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Completing the Connected Home with Smart Window Shades

ACEEE Summer Study
August 12-17, 2018

PANEL 12 - Smart Buildings, Smart Grid, and the Internet of Things

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PNNL-SA-135343

Do Automated Window Coverings have a place in the Connected Home?

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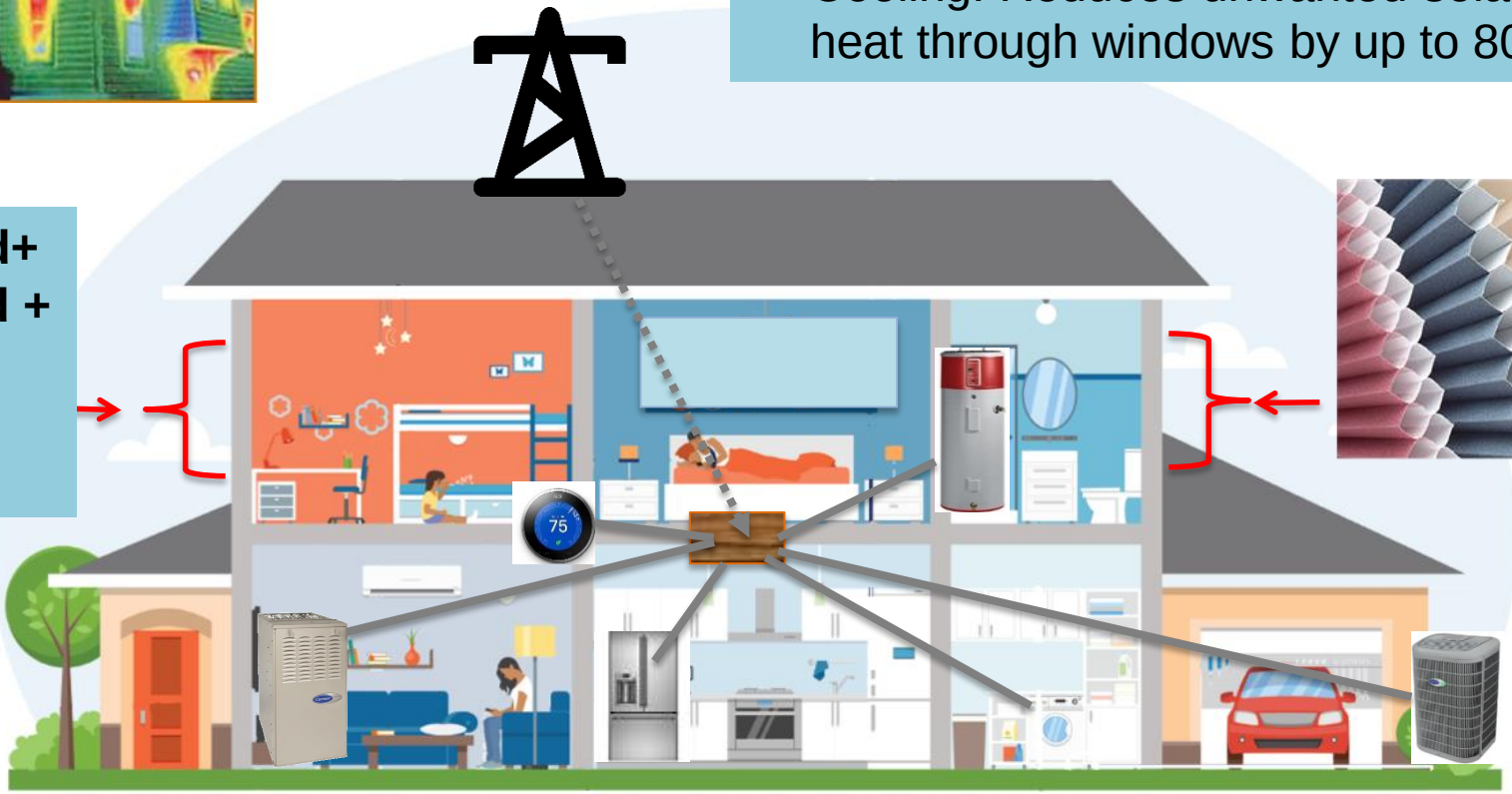
Cellular Shades Energy Savings:

- Heating: Can reduce heat loss through windows by 40% or more
- Cooling: Reduces unwanted solar heat through windows by up to 80%

Automated+ Connected + Smart + Efficient Windows!



Completing the Connected Home with Smart Window Shades

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Project Team

- Katie Cort (PM)
- Cheryn Metzger (PI)
- Greg Sullivan, Efficiency Solutions, (Senior Researcher – Lab Homes Field Testing)
- Joshua McIntosh (Engineer, Lab Homes Field Testing)
- Travis Ashley (Engineer Intern)
- Rick Pratt (Senior Researcher – Controls)
- Eric Wilcox Freeburg (Controls Testing)
- Andrew Hoffman (Controls Testing)
- Nick Fernandez (Control Strategies and Algorithm Development)

Partners and Funding

- Hunter Douglas
- Bonneville Power Administration (BPA-TI)
- Northwest Energy Efficiency Alliance
- DOE-Building America

Key Source: *Testing the Performance and Dynamic Control of Energy-Efficient Cellular Shades in the PNNL Lab Homes.* August 2018. PNNL-27663, https://spcollab.pnnl.gov/sites/library/pages/home.aspx.

