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# Evaluation of Cellular Shades in the PNNL Lab Homes

**October 2015**

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Prepared for the U.S. Department of Energy  
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory  
Richland, Washington 99352



# Summary

To examine the energy performance of cellular shade window coverings, a field evaluation was undertaken in a matched pair of all-electric, factory-built “lab homes” located on the Pacific Northwest National Laboratory (PNNL) campus in Richland, Washington. The 1500-square-foot homes were identical in construction and baseline performance, which allowed any difference in energy and thermal performance between the baseline home and the experimental home to be attributed to the retrofit technology installed in the experimental home.

To assess the performance of high efficiency window attachments in a residential retrofit application, the building shell air leakage, energy use, and interior temperatures of each home were compared during the 2015 winter heating and 2015 summer cooling seasons. Hunter Douglas Duette® Architella® Trielle™ opaque honeycomb “cellular” shades were installed over double-pane clear-glass, aluminum-frame primary windows in the experimental home and were compared to identical primary windows with no window coverings and with standard typical white vinyl horizontal blind window coverings in the baseline home.

The window coverings affected heating, ventilation, and air conditioning energy use in the following ways:

1. Reducing conductive heat transfer due to insulating capabilities
2. Reducing radiative energy losses due to insulative properties
3. Optimizing solar gains through advanced operational scheduling

Differing operational schedules were tested to help understand the effect of the window attachment technology on the heating, ventilation, and air conditioning (HVAC) energy use. The operational procedures that were completed in the 2015 heating and cooling seasons are detailed below with the associated HVAC energy savings. Based on the limited experimental period, the HVAC savings described in this report should be viewed as strictly preliminary.

1. Optimum Operation – The “optimum” operation schedule follows the Hunter Douglas developed HD Green Mode operation schedule for the experimental period to maximize the energy savings from insulated window shades. The schedule is specifically designed to optimize HVAC operation and solar heat gain while allowing some daylighting to accommodate consumer needs for natural daylight. Following this operation schedule, the impact of the cellular shades on the HVAC system is compared to the baseline home with no window attachments installed. During the heating experimental period, the cellular shades reduced the HVAC energy use by  $17.6 \pm 8.1\%$  compared to no blinds.
2. Optimum Operation Comparison – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades in the experimental home and typical white vinyl horizontal blinds in the baseline home. The window coverings in both Lab Homes were set to follow the HD Green Mode operational schedule for the experimental period. When compared to the typical vinyl horizontal blinds during the cooling experimental period, the cellular shades reduced the HVAC energy use by an estimated  $10.4 \pm 6.5\%$  when compared to typical vinyl horizontal blinds.

3. **Static Operation** – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades and typical white vinyl horizontal blinds during the cooling season. No operational schedules were implemented and both sets of window coverings remained closed for the duration of the experiment. The cellular shades installed in the experimental home reduced the HVAC energy use by  $13.3 \pm 2.8\%$  in comparison to the vinyl blinds installed in the baseline home.

The advanced insulating properties of the cellular shades add benefits across the all climate zones. The location of the Lab Homes, within the heating dominated northern climate, facilitate an ideal testbed for analysis of the cellular shades. The differing test scenario results suggest that the energy savings were primarily realized due to the increased insulative value of the cellular shades and optimization of the thermal gains through the window. The window attachments did not significantly decrease the air leakage of the home due to the air-tightness of the baseline primary window (i.e., the primary windows are already well-sealed).

This whole home experimental field evaluation has added to the body of knowledge surrounding window attachments performance and operational schedules by accurately measuring the energy savings of insulated cellular shades and vinyl blinds in a controlled setting. Future research should focus on longer duration evaluation with an objective of providing seasonal impacts of blind operation. Application of longer duration analysis would be to help calibrate energy-use models allowing for more informed annual energy use and savings analysis across building types and climate zones. Additional studies are needed to accurately quantify the performance of window attachments across a variety of building types and climate zones and determine the cost-effectiveness of specific window attachments in a variety of retrofit scenarios; however, the data clearly demonstrate that cellular shades can be an effective energy-saving measure that should be considered for retrofits in residential homes.

## **Acknowledgments**

The authors would like to thank Hunter Douglas, who donated the cellular shades for this experiment. Specifically, the authors would like to thank Stacy Lambright and Drake McGown for their assistance in installing the Hunter Douglas shades and assistance with the operational schedules.





## Acronyms and Abbreviations

ACH50	air changes per hour at 50 Pascals of depressurization with respect to the outside
AERC	Attachments Energy Rating Council
BTO	Building Technologies Office (U.S. Department of Energy)
Btu	British thermal unit(s)
cfm	cubic feet per minute
cfm50	cubic feet per minute at 50 Pascals of depressurization with respect to outside
CU	condensing unit
d	day(s)
DOE	U.S. Department of Energy
ET	emerging technologies
°F	degrees Fahrenheit
ft	foot (feet)
hr	hour(s)
HVAC	heating, ventilation, and air conditioning
kW	kilowatt(s)
kWh	kilowatt hour(s)
LAN	local area network
LBNL	Lawrence Berkeley National Laboratory
MRT	mean radiant temperature
NFRC	National Fenestration Rating Council
Pa	Pascal(s)
PNNL	Pacific Northwest National Laboratory
SEER	seasonal energy-efficiency ratio
SHGC	solar heat gain coefficient
VT	visible transmittance
Wh	watt-hour(s)
W/m <sup>2</sup>	watts per square meter
yr	year(s)



