peak before sunrise

Substantially non-coincident with solar availability

- Common in the southeast; elsewhere gaining momentum via electrification trend
- Utility concern: switch to winter peak

High-performance building envelopes can influence load shape



Both passive and active envelope technologies can affect load shape

Passive, Static Technologies

- Nominally static energy performance-related properties
- Influence load by managing unwanted heat transfer

Air Barrier Materials

Active, Dynamic Technologies

- Energy performance-related properties can be adjusted over time
- Influence load by managing unwanted heat transfer and leveraging favorable ambient conditions

View, Inc.

Dynamic Glazing

HVAC, sensors and controls, and envelope flexibility interactions

- **Greatest GEB opportunity is to use the building envelope to proactively and strategically manage HVAC loads**
  - Minimize occupant impacts
  - Minimize “recovery” effects
- **Assertion (CSMA Report): Shifting of HVAC loads should be provisioned at the highest level of coupling between thermal storage and HVAC system**
  - Device level for residential AC
  - District level for district hot/chilled water systems
  - Building or zone level depending on configuration

Process

Technology Evaluation

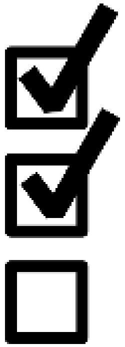
- Potential for shed, shift, and modulate

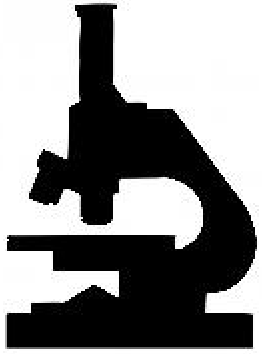
Technology Attributes

- Strengths, weaknesses, hurdles to market success

R&D Opportunities

- Needs and initiatives where DOE can add value





Three basic factors were used to qualitatively evaluate the technologies

1. **Capability rating for demand-side management strategy**
   – Qualitatively assessed based on grid services technical requirements

Capability Ratings							
○ (empty circle)	Not Applicable	◐ (half grey)	Low Capability	◐ (half green)	Medium Capability	● (full green)	High Capability

2. **Number of demand-side management strategies provided**
   – i.e., Efficiency, Load Shed, Load Shift, Modulate
3. **Weighting of demand-side management strategies**
   – Efficiency and peak reductions (shed/shift) higher value than frequency regulation, voltage support, ramping (modulate)

Multiple technologies evaluated can support demand flexibility

	Technologies	Efficiency	Load Shed	Load Shift	Modulate	Overall Potential
Windows	Dynamic Glazing	High	High	Low	NA	High
	Automated Attachments	High	High	Low	NA	High
	Photovoltaic Glazing	Low	Med	NA	Med	Medium
Opaque Envelope	Tunable Thermal Conductivity Materials	Med	Med	NA	NA	High
	Thermally Anisotropic Systems	High	High	Low	NA	High
	Thermal Storage	Med	Med	High	Low	High
	Moisture Storage and Extraction	High	Med	Med	NA	Medium
	Variable Radiative Technologies	Med	Med	NA	NA	Medium
	Building-integrated Photovoltaics	NA	NA	NA	Low	Low

Capability Legend: NA, Low, Med, High

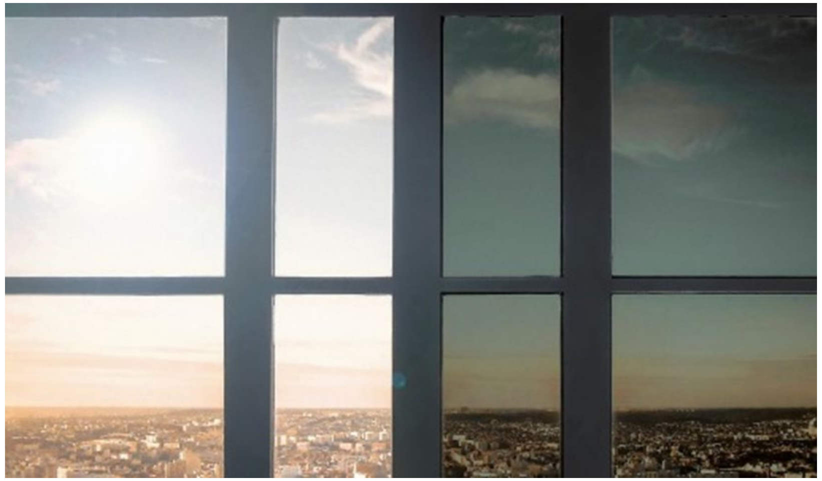
Dynamic Glazing

Technology

- Glazing with ability to adjust selective admission of some wavelengths
  - Electrochromics
  - Thermochromics
- Can be used to control glare, lighting levels

Flexibility

- Adjusts solar heat gain to capture desired or reflect unwanted heat energy
- Active control improves flexibility integration



Pilkington

View, Inc.

Flexibility Mode	Capability
Efficiency	●
Shed Load	●
Shift Load	◐
Modulate Load	○
Overall	High

Automated Attachments

Technology

- Interior or exterior window attachments that can automatically open or close in response a control signal or occupant request
- Can be used to control glare, lighting levels
- Exterior attachments yield greater energy savings

Flexibility

- Adjusts solar heat gain to capture desired or reflect unwanted heat energy

Somfy Systems

Hunter Douglas

Flexibility Mode	Capability
Efficiency	●
Shed Load	●
Shift Load	◐
Modulate Load	○
Overall	High

Photovoltaic Glazing

Technology

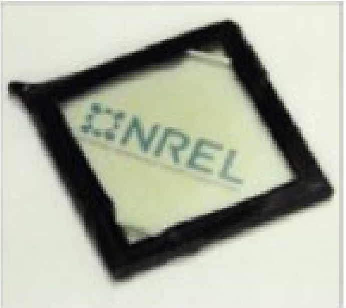
- PV glazing generates electricity from some portion of the solar spectrum
  - Semi-transparent
  - Transparent
  - Switchable

Flexibility

- Switchable PV glazing can adjust solar heat gain similar to dynamic glazing
- Electricity generation occurs while switched, coincident with peak cooling demand

Solar Window Technologies Inc.

National Renewable Energy Laboratory

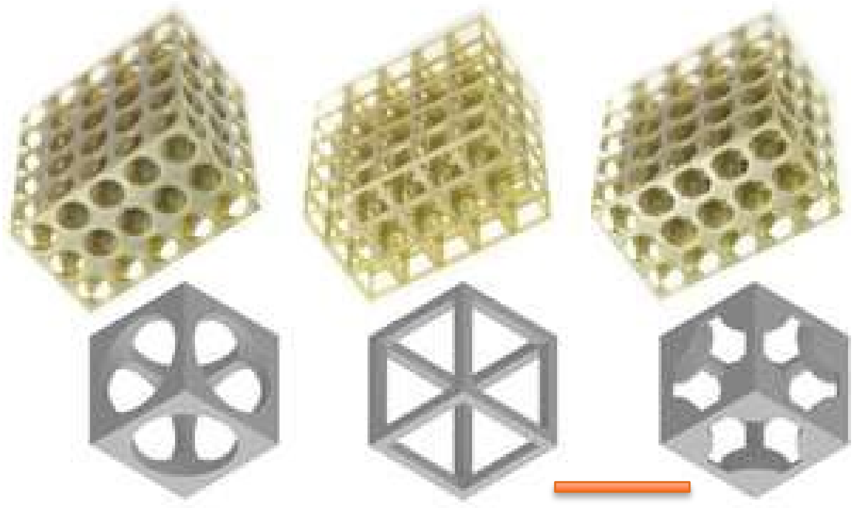


Flexibility Mode	Capability
Efficiency	◐
Shed Load	◐
Shift Load	○
Modulate Load	◐
Overall	Medium

Tunable Thermal Conductivity Materials

Technology

- **Materials that can actively modulate their heat transfer properties**
  - Thermal diodes
  - Thermal transistors
  - Dynamic insulation
  - Photonic metamaterials