Double-Cell Cellular Shades Thermal Performance and Control Experiments – (2017-2018)

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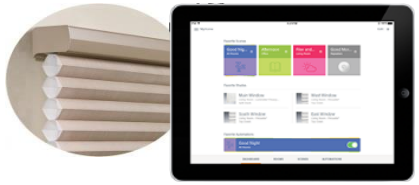
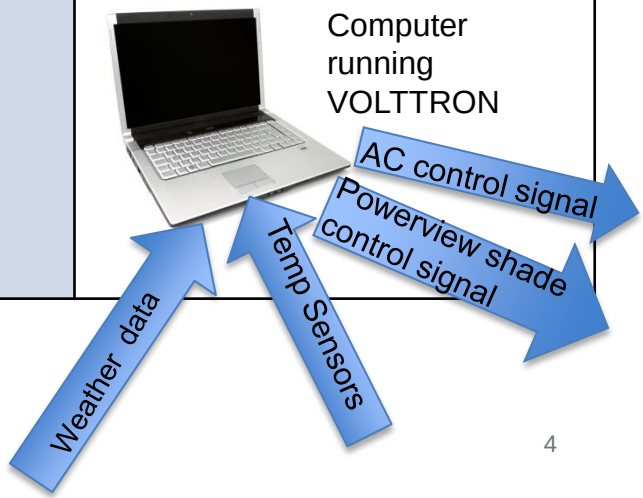
Technologies	Description	Picture
Cellular Shades (Hunter Douglas)	Hunter Douglas Duette® Architella®Elan honeycomb fabric shades. Designed as a double-cell (cell within a cell) structure made with 3 insulating air pockets. Inner cell is transparent and allows light to pass through. One of Hunter Douglas's highest selling products.	 
PowerView Motorization	Hunter Douglas's programmable wireless control system with battery-powered motor that operates (opens and shuts) shades on command or according to programmed schedule.	
VOLTTRON™ application platform	VOLTTRON is an lab-developed open source application platform (e.g., like Android or iOS) for distributed sensing and control applications.	

PNNL Lab Homes Testing Platform in Richland, Washington

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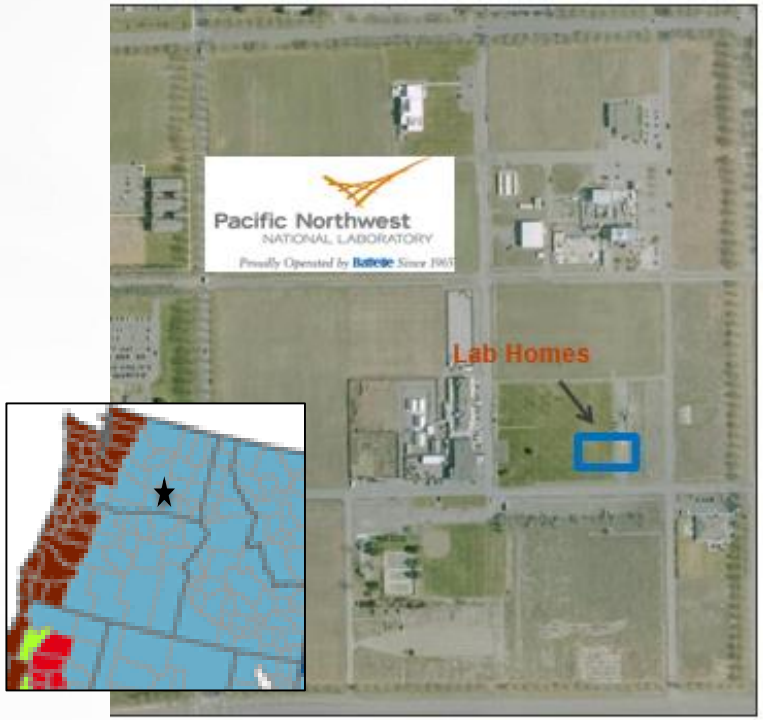
Lab Homes Characteristics

- Specified to represent existing manufactured and stick-built housing
- 3 BR/2BA, ~1500 ft^2
- All-electric with 13 SEER/7.7 HSPF heat pump central HVAC + alternate Cadet fan wall heaters throughout
- R-22 floors, R-11 walls & R-22 ceiling with composition roof
- 195.7 ft^2 (13%) window area with double-pane clear glass aluminum-framed windows



Thermal Performance of Cellular Shades compared to the most Common Window Coverings