# Contents

Summary .....	iii
Acknowledgments.....	v
Acronyms and Abbreviations .....	vii
Contents .....	ix
Figures .....	x
Tables.....	x
1.0 Introduction .....	1
2.0 Background.....	2
2.1 Window Attachment Technology .....	2
2.2 Window Attachment Development and Previous Research.....	3
2.3 Advantages of PNNL Lab Homes Research .....	4
3.0 Experimental Design .....	5
3.1 Lab Homes .....	5
3.2 Window Attachment Retrofit .....	5
3.2.1 Window Attachment Performance Ratings.....	6
3.3 Experimental Timeline.....	7
3.4 Metering Approach .....	8
4.0 Results and Discussion .....	11
4.1 Baseline Performance.....	11
4.2 Building Shell Air Leakage.....	13
4.3 Winter Heating Cellular Shades Energy Performance Results .....	13
4.3.1 Heating Season – Optimum Operation.....	14
4.4 Cooling Season Cellular Shades Energy Performance Results .....	16
4.4.1 Cooling Season – Static Operation.....	16
4.4.2 Cooling Season – Optimum Operation Comparison .....	18
5.0 Experimental Period and Future Work Discussion .....	21
6.0 Conclusions .....	22
7.0 References .....	23
Appendix A – HD Green Mode Operation Schedule.....	A.1

## Figures

2.1	Hunter Douglas Duette Architella Trielle shades: semi-opaque and opaque .....	2
3.1	Floor Plan of the Lab Homes as Constructed .....	5
3.2	Mounting Bracket for the Cellular Shades and Example of Installed Hunter Douglas Cellular Shade.....	6
3.3	Window Temperature Measurement Points.....	10
4.1.	HVAC Energy Use of the Baseline HVAC and the Experimental HVAC and during Heating Season Baseline Period.....	12
4.2	Cumulative HVAC Energy Use of the Experimental Home and the Baseline Home throughout one day of the Baseline Period .....	12
4.3.	HVAC Usage during the Implementation of the HD Green Mode Optimum Schedule between Hunter Douglas Cellular Shades in Experimental Home Compared to No Window Attachments in Baseline Home.....	15
4.4	Interior Temperature of Baseline Home Compared to Experimental Home during the March 18 <sup>th</sup> 2015 HD Green Mode Optimum Operation .....	15
4.5	Insulating Value of the Hunter Douglas Cellular Shades Compared to Vinyl Blinds .....	17
4.6	Interior Temperature of Baseline Home Compared to Experimental Home During the August 27 <sup>th</sup> 2015 Static Window Attachment Comparison .....	18
4.7	HVAC Usage during the Implementation of the HD Green Mode Optimum Schedule Between Hunter Douglas Cellular Shades Compared to Vinyl Blinds.....	19
4.8	Interior Temperature of Lab Home A Compared to Lab Home B during the September 11 <sup>th</sup> 2015 Optimum Operation Comparison.....	20

## Tables

2.1	Summarized Case Studies Focused on Window Attachments and Cellular Shades.....	4
3.1	Primary Window Characteristics .....	7
3.2	Experimental Timeline .....	8
3.3	Electrical Points Monitored .....	9
3.4	Temperature and Environmental Points Monitored.....	9
4.1	Blower Door Test Results Prior to Window Attachment Installation.....	13
5.1	Summary of Experimental Results of Cellular Shades Compared to a Baseline on the Same Schedule.....	21

# 1.0 Introduction

Residential buildings in the United States currently require approximately 8 quadrillion Btu/yr of energy for heating and cooling, which accounts for more than 40% of the primary energy consumed by homes<sup>1</sup>. Windows are a major source of heating losses and gains in residential buildings because of their heat transfer and infiltration properties, especially relative to other building shell components. For example, it has been estimated that windows account for approximately 25% of the energy use in a typical residential building (Huang et al. 1999). Retrofitting and renovating existing homes to save energy has become an increasingly important component of U.S. energy strategy, and energy-efficient window attachments, such as high efficiency shades<sup>2</sup>, blinds<sup>3</sup>, storm windows, or other window coverings, can significantly improve the thermal performance of a window at a fraction of the financial cost of a full primary window replacement. A honeycomb or “cellular” shade retrofit could potentially offer a cost-effective solution to improving a window’s thermal performance by interrupting and reducing the heat transfer through the window.

This report describes whole home experimental research conducted in support of the Building America’s Window Attachments program and the Northwest Energy Efficiency Alliance (NEEA). The U.S. Department of Energy’s (DOE’s) Building America Program serves as a catalyst to accelerate the residential building energy-efficiency market transformation and support increasing levels of cost-effective whole-house energy savings. NEEA is an alliance of more than 140 Northwest utilities and energy efficiency organizations working on behalf of more than 13 million energy consumers.<sup>4</sup> Its mission is to accelerate both electric and gas energy efficiency, leveraging regional partnerships to advance the adoption of energy-efficient products.

The purpose of this project is to evaluate the energy savings potential of installing insulated cellular shades over typical double-pane clear aluminum-frame windows in the Pacific Northwest National Laboratory’s (PNNL) matched pair of Lab Homes.<sup>5</sup> The performance of the home’s heating, ventilation, and air conditioning (HVAC) system was measured and compared to the thermal performance of a home with and without standard and high efficiency windows attachments during heating and cooling season periods. Both homes deploy identical simulated occupancy schedules so that the performance and effects of the window attachments will be isolated from all other variables. The results from the research, as presented in this report, help validate savings and performance of installing window attachments over double-pane clear glass primary windows.

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<sup>1</sup>“Residential sector key indicators and consumption.” Annual Energy Outlook (DOE). Available online: <http://www.eia.gov/forecasts/aeo/pdf/tbla4.pdf>

<sup>2</sup> Cellular shade is defined as a window covering made of pleated fabric that is “honeycombed” and can be raised and lowered. Their adjustability adds elements balancing view, privacy, glare control, and daylighting. Also called insulated cellular shade.