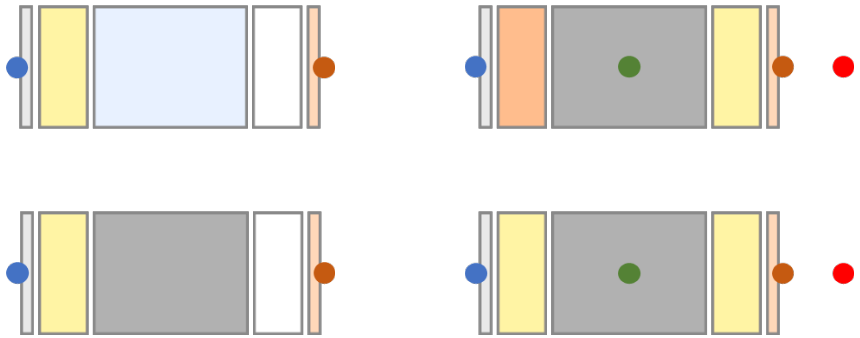


Argonne National Laboratory

Flexibility Mode	Capability
Efficiency	◐
Shed Load	◐
Shift Load	○
Modulate Load	○
Overall	High

Flexibility

- **Adjust to allow or resist conduction when advantageous**
- **Combination with other dynamic envelope technologies increases GEB, EE potential**



Oak Ridge National Laboratory

Thermally Anisotropic Systems

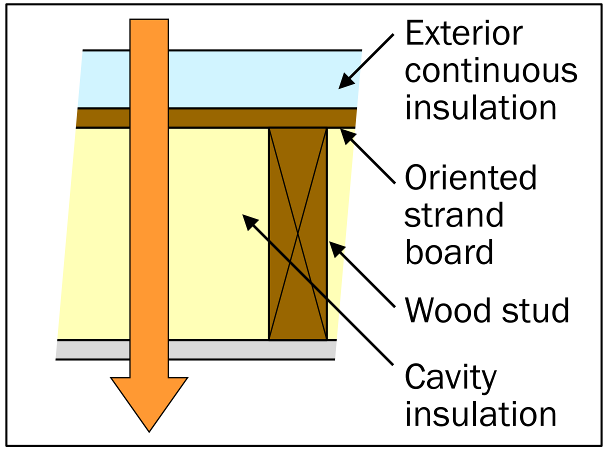
Technology

- Systems that redirect heat flow through the envelope to a heat sink or from a heat source
- Includes inherently anisotropic materials and composites
- Composites are comprised of alternating layers of materials with high and low thermal conductivity

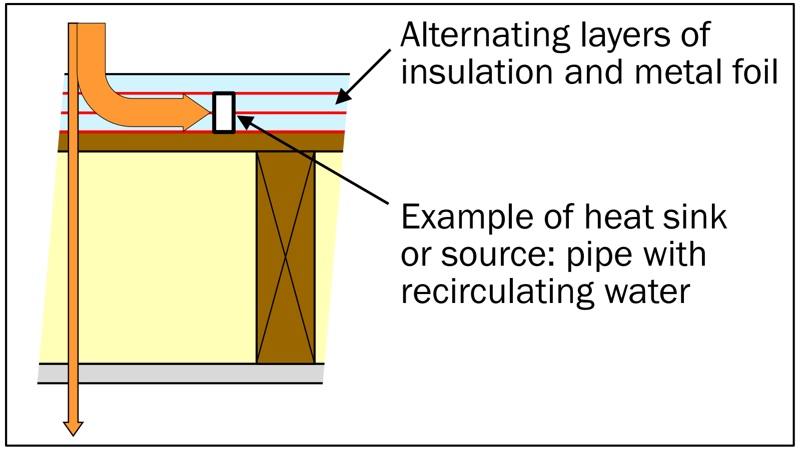
Flexibility

- Adjust redirection fraction to/from heat sink/source in response to conditions

Typical wall



Wall with thermally anisotropic composite



Oak Ridge National Laboratory

Flexibility Mode	Capability
Efficiency	●
Shed Load	●
Shift Load	◐
Modulate Load	○
Overall	High

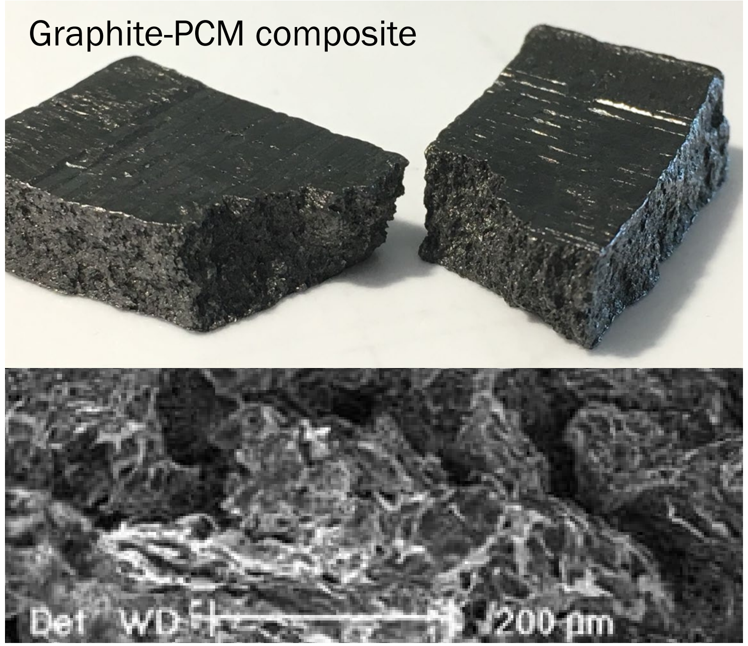
Thermal Storage

Technology

- Materials that store and release thermal energy
- Storage methods and materials are varied
  - Envelope-integrated materials likely require high volumetric and gravimetric energy density

Flexibility

- Store and release thermal energy to maintain thermal comfort for occupants
- Active control capability enables GEB operation



Graphite-PCM composite

National Renewable Energy Laboratory
Mills, et al. Appl Therm Eng


PCM before and after phase change

Suricata

Flexibility Mode	Capability
Efficiency	◐
Shed Load	◐
Shift Load	●
Modulate Load	◐
Overall	High

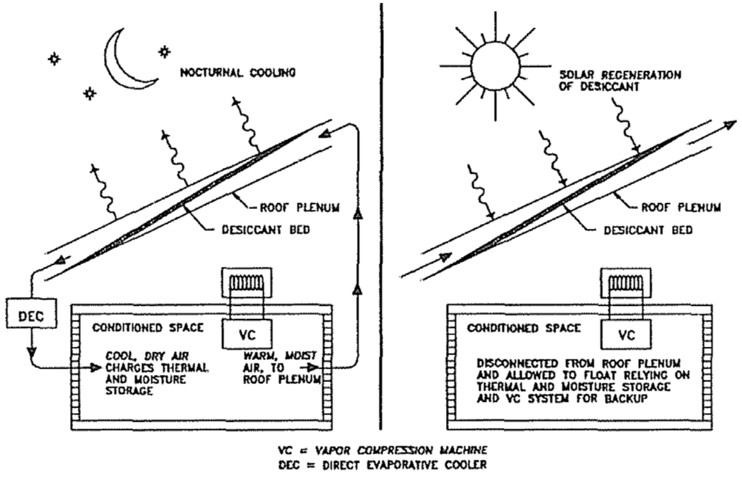
Moisture Storage and Extraction

Technology

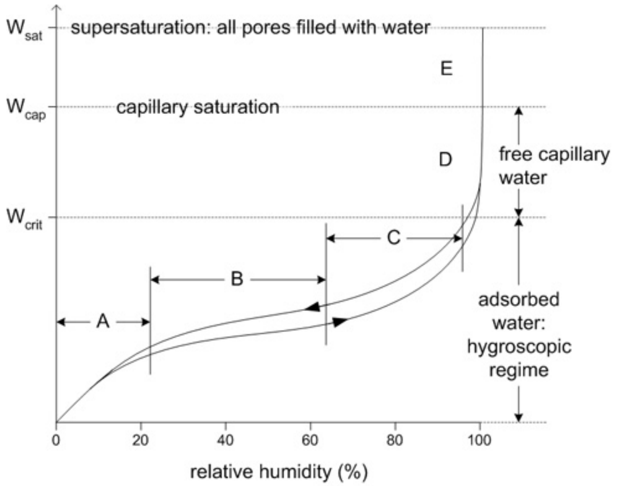
- Materials that actively sequester water vapor from building interiors
- Could include moisture rejection to exterior
- Significant efficiency benefits require energy efficient moisture rejection