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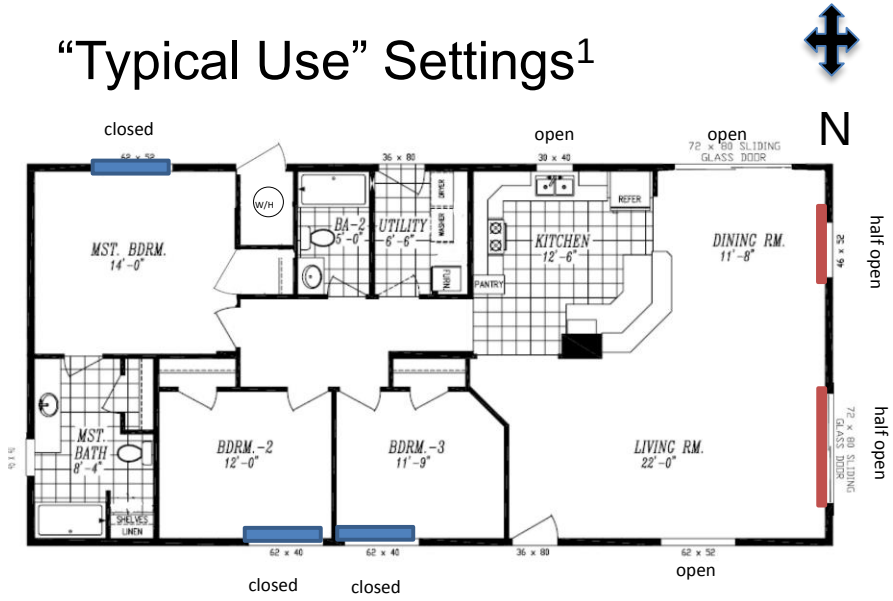
Experiment	Season	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
All Shades Down: Cellular Shades versus Vinyl Venetian Blinds	Cooling	13.3 (±1.3)	2,650
	Heating	9.3 (±1.9)	7,011
Typical Use: Cellular Shades versus Vinyl Venetian Blinds	Cooling	5.8 (±0.5)	1,487
	Heating	2.0 (±1.3)	1,505

Semi-opaque double-cell shade pulled down (left) allows filtered natural light into north-side bedroom. Close-up view of same shade (right).

"Typical Use" Settings[1]



[1]D&R International. 2013. *Residential Windows and Window Coverings: A Detailed View of the Installed Base and User Behavior* http://energy.gov/sites/prod/files/2013/11/f5/residential_windows_coverings.pdf.

Energy Savings Potential of Cellular Shades in the Summer

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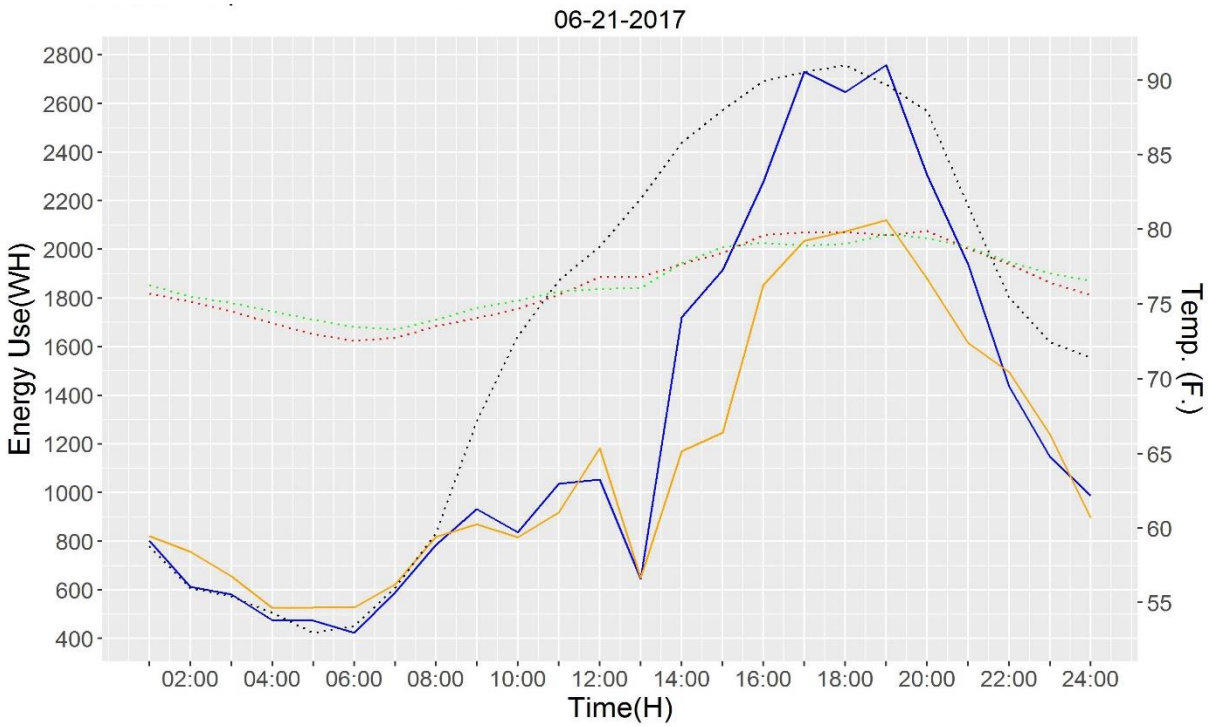