<sup>3</sup> Blind is defined as a louvered window covering with stacked vanes that can be both tilted and raised/lowered.

<sup>4</sup> See <http://neea.org/about-neea> for more information (accessed September 2015).

<sup>5</sup> See <http://labhomes.pnnl.gov> for more information on Lab Homes.

## 2.0 Background

Window attachments, such as window shades and blinds, have been used for privacy for as long as windows have been in use. Only recently, however, has attention been drawn to the energy savings potential achieved through increasing the insulating values of window coverings, and reducing or optimizing the solar gains added to the space. The type and selection of differing attachment technology has greatly expanded in previous years; however, there is limited information on the differing energy-saving characteristics of these products and currently no comprehensive rating system exists to help distinguish the energy-saving features of one window covering from another (Curcija et al. 2013).

High-efficiency shading devices, such as cellular shades (a.k.a. honeycomb shades), can be an option for utilities (and homeowners) to consider as part of a package of retrofits to cost-effectively improve the home's thermal performance and to meet conservation goals. Retrofitting and renovating existing homes to save energy has become an increasingly important component of the nation's energy strategy, and energy-efficient window attachments, such as cellular shades, can offer an affordable way to significantly improve the thermal performance of a window. This study examines the energy saving potential from installing honeycomb-style cellular shades over a double-pane clear glass windows.

### 2.1 Window Attachment Technology

Within the window coverings category, honeycomb cellular shades are typically considered to have the highest R-value. Introduced in the 1980s, cellular shades are designed to trap air inside pockets that act as insulators and can increase the R-value of the window covering and reduce the thermal heat transfer through window that it covers (Ariosto et al. 2013). The specific technology examined as part of this study was the Hunter Douglas Duette® Architella® Trielle™ honeycomb fabric shades, which are made with six layers of fabric including two opaque layers and five insulating air pockets (See Figure 2.1). The inclusion of insulating air pockets as well as the layer of metallized Mylar that lines the air pockets, minimizes radiant heat transfer and effectively increases the R-value of the fabric.



**Figure 2.1.** Hunter Douglas Duette Architella Trielle shades: semi-opaque (left) and opaque (right)<sup>1</sup>.

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<sup>1</sup> Photo Courtesy of Hunter Douglas - <http://www.hunterdouglas.com/honeycomb-shades/duette-architella>

## 2.2 Window Attachment Development and Previous Research

In 2013, the DOE sponsored a comprehensive energy modeling study led by Lawrence Berkeley National Laboratory (LBNL) that focused on a range of window attachments, including products such as shades, blinds, storm window panels, and surface applied films simulated in four types of “typical” houses, located in 12 characteristic climate zones. The simulations captured the optical and thermal complexities of these products (Curcija et al. 2013) and also considered typical operation and usage patterns based on a separate study focusing on user behavior with respect to operable window coverings (Bickel et al. 2013). The study found that many of the window attachments examined can yield significant energy savings when installed over windows; however, the degree of savings depends on the attachment type, baseline window conditions, seasonal and climate factors, and how the attachment is operated, when applicable. Nevertheless, the study concluded that in heating dominated climates, particularly in the north-central climate zones, low-e storm windows and insulated cellular shades are two of the most effective window attachments at reducing HVAC usage.

In addition to DOE’s research focusing on window coverings, a number of research institutions, energy-efficiency programs, and utilities have completed characterization and meta analyses<sup>1</sup> (Ariosto et al. 2013) and energy simulation analyses (CEE 2014; Garber-Slaght and Craven 2011; Zirnelt et al. 2015) validating energy savings from cellular shades and other window attachments in multiple climate zones and prototype residential buildings. There have also been some field studies examining energy savings from cellular shades over aluminum-framed clear glass windows (PGE 2015).

This side-by-side evaluation in the PNNL Lab Homes represents the first controlled whole-house experiments performed with cellular shading devices. The data collected as a result of the PNNL Lab Homes experiments can complement previous modeling and field studies to help describe the performance of cellular shades as a retrofit option for typical residential homes. The detailed results describe the performance of the cellular shades more precisely than field studies, because the experiments are not confounded by weather or occupancy impacts, and thus can potentially be used to calibrate whole-house energy models.

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<sup>1</sup> See, for example, the website: <http://www.efficientwindowcoverings.org/>, sponsored and developed by DOE, Building Green, and LBNL and DOE’s <http://energy.gov/energysaver/articles/energy-efficient-window-treatments>.

**Table 2.1. Summarized Case Studies Focused on Window Attachments and Cellular Shades**

Study	Sponsor	Technology Analyzed	Summary of Findings
Energy Savings from Window Shades (Zirnhelt et al. 2015)	Hunter Douglas and Rocky Mountain Institute	Hunter Douglas cellular shades	<ul style="list-style-type: none"> <li>• Denver Max Cooling Savings – 25%</li> <li>• Denver Max Heating Savings – 10%</li> <li>• Peak electrical demand reduction of 9% for new homes</li> <li>• Increased thermal comfort</li> </ul>
Evaluation of Residential Window Retrofit Solutions for Energy Efficiency (Aristo et al. 2013)	The Pennsylvania Housing Research Center	Modeled cellular shades	<ul style="list-style-type: none"> <li>• Reduction in U-Value by 38%</li> <li>• Reduction in SHGC by 39%</li> </ul>
Residential Windows and Window Coverings (Bickel et al. 2013)	DOE, BTO	Behavior and window coverings installed base study	<ul style="list-style-type: none"> <li>• 18% of northern climate homes have no coverings</li> <li>• 62% of all window attachments are blinds</li> </ul>
Evaluating Window Insulation for Cold Climates (Garber-Slaght and Craven 2011)	Cold Climate Housing Research Center	Modeled interior insulated blinds	<ul style="list-style-type: none"> <li>• U-value reduction of 15%</li> </ul>
Energy Savings from Window Attachments (Curcija et al. 2013)	DOE, BTO	Energy modeling of window attachment technologies	<ul style="list-style-type: none"> <li>• Cellular shades over double pane window</li> <li>• U- value – 0.2-0.43</li> <li>• SHGC – 0.15-0.48</li> </ul>