Flexibility

- Extract moisture to decouple latent and sensible heat control and increase HVAC operational flexibility



Rudd, A.F. BSC Report PA-0941



A: Single-layer of adsorbed molecules
B: Multiple layers of adsorbed molecules
C: Interconnected layers (internal capillary condensation
D: Free water in Pores, capillary suction
E: Supersaturated Regime

BSC

Flexibility Mode	Capability
Efficiency	●
Shed Load	◐
Shift Load	◐
Modulate Load	○
Overall	Medium

Variable Radiative Technologies

Technology

- Conceptually similar to dynamic windows but for opaque envelope surfaces
- Potential to enhance operation of other dynamic envelope components

Flexibility

- Adjust surface properties to strategically absorb or reflect solar radiation

Walmart

Peter Rockwood

Flexibility Mode	Capability
Efficiency	◐
Shed Load	◐
Shift Load	○
Modulate Load	○
Overall	Medium

Poll

Do you agree with the capability ratings of the technologies presented today?

- Strongly Agree
- Somewhat Agree
- Neutral
- Somewhat Disagree
- Strongly Disagree

Attributes Considered

We also considered these attributes of each technology which can serve as additional benefits or barriers to implementing the technologies.

System Attribute	Definitions
Resilience	The ability of the technology to predict and prepare for, withstand, recover rapidly from, and adapt to major disruptions including natural disasters and energy supply losses (electricity, natural gas, etc.) by providing energy, services, occupant comfort, protection, and/or damage resistance.
Usability	The ease of use of the technology to the customer, including ease of installation, ease of implementation, ease of operation, and ease of maintenance.
Cost	The manufacturing and capital costs of the technology and components.
Human Health	The extent to which the technology contributes to a healthy and safe living environment for the building occupants.
Energy Performance	The estimated impact on energy use from implementing the technology relative to baseline technologies.

Challenges & Opportunities: All Connected Technologies

Technology	Challenge	Opportunity
All Connected Technologies	**Interoperability**	• Support the development and adoption of standardized semantic and syntactic specifications for connected devices and software systems
	Cybersecurity	• Support the adoption of secure system architectures and cybersecurity best practices
	Cost	• Develop manufacturing processes that have low capital costs or can use existing manufacturing equipment with minimal investment • Develop materials and technologies compatible with scalable manufacturing methods that enable increasing production volumes

Challenges & Opportunities: All Window & Envelope Technologies

Technology	Technical Challenges	R&D Opportunities
All Dynamic Window and Opaque Envelope Technologies	Grid Service-Specific Control Strategies That Can Balance Occupant Needs and Grid Benefits	• Identify approaches for in-situ, real-time measurement of occupant comfort • Develop adaptive control systems that balance multiple objectives—demand flexibility, utility costs, occupant comfort, etc. • Characterize conditions that lead to occupant overrides and develop strategies to minimize overrides
	Parameterization of Grid Response Capability	• Identify and quantify the key figures of merit that influence demand flexibility by grid service type • Develop deterministic quantitative methods for the design of sensors and control systems specific to each GEB-relevant window and opaque envelope technology
	Methods to Quantify Building-Specific Response Characteristics	• Parametric study of the thermal response of residential and commercial buildings • Simulation of the time-series interaction between GEB-relevant window and opaque envelope technologies and other building systems

Poll

Which challenges do you think BTO is in the best position to address? (Choose two.)

- Interoperability
- Cybersecurity
- Cost
- Grid Service-Specific Control Strategies
- Parameterization of Grid Response Capability
- Methods to Quantify Building-Specific Response Characteristics

Dynamic Solar Control

Christian Kohler
Berkeley Lab

LBNL Researchers

Eleanor Lee
Christoph Gehbauer
Taoning Wang
Luis Fernandes
Charlie Curcija
Robert Hart
Howdy Goudey
Steve Selkowitz

Windows role in GEB

Windows don't use energy……………………….
**except for a tiny current to switch and hold electrochromics and to raise shades*

But

- A **large** fraction of HVAC loads come from window transmitted solar gains
- Lighting energy in perimeter zone is directly related to daylight from windows

Controlling Solar Gains

Electrochromic Windows

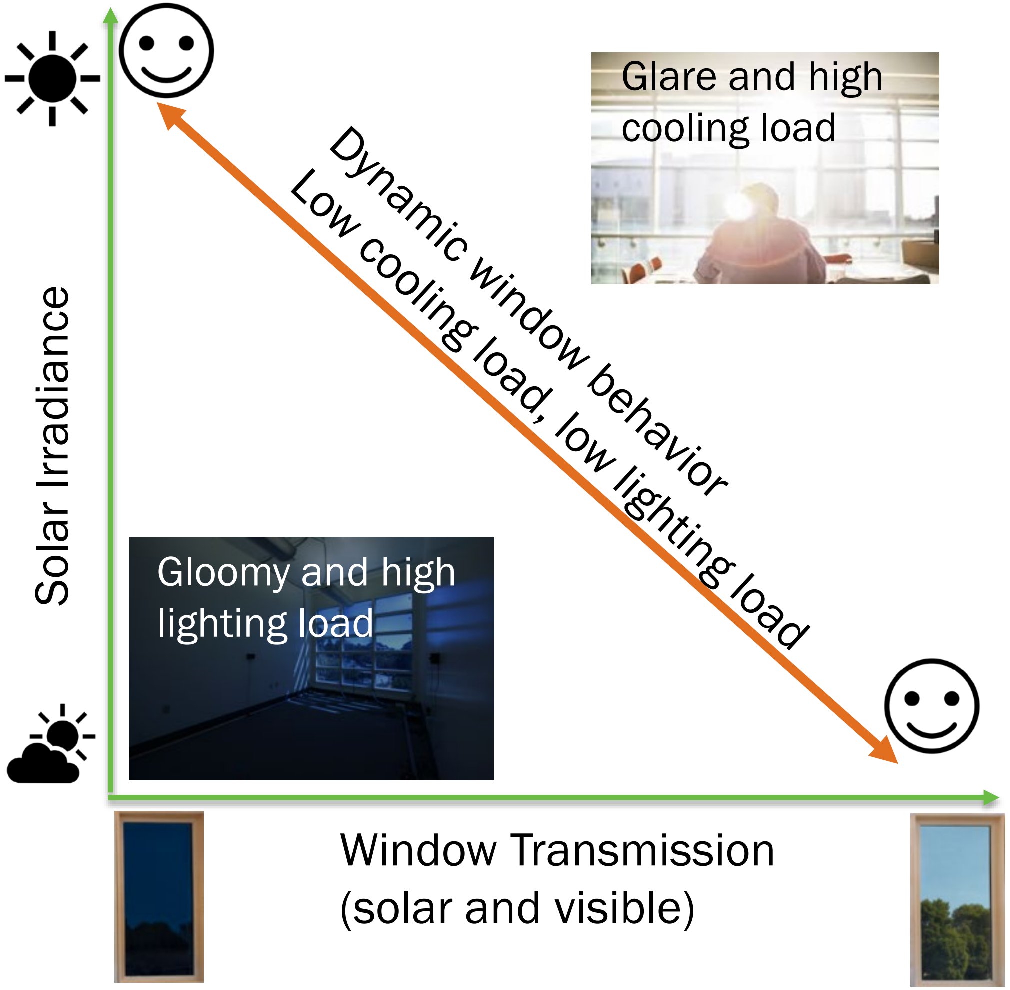
Electrochromic windows can tint to reduce solar gain. They can be controlled manually or automated to respond to a control signal