Energy Consumption Comparison between the Lab Homes

Experimental Home	Baseline Home	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
Cellular shades always down	No shades	24.8% (±8.6%)	3,359
Typical Use with Cellular Shades	No shades	4.7% (±1.3%)	1,808

Automated Shading Control Strategies: Summer Cooling Season

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Experimental Home	Baseline Home	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings	Average Max Peak Demand Reduction (Watts)
HD "Green Mode": Cellular shades operated on schedule to minimize heat gain through windows while allowing views during the day	Vinyl Blinds, Typical Use	15.1% (±2.0%)	3,287	
Typical Use with Occupancy Override: Cellular shades pulled down when occupant goes to work (9AM-5PM), typical use all other hours		15.2% (±2.2%)	3,814	
Demand response: Cellular shades pulled down in common areas during 4-hr peak period (3PM-7PM) and 4°F thermostat increase (typical use settings during non-peak hours)	Vinyl Blinds, Typical Use	15.7 (±2.2%)	4,060	1600
	Vinyl Blinds, Typical Use with 4°F thermostat increase at peak	16.6 (±2.94)	2,998	700

Demand Response (DR) – Combining Thermostat Adjustments with Shading

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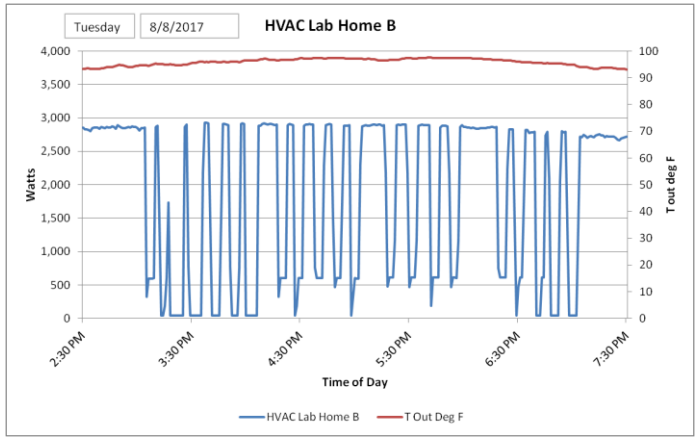
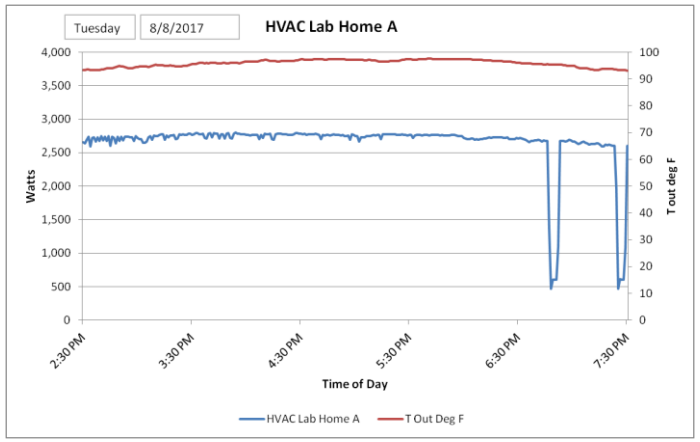
HVAC Cycling during Peak Period: DR Participant vs Non-Participant



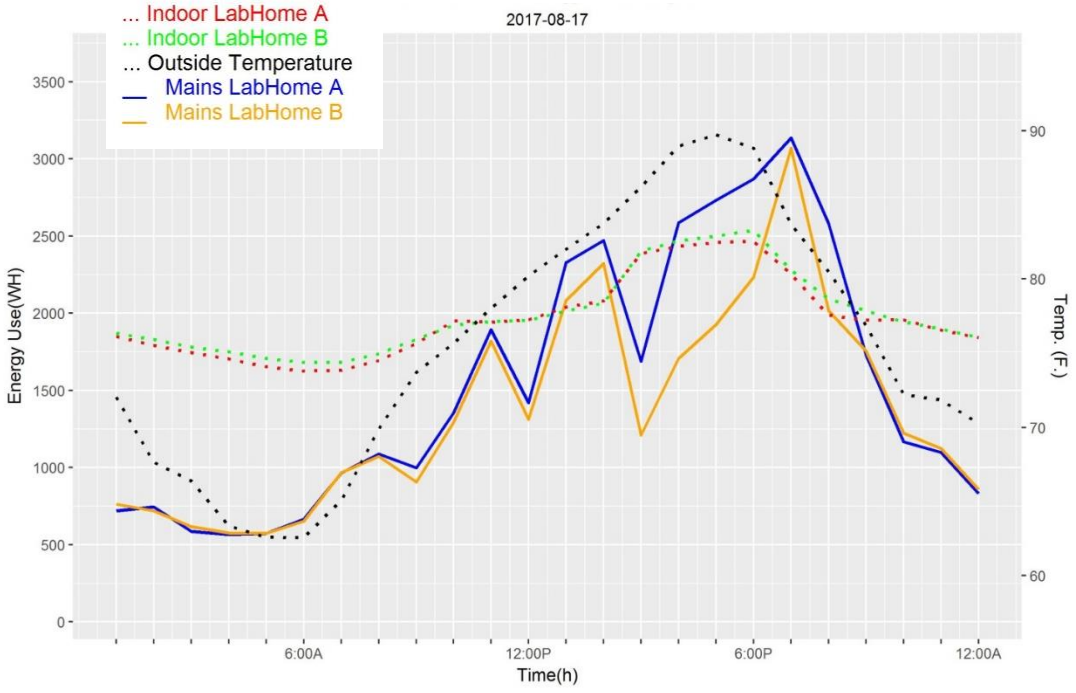
Lab Home B: DR participant (with cellular shades drawn down during peak event)