### 2.3 Advantages of PNNL Lab Homes Research

Although field data and case studies provide valuable insights related to the savings potential of window attachments in specific applications or climate zones, the variability that occurs due to home type and occupancy behavior can make it difficult to isolate the savings from the window attachment and project these savings to alternative circumstances. Controlled side-by-side experiments, such as those conducted in the PNNL Lab Homes, provide a platform for more detailed and comprehensive data collection on the HVAC energy performance of cellular shades. The PNNL Lab Homes provide controlled experimental HVAC data, which can be used to appropriately tailor and calibrate building simulation models to account for relevant interactions, occupancy, climate zones, and baseline characterizations.



## 3.0 Experimental Design

The evaluation of window attachments took place in the PNNL Lab Homes between February 2015 and September 2015. This section describes the experimental timeline, the Lab Homes, the window attachments used in the experiment, and the data collection and analysis methodologies.

### 3.1 Lab Homes

The experiments were conducted in PNNL’s side-by-side Lab Homes, which form a platform for precisely evaluating energy-saving and grid-responsive technologies in a controlled environment. The PNNL Lab Homes are two factory-built homes installed on PNNL’s campus in Richland, Washington. Each Lab Home has seven windows and two sliding glass doors, for a total of 196 ft<sup>2</sup> of window area. For the primary experiments examined in this study, the “experimental home” was retrofitted with Hunter Douglas honeycomb shades<sup>1</sup>, while a matching “baseline home” was equipped with typical vinyl blinds<sup>2</sup> or no window coverings, depending on the experiment. The floor plan of the Lab Homes as constructed is shown in Figure 3.1.

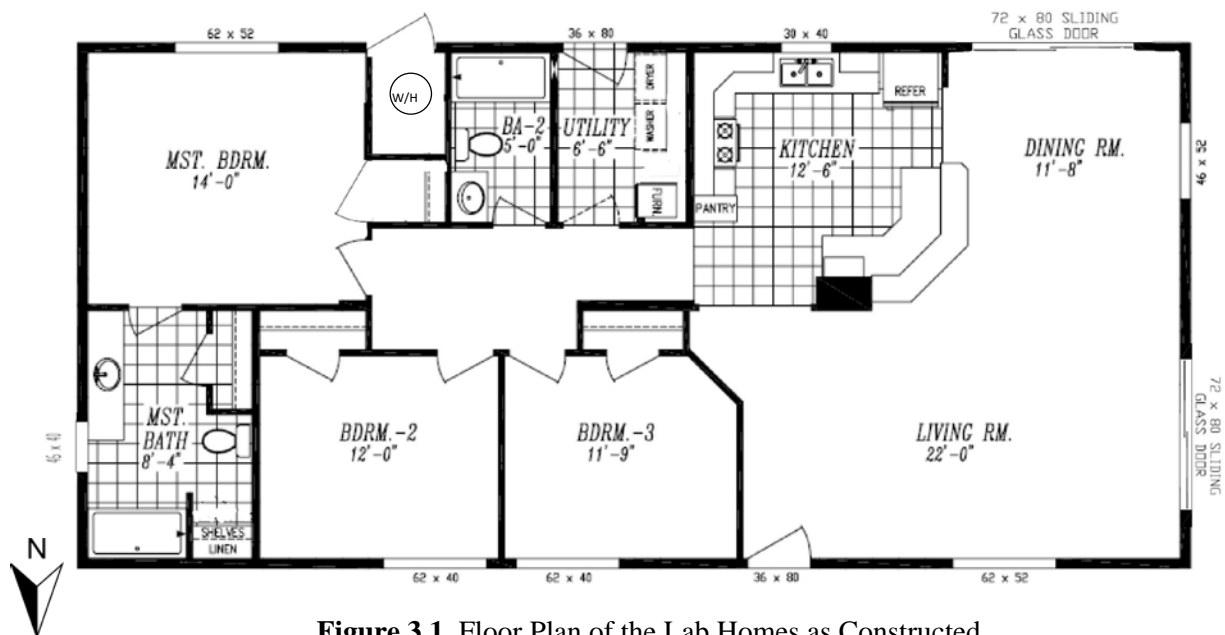


Figure 3.1. Floor Plan of the Lab Homes as Constructed

### 3.2 Window Attachment Retrofit

The primary windows and patio doors currently installed in both of the Lab Homes are double-pane, clear-glass aluminum-frame sliders. For the experiment, window attachments were installed over the experimental home’s windows and sliding glass doors. Hunter Douglas cellular shades were installed on the interior side of the primary windows. The number and dimensions of the windows were as follows:

- 2 ea 62" × 52" – Two-track Sliders

<sup>1</sup> Hunter Douglas Duette Architella Trielle honeycomb shades Fabric: C83 Trielle Daisy White

<sup>2</sup> Where “typical” blinds are horizontal slatted “Vinyl” style blinds with 1-inch slats.