Automated Shading

Automated (motorized) shading can reduce solar gains and modulate light levels. Exterior shading is particularly effective for reducing cooling

Static vs Dynamic window technologies

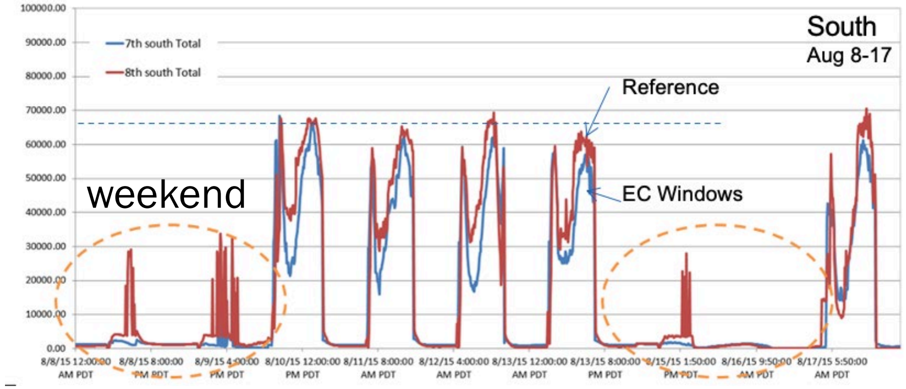
- When it is sunny and the building is in cooling mode, you want a darker window to block solar gain, and allow limited daylight
- When it is overcast, you want a window that transmits more light
- Static windows are in the wrong state most of the time
- Dynamic windows can adjust to outside conditions and grid needs
- Attachments rated by Attachments Energy Rating Council (AERC)



Results

Electrochromics

- Portland GSA Proving Grounds (GPG) study
  - Lighting Energy Savings 36-74%
  - Limited cooling savings during weekdays because existing windows were dark
  - 57% reduction in VAV cooling load during weekends by going to darkest state (82F)

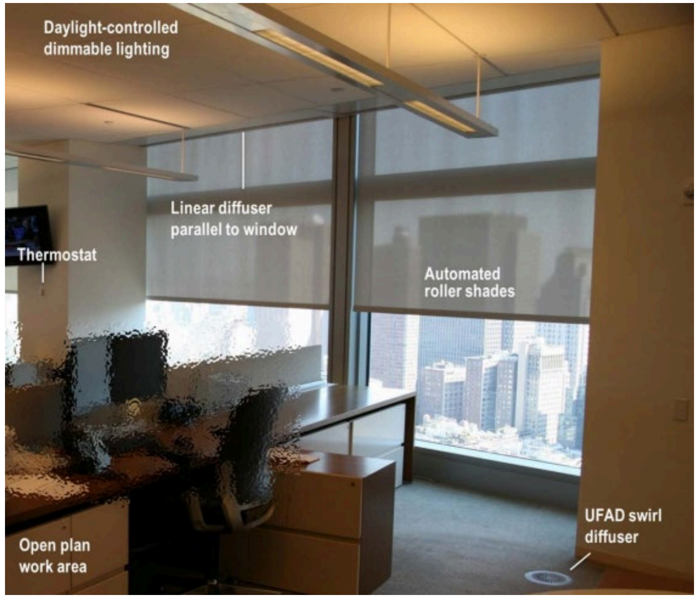


- Berkeley Lab Advanced Window Testbed:
  - 29-65% cooling load savings
  - 25-58% peak load reduction

Results

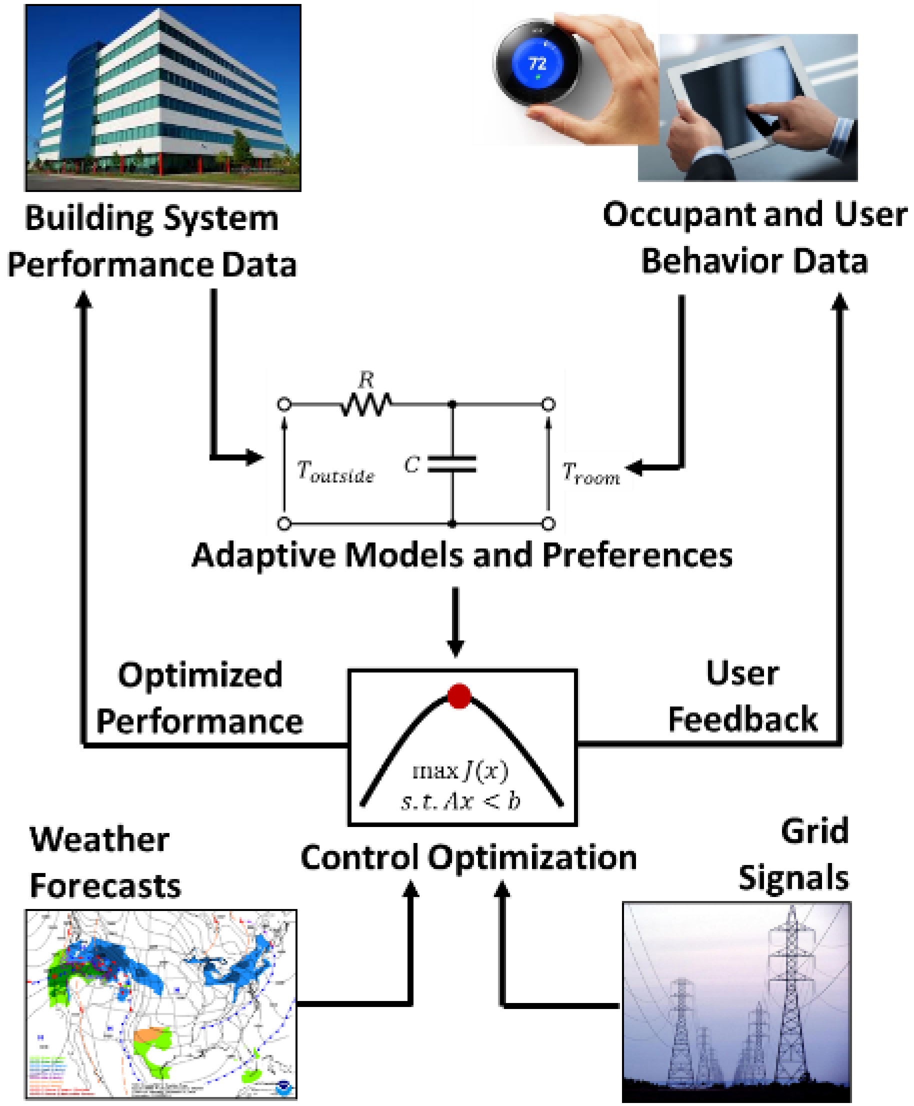
Automated Shading

- **Berkeley Lab FLEXLAB Testing:**
    - Exterior motorized roller shade
    - Cooling load reduction of 12-24%
    - Peak cooling demand reduced by 26%
    - No lighting savings because of dark shade
- **New York City Goldman Sachs:**
    - Lighting retrofit with automated interior shades
    - Electric lighting demand reductions during peak afternoon periods (2-5 PM) were 0.60-0.63 W/ft2 (64-81%)
- **Pella Residential integral shade:**
    - 12-29% energy savings, 25% more daylight