Lab Home A: Typical blinds, typical use and no participation in DR during peak event

Whole House Energy Use Comparison

Both homes participating in DR (i.e., thermostat setback during peak period), but only Lab Home B pulls down cellular shades in living room during peak event. HVAC savings = 3,936 W-hrs with cellular shades on this day.



Heating Season: Shades drawn down (always) versus "optimal" operation

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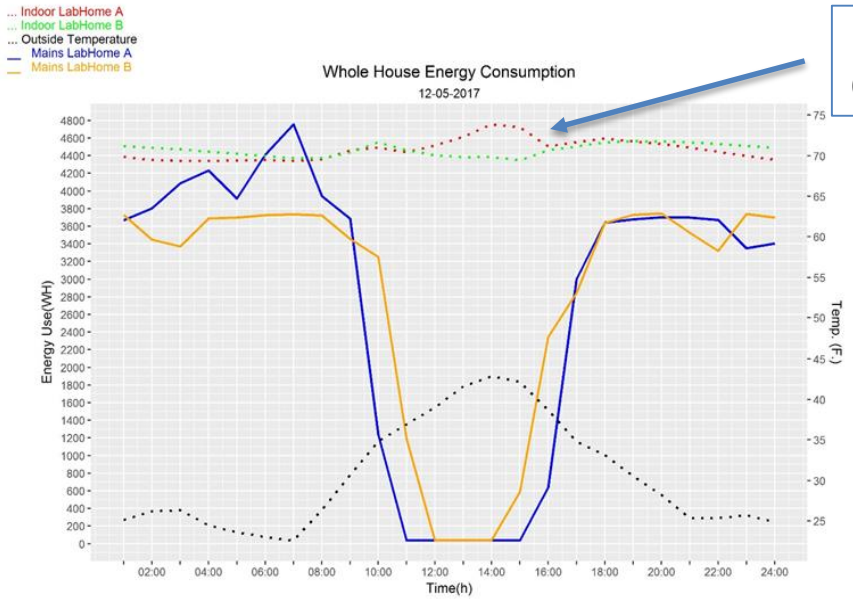
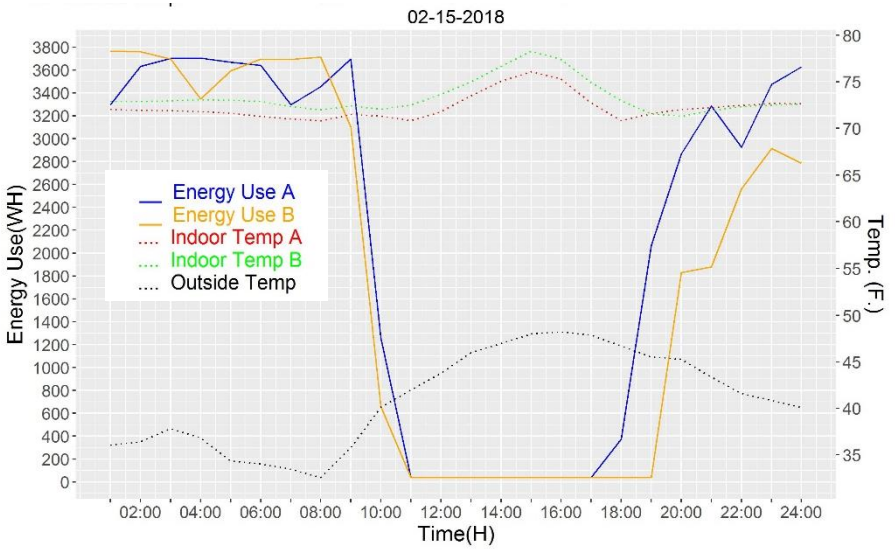


Beneficial heat gains not fully realized when shades are drawn down during the day (Sunny day, avg. temp 31° F)

- **Closed Shades Scenario**: Cellular shades covering all windows in Lab Home B (experimental home) and no shades on Lab Home A (control home) windows
- **Results:** Modest average savings (2%) when shades down all the time. Average of 5% savings recorded on very cloudy days, but negative savings on some sunny days.