- 2 ea 62" × 40" – Two-track Sliders
- 1 ea 30" × 40" – Two-track Sliders
- 1 ea 46" × 52" – Two-track Sliders
- 1 ea 46" × 40" – Single Hung
- 2 ea 72" × 80" – Sliding glass doors

The cellular shades were installed over the primary windows such that the gap between the windows and the blind brackets was 1.5 inches. Equipped with a battery pack and small motor, the shades had the ability to be automatically raised and lowered via predefined schedules programmed by PNNL staff into the Hunter Douglas PowerView™ Motorization app. A Hunter Douglas Local Area Network (LAN) was used to communicate to individual or groups of shades within the system. Wireless signals were sent via the LAN to specified window coverings to open and close based on predefined schedules. Due to the size of the Lab Homes, a signal wireless repeater was used to ensure that the communications between the programmed router and shades were effectively transmitted. Figure 3.2 details the installation location of one of the two mounting brackets and an example of the shade installed in the kitchen.



**Figure 3.2.** Mounting Bracket for the Cellular Shades and Example of Installed Hunter Douglas Cellular Shade

### 3.2.1 Window Attachment Performance Ratings

The U-factor and solar heat gain coefficient (SHGC) for the primary windows are listed in Table 3.1. Installing a shade behind a primary window will alter the SHGC, U-Factor, and visible transmittance (VT). When fully closed, typical vinyl blinds are expected to decrease the U-factor of the window opening by approximately 0.07–0.13 Btu/hr-ft<sup>2</sup>-F (Curcija et al. 2013) and depending on the blind, greatly reduce the SHGC and VT, which should decrease the observed energy use in both homes.

**Table 3.1.** Primary Window Characteristics

Value	Primary Windows in Lab Homes A and B	
	Windows	Patio Doors
U-factor (Btu/hr-ft <sup>2</sup> -F)	0.68	0.66
SHGC	0.7	0.66
Visible Transmittance	0.73	0.71

Although the NFRC provides U-factor ratings for primary windows, there is currently no standard performance or energy-efficiency rating system that exists for window attachments, such as window shades. To address the lack of a nationally-recognized rating system for window attachments and coverings, the Attachments Energy Rating Council (AERC)<sup>1</sup> was launched in 2015 with the support of the U.S. DOE. The mission of AERC is to develop a third-party program that creates a consistent set of energy performance-based rating and certification standards and program procedures for energy-efficient window attachments. When complete, AERC will oversee the implementation of rating, certification, labeling, and performance verification procedures. AERC will also develop and maintain a publicly available, searchable electronic database of window attachment product performance.

### 3.3 Experimental Timeline

A timeline of the operating parameters and experimental scenarios exercised during the data collection periods is presented in Table 3.2. The thermostat set point in the heating and cooling season was set to 71°F with no set-backs. The set point was chosen to generate a large temperature differential between indoors and outdoors to maximize the observed HVAC impacts while keeping the set points in a range representative of real home occupancy conditions. The cellular shades were first installed in March 2015, and a preliminary 2015 heating season experiment was run to evaluate the energy savings of the window attachments in differing operational modes. Cooling season data was collected in August and September 2015. In both the heating and cooling season, the impacts of the cellular shades on the HVAC systems were compared during differing operational modes and to other window attachments. Below are the experiments that were conducted and a brief explanation of the process:

1. Optimum Operation – The “optimum” operation schedule follows the Hunter Douglas developed HD Green Mode operation schedule for the experimental period to maximize the energy savings from insulated window shades. The schedule is specifically designed to optimize HVAC operation and solar heat gain while allowing some daylighting to accommodate consumer needs for natural daylight. Details of the HD Green Mode operational schedule can be found in Appendix A. Following this operation schedule, the impact of the cellular shades on the HVAC system is compared to the baseline home with no window attachments installed.
2. Optimum Operation Comparison – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades in the experimental home and typical white vinyl horizontal blinds in the baseline home. The window coverings in both Lab Homes were set to follow the HD Green Mode operational schedule for the experimental period.
3. Static Operation – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades and typical white vinyl horizontal blinds

<sup>1</sup> <http://energy.gov/eere/buildings/downloads/attachments-energy-ratings-council> and <http://aercnet.org>.

during the cooling season. No operational schedules were implemented and both sets of window coverings remained closed for the duration of the experiment.

The interior blinds in the baseline home were typical white vinyl horizontal blinds over the windows and vertically hung slat blinds for the sliding glass doors. These were chosen to be representative of blinds that would be found in a typical Northwest home. In operational modes that required these window attachments to follow schedules, PNNL engineers manually opened and closed the attachments per schedule for the vinyl blinds within the baseline home. The Hunter Douglas cellular shades, installed in the experimental home, utilized the Hunter Douglas PowerView Motorization lift system to automatically adjust the window coverings to the required schedule.

**Table 3.2.** Experimental Timeline

Description	Duration (days)	Date
<b>Heating Season Experiment Setup</b>		
Air leakage testing	1	2/24/2015
Baseline (no window attachments)	7	2/25/2015 – 3/3/2015
Installation of cellular shades	1	3/4/2015
<b>Preliminary Heating Season Experiment</b>		
Cellular shades optimum operation	10	3/9/2015 – 3/19/2015
Cellular shades and vinyl blinds comparison <sup>1</sup>	11	3/23/2015 – 4/2/2015
<b>Post Test Heating Season Experiment</b>		
Remove cellular shades	1	4/3/2015
<b>Cooling Season Experiment Setup</b>		
Air leakage testing	1	7/10/2015
Baseline (no window attachments)	10	7/11/2015 – 7/22/2015
Installation of cellular shades	1	8/18/2015
<b>Preliminary Cooling Season Experiment</b>		
Cellular shades and vinyl blinds static operation	15	8/19/2015 – 9/2/2015
Cellular shades and vinyl blinds optimum operation	13	9/3/2015 – 9/15/2015
<b>Post Test Cooling Season Experiment</b>		
Remove cellular shades	1	9/16/2015

### 3.4 Metering Approach

The approach to the metering includes metering and system-control activities taking place at both the electrical panel and at the end-use. Monitoring is broken into electrical (Table 3.3) and temperature/other (Table 3.4). Each table highlights the equipment being monitored, the monitoring method and/or point, the monitored variables, and the data application.