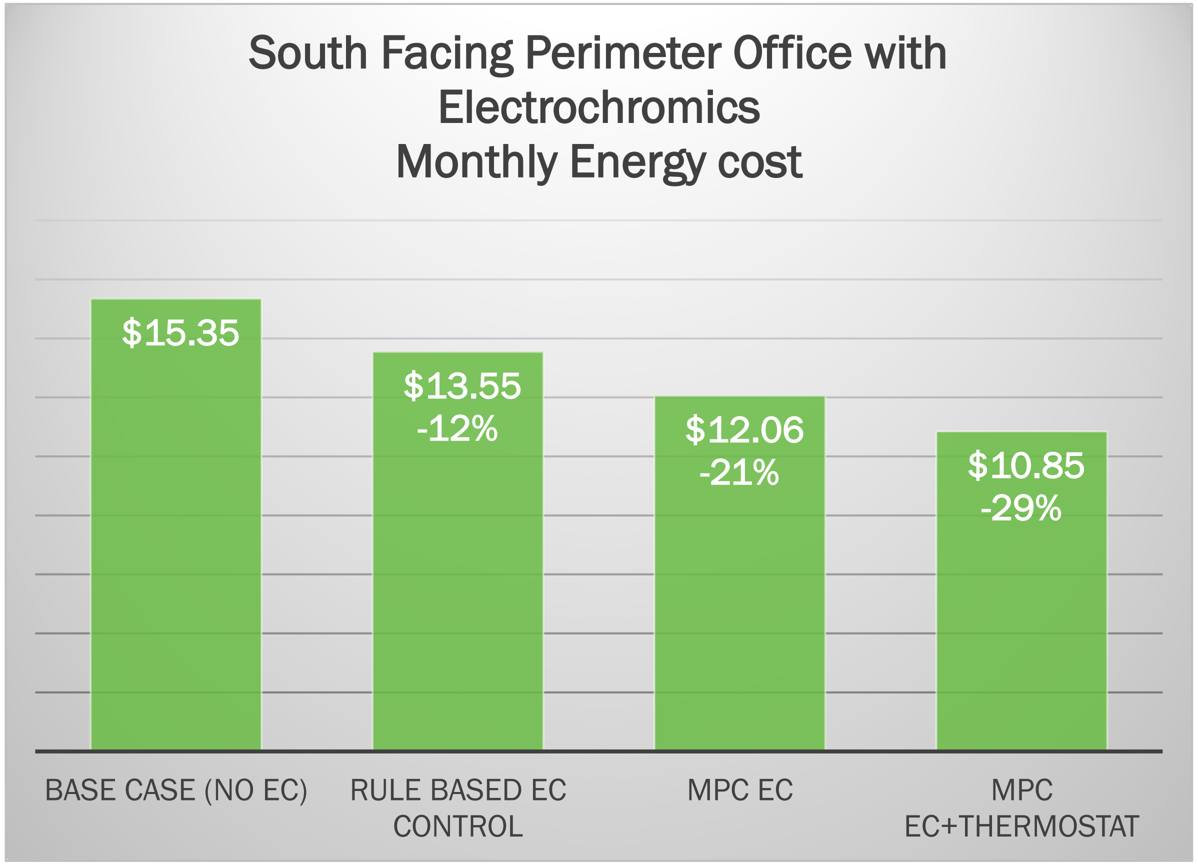


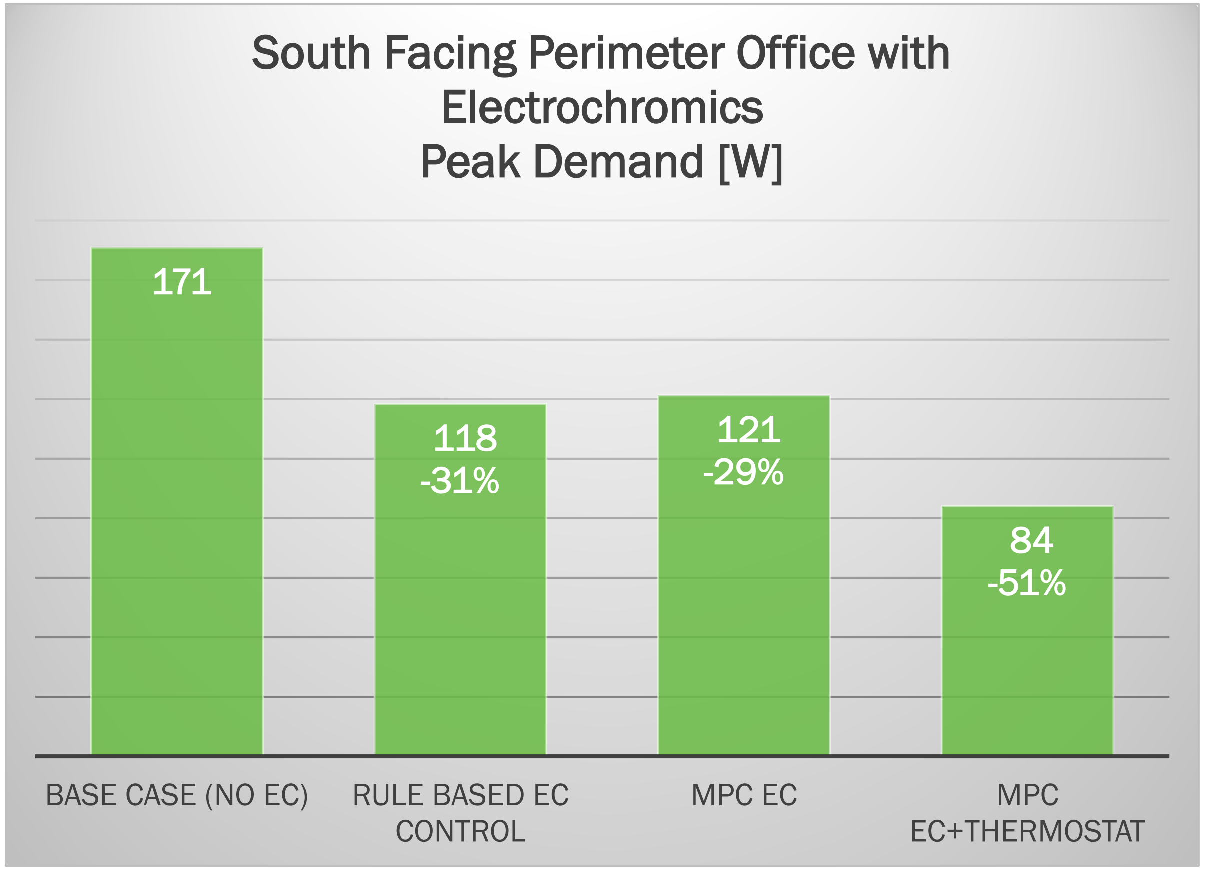
Model Predictive Controls

- Electrochromic glazing tinting state and motorized shading position are the levers that can be pulled by a control system
- Most systems today use simple rule-based controls
  - If solar-intensity-on-façade > 500, then lower shade
- Model Predictive Controls are a smarter way to pull these levers
- Use weather forecast, grid forecast to optimize for multiple objectives—energy, view, glare control, etc.
- Coordinate multiple systems



Model Predictive Control Results

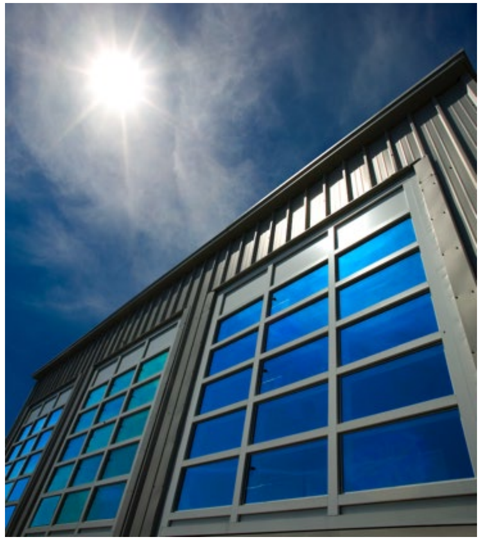




Model Predictive Controls of 3 section electrochromic window in a 150 ft^2 office in Burbank, California
Base case is a Low-E window (SHGC=0.40) with an indoor roller shade.
“MPC EC” denotes a scenario where the MPC controller controls the windows only
“MPC EC+THERMOSTAT” allows the MPC controller to also control the HVAC system and perform pre-cooling

Conclusion

- Windows can be an effective way to control the solar gain into a building
- Model Predictive Controls offer opportunity to integrate better with grid signals and other buildings systems such as HVAC to take maximum advantage of the window features
- Working with HVAC and Lighting systems to Shed and Shift Loads



To reduce peak cooling: First reduce the solar load …….. and then install efficient HVAC

Poll

BTO should invest in continued research, development, and validation of active window technologies to support GEB.