- **Optimal Operation Scenario:** Cellular shades up during some portion of the day and closed at night (3 operating scenarios tested).
- **Results:** Achieved consistent HVAC savings between 5% to 9% compared to the home with blinds operated with typical settings.



Year-Round Savings Potential Across Multiple Climate Zones for New and Existing Homes

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Key Conclusions:

- "Smart" Window Shading Strategies more than Quadruple Energy Savings
- Smart Shade Control ≠ Complicated Control
- Shade Control Integrates well with other Connected Home Devices and Strategies
- Large Market Opportunity
  - >80% homes have window attachments
  - Applicable for new and existing homes
  - Many non-energy benefits
  - Automation commercially available (but pricey)
  - Trend toward automation

Energy Savings Simulation Results (Santa Clara, CA example)

	Window-to-Wall Area (%)	Percent Annual Savings Compared to No Shades
Prototype		Double-Cell Shades
Prototype # 1 (U=0.32)	15%	15%
	18%	18%
Prototype #2 (U=0.68)	15%	25%
	18%	29%
Prototype #3 (U=0.68)	15%	28%
	18%	31%

- Simulated savings in 13 US climate zones[1]
- Shade operation assumptions:
  - Summer (Apr-Sept): Shades down
  - Winter (Oct-Mar): Shades up day and down at night

[1]Metzger CE, J Zhang, VV Mendon, and KA Cort. 2017. *Modeling Cellular Shades in Energy Plus*. PNNL-27187. For City of Santa Clara and Silicon Valley Power.

Achieving the Maximum Potential Savings and Making Energy Efficiency Part of the Equation

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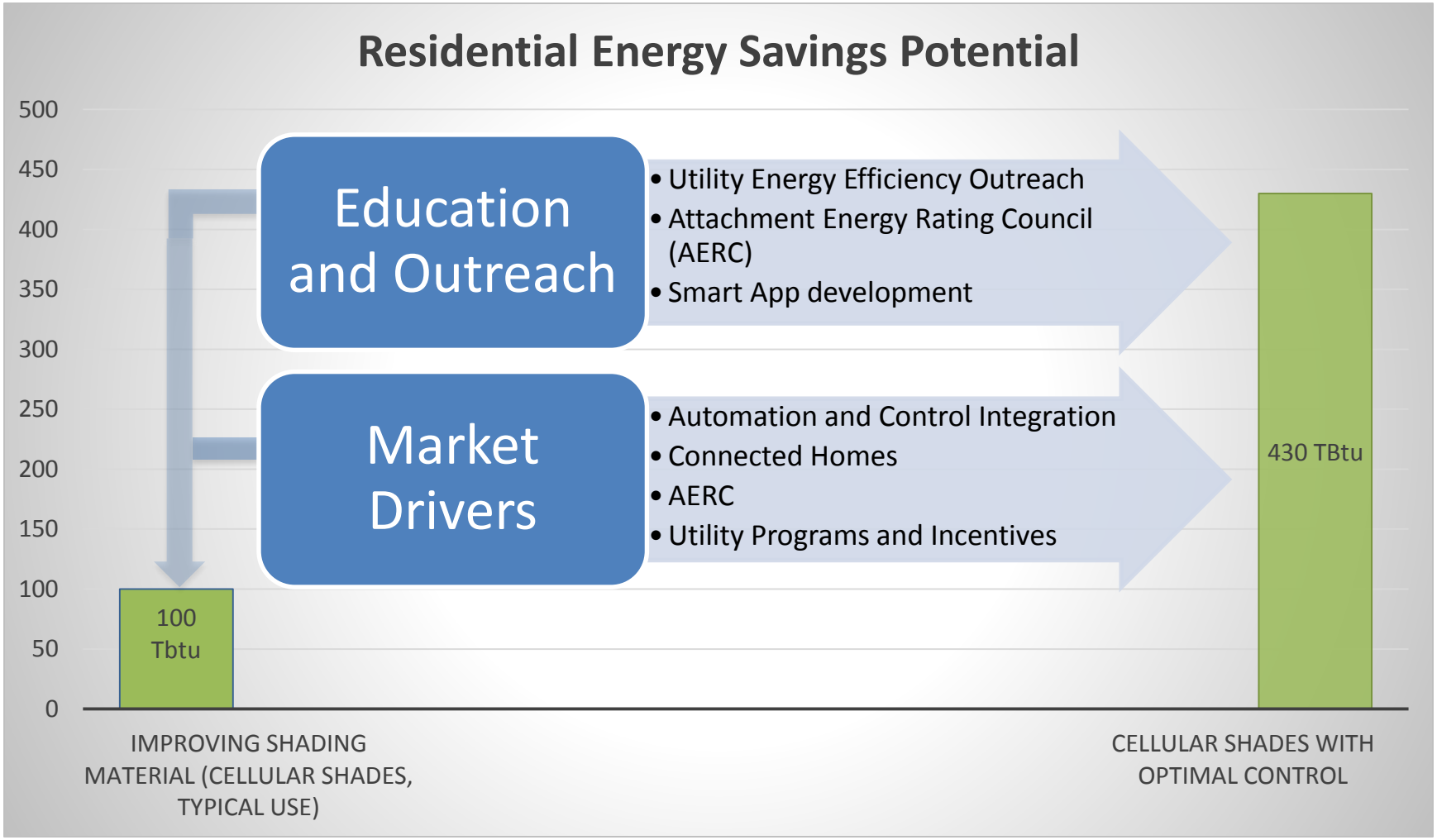