<sup>1</sup> Of the eleven experimental days, only three were considered to be valid due to weather variability. Due to the limited valid experimental days, this experiment was not included.

**Table 3.3. Electrical Points Monitored**

Performance Metric	Monitoring Method/Points	Monitored Variables	Data Application
Whole Building Energy Use	Electrical panel mains	kW, amps, volts	Comparison between homes of <ul style="list-style-type: none"> <li>power profiles</li> <li>time-series energy use</li> <li>differences and savings</li> </ul>
HVAC Energy Use (heat pump)	Panel metering compressor	kW, amps, volts	Comparison and difference calculations between systems of <ul style="list-style-type: none"> <li>power profiles</li> <li>time-series energy use</li> <li>differences and savings</li> </ul>
	Panel metering air handling unit	kW, amps, volts	
	End-use metering condensing unit (CU) fan/controls	kW, amps, volts	
HVAC Energy Use (ventilation)	Panel metering of 3 ventilation breakers (2 bathroom and whole-house fans)	kW, amps, volts	Comparison and difference calculations between systems of <ul style="list-style-type: none"> <li>power profiles</li> <li>time-series energy use</li> <li>differences and savings</li> </ul>
Appliances and Lighting	Panel metering of all appliance and lighting breakers	kW, amps, volts	Comparison and difference calculations.

**Table 3.4. Temperature and Environmental Points Monitored**

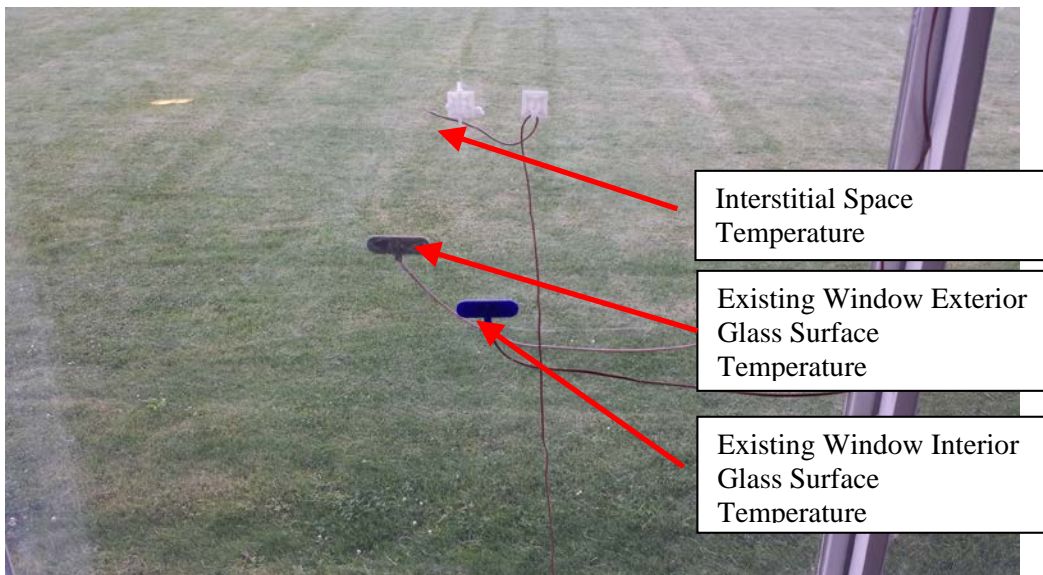
Performance Metric	Monitoring Method/Points	Monitored Variables	Data Application
Space Temperatures	13 Ceiling-hung thermocouples/1–2 sensors per room/area, and 1 HVAC duct supply temperature per home	Temp. (°F)	Comparison and difference calculations between homes of <ul style="list-style-type: none"> <li>temperature profiles</li> <li>time-series temperature changes</li> </ul>
	2 mean radiant sensors per home (main living area, master bedroom)	Temp. (°F)	
Glass Surface Temperatures	22 thermocouples (2 sensors per window interior/exterior center of glass); west window with 6 sensors. 2 thermocouples per home to measure temperature between the primary and storm windows.	Temp. (°F)	Comparison and difference calculations between homes of <ul style="list-style-type: none"> <li>temperature profiles</li> <li>time-series temperature changes</li> </ul>
Through-Glass Solar Radiation	1 pyranometer sensor per home trained on west-facing window	W/m <sup>2</sup>	Comparison and difference calculations between homes of <ul style="list-style-type: none"> <li>profiles by window and location</li> </ul>

All metering was completed using Campbell Scientific data loggers and matching sensors. Two Campbell data loggers were installed in each home, one allocated to electrical measurements and one to temperature and other data collection. Data from all sensors were collected via cellular modems that were individually connected to each of the loggers.

All data were captured at 1-minute intervals by the Campbell Scientific data loggers. These 1-minute data were averaged over hourly and daily time intervals to afford different analyses.

Occupancy in the homes was simulated via a programmable commercial lighting breaker panel (one per home) using motorized breakers. These breakers were programmed to activate connected loads on schedules to simulate human occupancy by introducing heat to the space.