- Strongly Agree
- Somewhat Agree
- Neutral
- Somewhat Disagree
- Strongly Disagree

Poll

What window technologies do you think BTO should pursue further for their GEB potential? (Choose two.)

- Electrochromic glazing
- Exterior automated shading for commercial buildings
- Exterior automated shading for homes
- Interior automated shading for commercial buildings
- Interior automated shading for homes

References

- Technology Assessments of High-Performance Envelope with Optimized Lighting, Solar Control, and Daylighting. https://eta.lbl.gov/publications/technology-assessments-high
- An assessment of the load modifying potential of model predictive controlled dynamic facades within the California context https://eta.lbl.gov/publications/assessment-load-modifying-potential
- Electrochromic Window Demonstration at the John E. Moss Federal Building, 650 Capitol Mall, Sacramento, California https://eta.lbl.gov/publications/electrochromic-window-demonstration-0
- Electrochromic Window Demonstration at the 911 Federal Building, 911 Northeast 11th Avenue, Portland, Oregon
- https://eta.lbl.gov/publications/electrochromic-window-demonstration-1

Dynamic Technologies for Opaque Envelopes

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Thermally Anisotropic System
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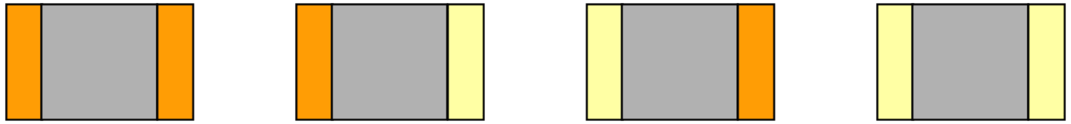
Active Insulation System (AIS)

Tunable Thermal Conductivity Materials Coupled with Thermal Storage

Variable R-value that enables on demand use of

- Thermal mass in buildings (heat capacity of OSB/wood in 2×6 walls in 2,000 ft^2 house is ~6× > 50-gal water)
- Free low/high exterior surface temperature
- Renewable sources of energy