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Thank You!

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Backup Slides

Optimal insulated cellular shade usage compliments thermostat setback energy saving strategies

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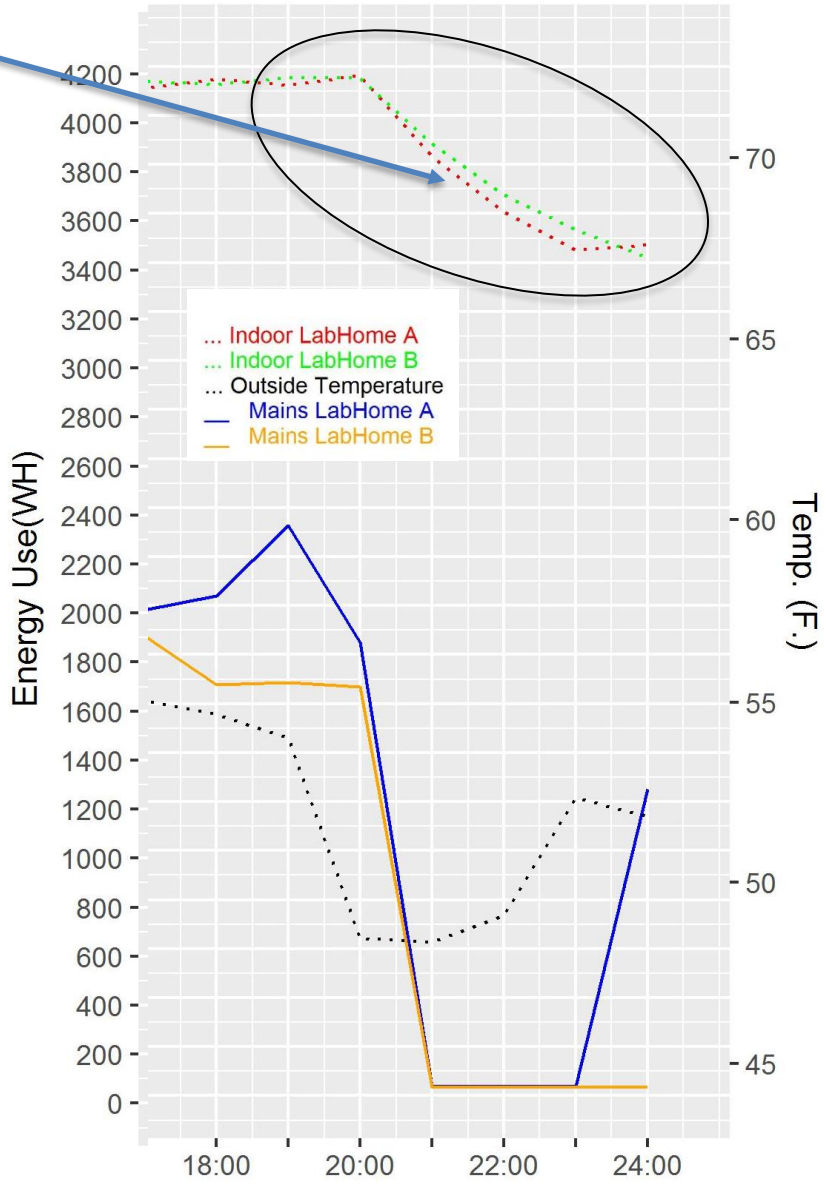
Lab home with insulated cellular shades maintains warmer indoor temperature longer after thermostat setback, providing additional savings and comfort.

- In Experimental Home – Cellular shades are drawn down in evening hours, and temperature is set back 5° F (from 9PM to 10 to 6AM).
- In Control Home – Venetian blinds are used in typical manner, and temperature is set back 5° F (from 9PM to 10 to 6AM).
- Average HVAC savings of 5% on this day (2/7/2018)



Testing of "Smart" Control Algorithm

- Developed control algorithm to control cellular shades, which works by estimating the total heat flux (W/m^2) into or out of the window, both when it is uncovered, and when it is covered by the cellular shades at the current time. The estimated heat flux is based on
  - The thermal properties of the window and shades, coupled with the interior and exterior temperatures
  - The optical properties of the window and shades, coupled with the estimated incident solar radiation on the exterior of the window.
- The algorithm decides on a preference for the window shade setting, which is a function of the space temperature, the thermostat setpoint temperature, the thermostat mode (heating).
- This control strategy is for demonstration purposes and is based purely on optimizing the energy performance of the window system. Other practical considerations like views, privacy preferences, and daylighting are not accounted for. During this period, the HVAC thermostat will be set at 71°F for heating mode.