To help understand the dynamic flow of heat from the outside of the each home to the inside, advanced metering techniques were used to catalog the temperature at points both on the primary window and in the space between the primary window and window attachment. Figure 3.3 displays the temperature measurement points that were placed on one window facing each cardinal direction, except east.



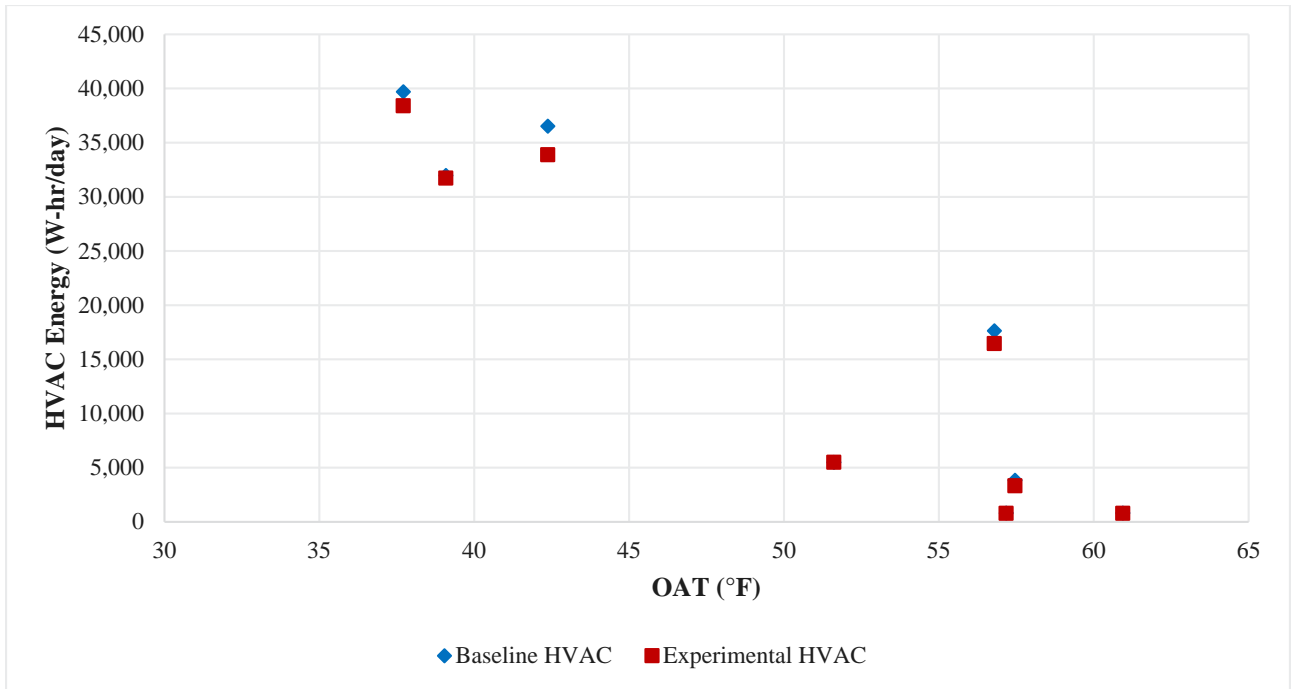
**Figure 3.3.** Window Temperature Measurement Points

## 4.0 Results and Discussion

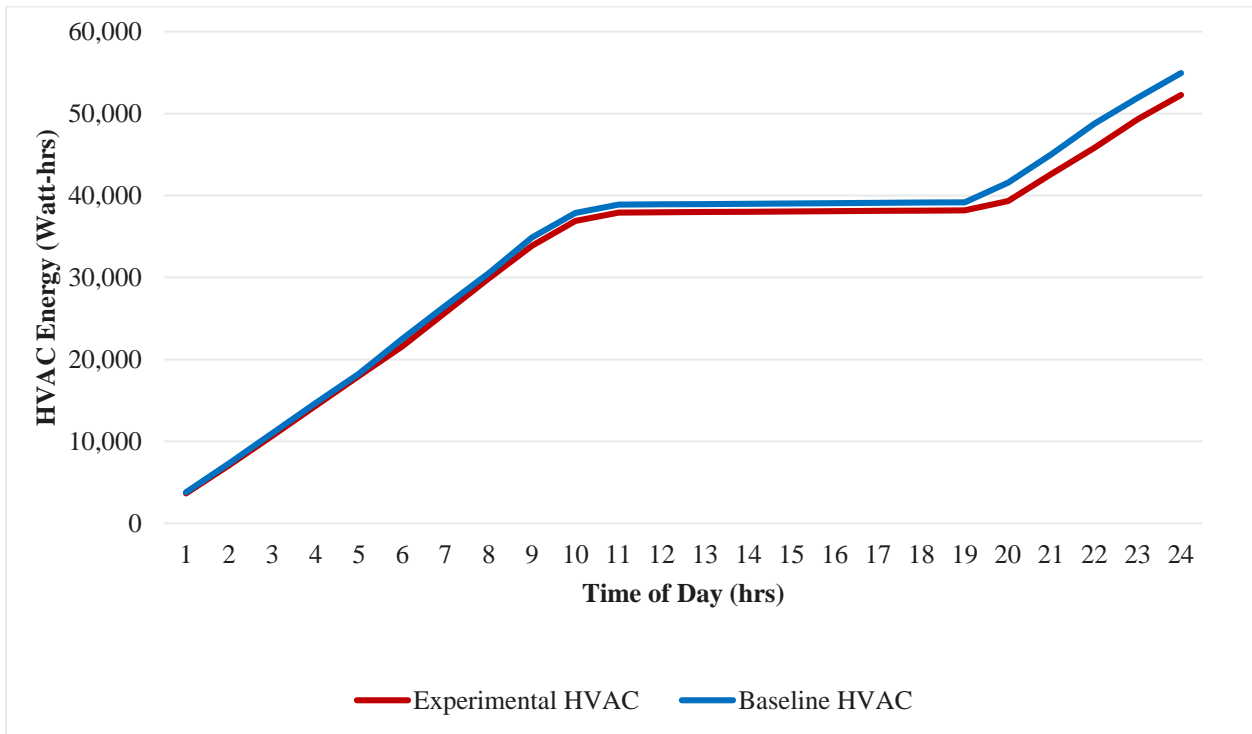
The air-leakage and HVAC energy performance of window attachments were evaluated during the 2015 heating season and the 2015 cooling season in the PNNL Lab Homes. The subsequent sections provide a summary of the baseline performance of the two homes, as well as a comparison of the energy usage of the experimental home equipped with double-pane clear-glass windows with interior cellular shades and the baseline home equipped with double-pane clear-glass windows and either no attachments or typical horizontal vinyl blinds. Note that all experimental results are presented, in general, as daily averages with 95% confidence intervals calculated for each measured quantity, assuming a normal distribution of the data and applying a student's t-statistic. The 95% confidence interval is then used to establish the significance of the differences observed as a result of the window attachment retrofit by applying a traditional significance test.