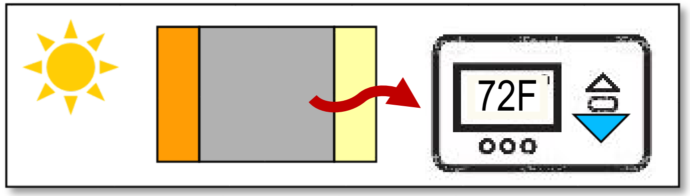


Low R-value   High R-value   Thermal mass

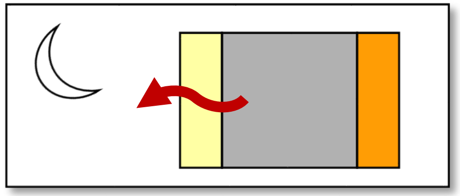
Summer

Charge: lower temperature of thermal mass

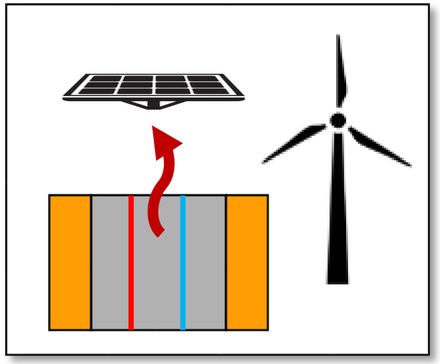
1. HVAC during low demand hours



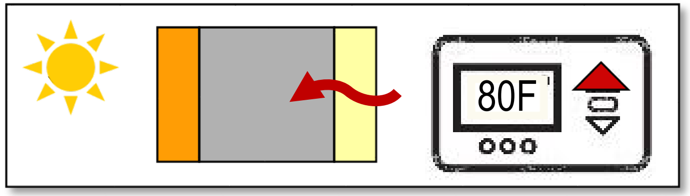
2. Lower outdoor temperatures



3. Excess renewable energy + dedicated system



Discharge: provide occupant comfort via radiation, thus lower HVAC loads



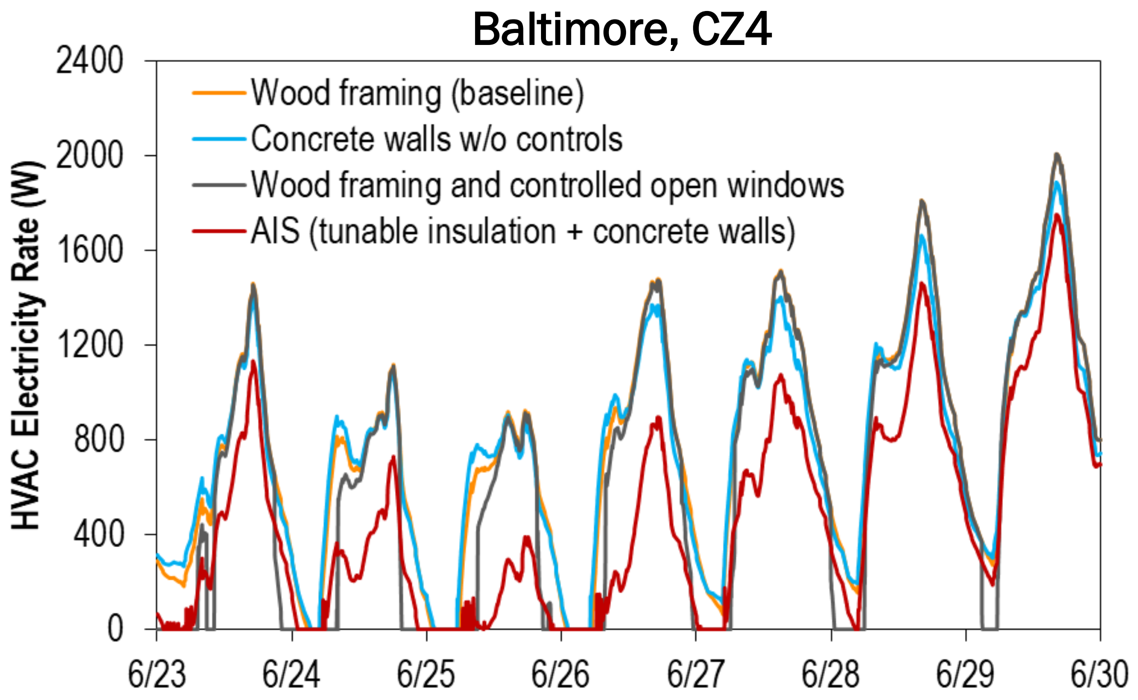
GEB benefits: HVAC loads

- Reduce overall demand
- Shed peak demand
- Shift peak load
- Shape load

Results using Rule-Based Controls

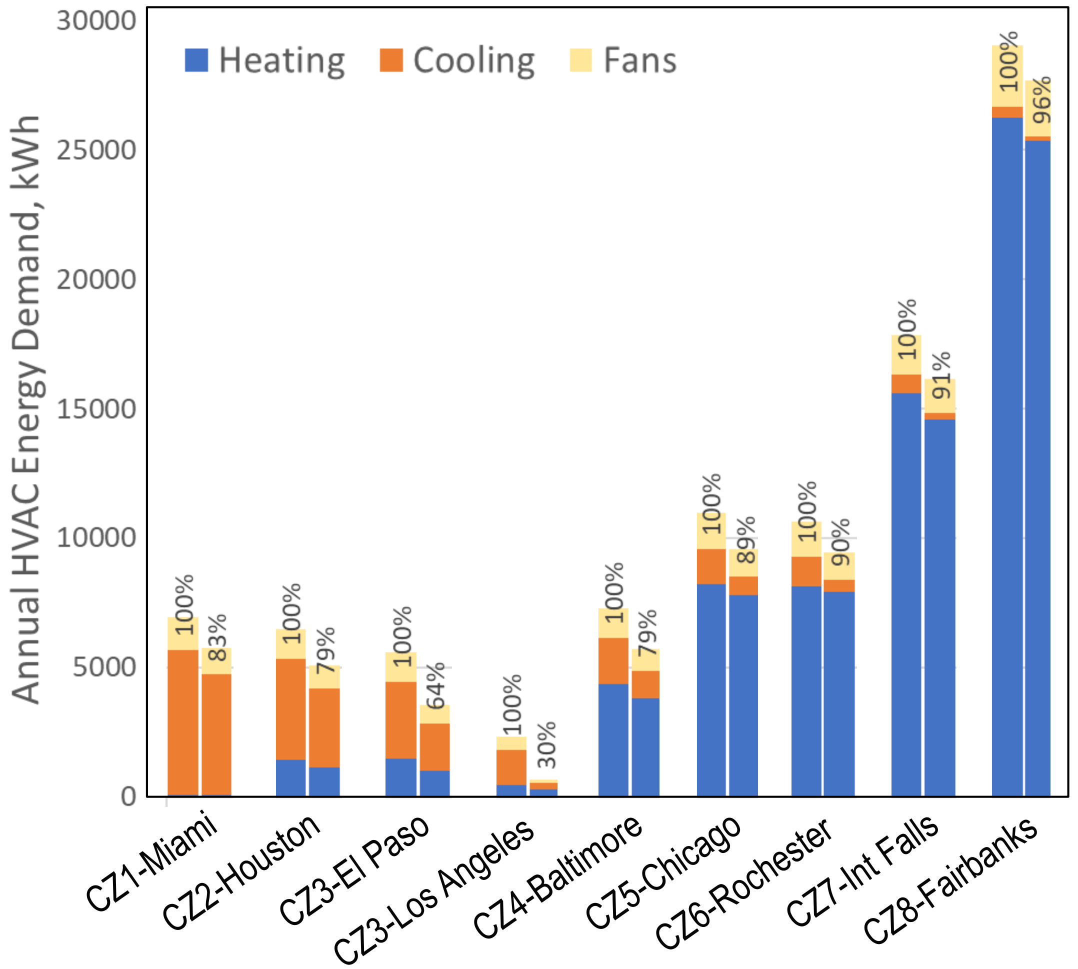
AIS vs. Other Systems

- DOE residential prototype building
- Rule-based controls
  - Windows: indoor & outdoor air temperature
  - AIS: exterior & interior surface and thermal mass temperature



Savings Concrete walls: 2% Windows: 15% AIS: 40%

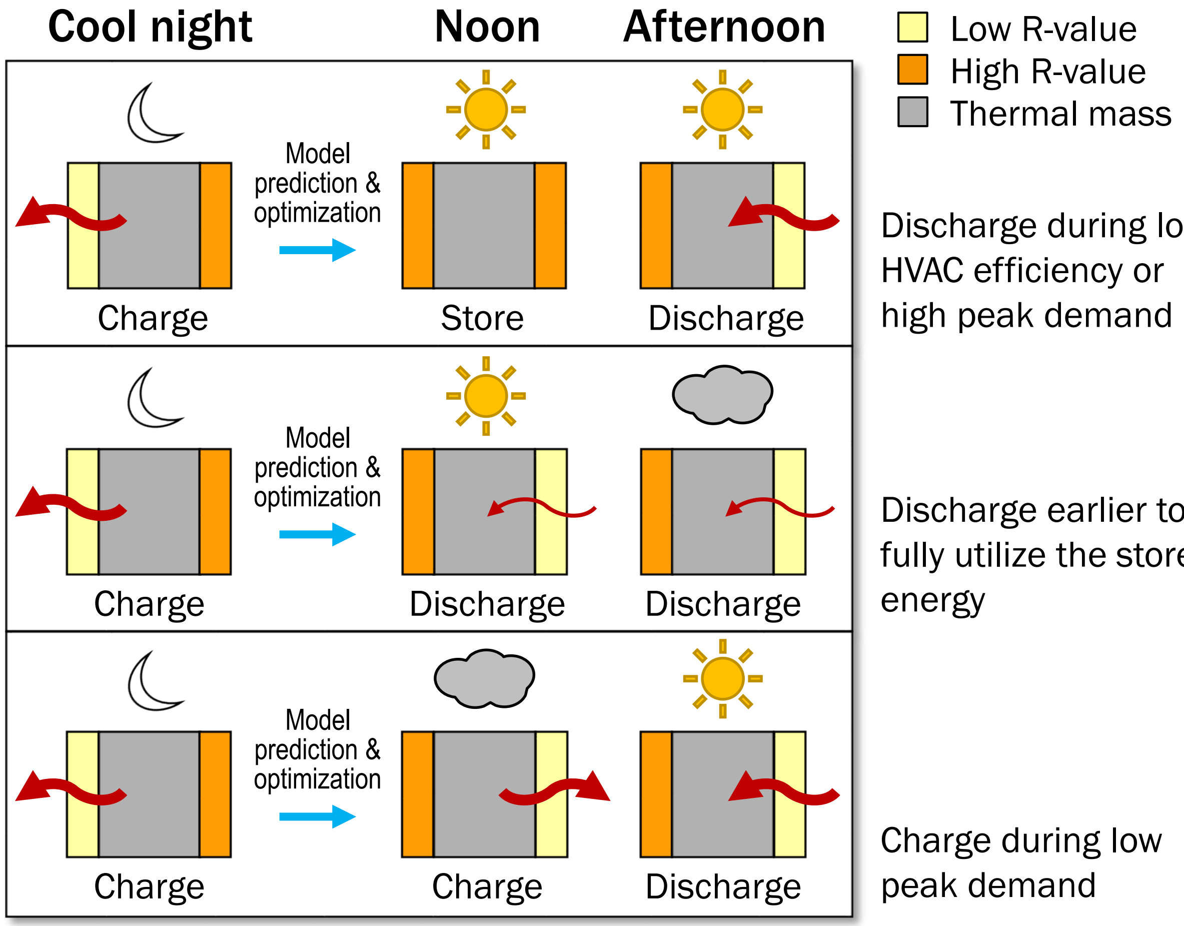
Potential Savings per Climate Zone



CZ Savings Moderate ≤70% Warm ≤36% Cool ≤21%

Ongoing Research

Optimization thru Model Predictive Controls (MPC)



Discharge during low HVAC efficiency or high peak demand

Discharge earlier to fully utilize the stored energy

Charge during low peak demand

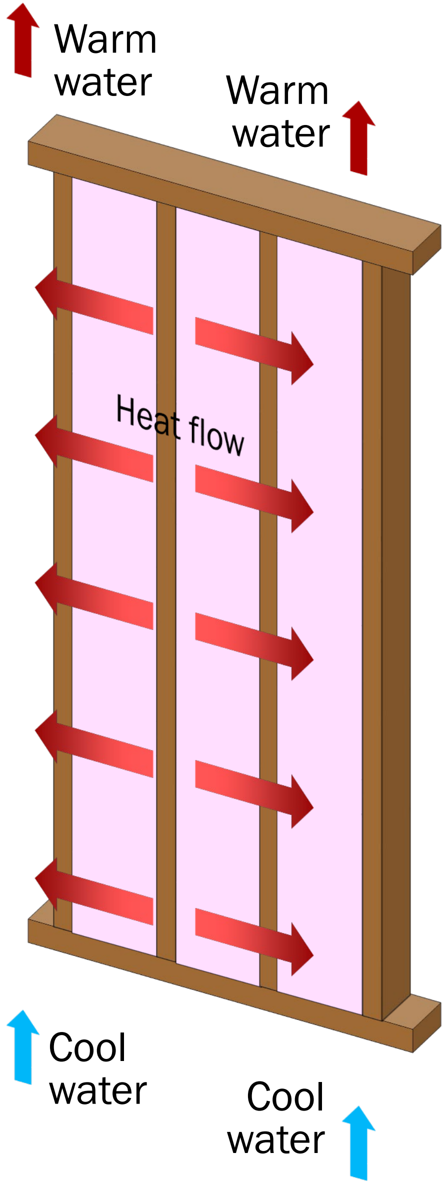
Optimize energy savings, cost, and/or peak demand

Validation of Simulation Results thru Lab Tests

- Component level data to confirm EnergyPlus results
- Large-scale chamber setup
  - Dynamic indoor/outdoor conditions
  - Active insulation: Low R = 1 High R = 10
  - Fully-grouted CMU
  - Monitor temperatures and heat fluxes