Do smart window shading controls save energy?

- Yes. The "smart" control algorithm was implemented over a 24-day period during the end of the heating season and start of the "shoulder" season.
- Average HVAC savings of smart control algorithm was on par with optimized schedules (e.g., best practices and HD green mode); however, results were more variable.
- Smart controls can be a useful application during shoulder seasons when weather and HVAC needs can vary from day-to-day.

Heating Test Protocol – Dynamic Control of Cellular Shades Lab Homes Testing	Duration	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
"Smart" Controls			
Shoulder season testing with enhanced "smart" control features (compared to typical blinds and typical use)	24 days	5.5% (±3.7%)	2,324

Cellular Shades - Lab Homes PRELIMINARY 2017 Cooling Season Results

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Cooling Test Protocol – Dynamic Control of Cellular Shades Lab Homes Testing	Duration	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
Static Use (always down) of Cellular Shades (compared to no window coverings)	10 days	24.8% (±8.6%)	3,359
Static Use (always down) of Cellular Shades Compared (compared to "typical" horizontal slatted vinyl blinds in baseline home)	6 days	13.3% (±1.3%)	2,650
Typical Use with Cellular Shades (compared to no shades in baseline)	4 days	4.73% (±1.3%)	1,808
Typical Use with Cellular Shades (compared to typical blinds and typical use in baseline)	8 days	5.8% (±0.5%)	1,487
Optimal and Integrated Control Strategies			
Optimal Control – HD "Green Mode" Schedule with Cellular Shades (compared to typical blinds and typical use)	6 days	15.1% (±2.0%)	3,287
Typical Use with Occupancy Override 9AM-5PM (compared to typical blinds and typical use)	11 days	15.2% (±2.2%)	3,814
Integrated Control and Demand Response			
Part 1: 4 degree setback 3pm-7pm and cellular shades closed during this peak period (compared to LHA typical blinds and typical use)	15 days	15.7% (±2.2%)	4,060
Part 2: LHB 4 degree setback 3pm-7pm and cellular shades closed during this peak period (compared to LHA 4 degree setback, typical blinds and typical use)	8 days	16.6% (±2.94%)	2,998

Cellular Shades - Lab Homes PRELIMINARY 2017-2018 Heating Season Results

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Heating Test Protocol – Dynamic Control of Cellular Shades Lab Homes Testing	Duration	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
Static Use (always down) of Cellular Shades (compared to no window coverings): CLOUDY DAYS ONLY	6 days	5.0% (±1.3%)*	4,416
Static Use (always down) of Cellular Shades (compared to no window coverings): VARIABLE CLOUD COVER AND TEMPERATURE	9 days	2.4% (±3.2%)	1,970
Static Use (always down) of Cellular Shades Compared (compared to "typical" horizontal slatted vinyl blinds in baseline home)	6 days	9.3% (±1.9%)	7,011
Typical Use with Cellular Shades (compared to typical blinds and typical use in baseline)	4 days	2.0% (±1.3%)	1,505
Optimal and Integrated Control Strategies			
Optimal Control – HD "Green Mode" Schedule with Cellular Shades in common rooms (compared to typical blinds and typical use)	5 days	6.7% (±1.0%)	4,728
Best Practices I – Operating shades in common area only – Shades open at 6AM and closed at 6PM (compared to typical blinds and typical use)	9 days	5.4% (±1.2%)	3,007
Best Practices II – Operating all shades in home– Shades open at 6AM and closed at 6PM (compared to typical blinds and typical use)	3 days	8.7% (±1.2%)	5,445
Integrated "Smart" Controls			
Shoulder season testing with enhanced "smart" control features (compared to typical blinds and typical use)	24 days	5.5% (±3.7%)	2,324

*indicates a minimum savings on cloudy days due to issues with float in thermostat set points

Do you have to operate the all the window shades to realize the benefit?

- Optimal operation of shades over the larger view windows, particularly if they are south or west-facing, will provide consistent savings; however, additional savings can be realized if all shades are operated optimally

- Partial optimal operation (i.e., operation of the 5 common area windows) of shades yields average HVAC savings from 5.4% (best practice schedule) to 6.7% (HD Green Mode) and provides almost 90% of your potential savings.
- Full operation results in HVAC savings of 8.7% during experimental days observed.

Heating Test Protocol – Dynamic Control of Cellular Shades Lab Homes Testing	Duration	HVAC Savings % (+/- 95% confidence)	Average W-hr/day Savings
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