Validate AIS savings potential with experimental data

Thermally Anisotropic System



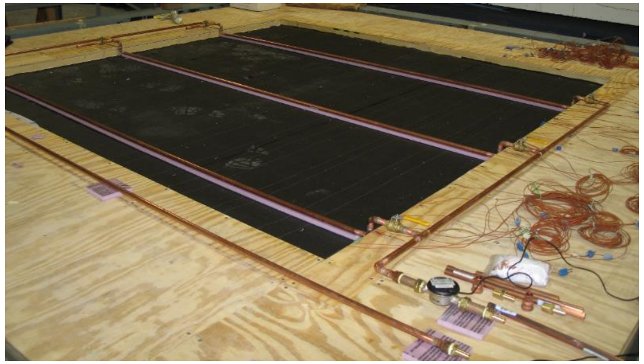
- Thermal anisotropy: preferential heat transfer direction
- Phase 1: Redirect heat on envelope to lower HVAC loads
- Phase 2: Harvest and use low-grade heat
- Thermally anisotropic system for envelopes
  - Composite: alternate layers of insulation boards and metal foils
  - Heat sink/source: e.g., water flowing through pipes
  - System made of readily available materials to redirect heat
- Excellent candidate for prefab construction

Benefits

- Redirect heat instead of increasing insulation
- Potential to harvest low-grade heat
- HVAC loads
  - Reduce overall demand
  - Shed peak demand
  - Shape load

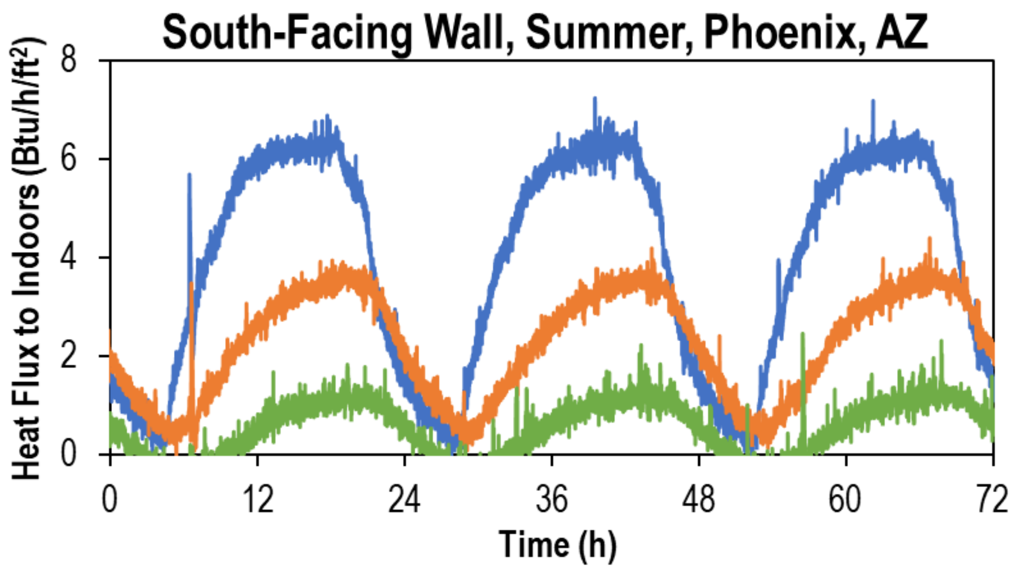
Non-Optimized Test Evaluations

8ft × 8ft
Anisotropic Test Assembly



Water supply temper = 81.8°F

- Cavity insulation
- Cavity insulation + 1.5” XPS
- Cavity insulation + anisotropic system: (3) alternate layers 0.5” XPS and 5 mil aluminum foil



Thermal assembly in wall	Non-optimized reduction in peak heat gains	
	3-day lab test of south-facing wall	Summer E+ simulations of all walls in DOE residential prototype building
Cavity insulation + 1.5” XPS	39%	33%
Cavity insulation + anisotropic system	66%	56%

Water temperature and flow rate can regulate HVAC loads due to the envelope

Ongoing and Future Research

Field Evaluations

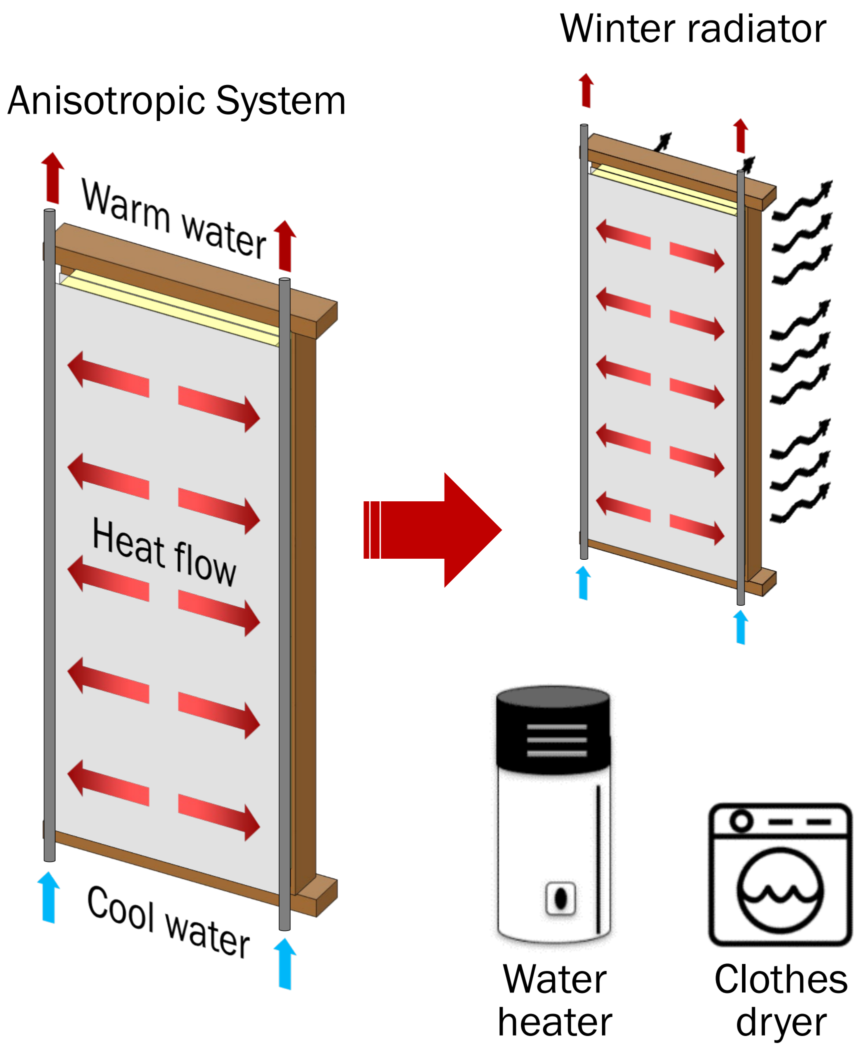
Commercial Roof Tests
Oak Ridge, TN

Residential Wall Tests
Charleston, SC

- Evaluate assembly effectiveness
- Validate simulation results
- Assess variations in assembly of components
  - Examine use of low-grade heat in winter radiator
- Study seasonal performance
- Develop controls to optimize energy savings and shed peak demand

Comprehensive assessment based on simulation, lab and field results

Potential Heat Harvest and Use



Poll

BTO should invest in continued research, development, and validation of active opaque envelope technologies to support GEB.

- Strongly Agree
- Somewhat Agree
- Neutral
- Somewhat Disagree
- Strongly Disagree

Poll

What opaque envelope technologies do you think BTO should pursue further for their GEB potential? (Choose two.)

- Tunable thermal conductivity materials coupled with thermal storage
- Thermally anisotropic systems
- Thermal storage materials
- Moisture storage and extraction
- Variable radiative technologies

Open Q&A

Use the question feature to ask a question or provide a comment.

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