### 4.1 Baseline Performance

Prior to installing the window attachments in both the heating and cooling seasons, baseline performance data was collected over 7 days in the heating season and 10 days in the cooling season to ensure that the HVAC and simulated occupancy systems were operating as expected in the Lab Homes. Over the 17 days of baseline data collection from the heating and cooling seasons, the HVAC energy use in the Lab Homes was observed to be statistically different, showing a consistent offset within 5%. Specifically, the baseline home used  $4.56 \pm 1.25\%$  more HVAC energy per day than the experimental home over the baseline period. Prior to the baseline period, general maintenance on the HVAC system and envelope of each lab home had been done to reduce the HVAC energy use offset. The heating season baseline period required an extended period for evaluation to adequately understand and catalog the energy use differential between the two homes. The statistical difference within the baseline is sufficiently significant that the HVAC savings described in this report have been statistically modified to reflect the offset. The HVAC usage differential is related to variables that are outside of experimental control and are compounded as the lab homes age. These include the following: differing settling patterns of wall insulation and degradation of HVAC technology efficiency. The baseline period allowed verification that the HVAC energy use offset of the monitored metrics (HVAC, occupancy, lighting, equipment, and the water heater) were significant in both homes prior to installation of the window attachments in the experimental home. Figure 4.2 depict the HVAC energy use of each home compared to the outdoor air temperature (OAT). It can be seen that the aging factors increase the HVAC energy use differential as the outdoor air temperature drops. The baseline home consistently required more HVAC energy than the experimental home. This differential shrinks as the OAT increases toward the HVAC set point of 71°F.



**Figure 4.1.** HVAC Energy Use of the Baseline HVAC and the Experimental HVAC and during Heating Season Baseline Period



**Figure 4.2.** Cumulative HVAC Energy Use of the Experimental Home (Red) and the Baseline Home (Blue) throughout one day of the Baseline Period



## 4.2 Building Shell Air Leakage

Building shell air leakage in both Lab Homes was measured prior to the beginning of the experiment to obtain a baseline reading on the homes and ensure equivalent air-leakage performance between the two homes. Prior to the window attachment installation, the blower door test<sup>1</sup> results showed the air leakage of the two homes to be statistically the same, with 95% confidence, as shown in Table 4.1. The baseline home had an air-leakage rate of  $789.7 \pm 25.7$  cfm at 50 Pa depressurization (cfm50) with respect to the outside, and the experimental home had an air leakage of  $820.1 \pm 26.5$  cfm50. Accounting for experimental error in the blower door measurement and the blower door instrument accuracy, the two homes demonstrated equivalent rates air leakage with 95% confidence prior to installing the cellular shades in the experimental home. The calculated air changes per hour at 50 Pa depressurization with respect to the outside (ACH50) and air changes per hour at normal pressurization (ACH<sub>n</sub>) are also presented in Table 4.1.

After installation of the Hunter Douglas cellular shades in the experimental home, the home was retested for air leakage. The experimental home's air leakage measured  $822.0 \pm 24.7$  cfm50. This indicates that the installation of the cellular shades did not have a significant impact on the air leakage in the experimental home. For buildings with leakier envelopes, the installation of cellular shades could reduce the total infiltration. This was not seen in the lab homes due to the tightness of the primary windows.

**Table 4.1.** Blower Door Test Results Prior to Window Attachment Installation

Parameter	Baseline Home		Experimental Home	
	Average Value	95% Confidence Interval	Average Value	95% Confidence Interval
cfm50 <sup>(a)</sup>	789.7	25.7	820.1	26.5
ACH50	3.80	0.12	3.95	0.13
ACH <sub>n</sub> <sup>(b)</sup>	0.18	0.01	0.18	0.01

(a) Cubic feet per minute at 50 Pascals of depressurization

(b)  $n = 21.5$ , based on single-story home in climate zone 3, with minimal shielding

## 4.3 Winter Heating Cellular Shades Energy Performance Results

Heating during the winter was provided solely by a forced-air electric resistance furnace. Although a variety of heating systems and fuel types are used in homes, using electric resistance heating allows precise direct measurement of thermal energy impact of the window attachments in the Lab Home experiments, because the electric resistance elements are 100% efficient. These results can then be easily extrapolated to other heating system types based on the relative efficiency of those systems. The energy performance of the window attachments was initially evaluated from March 4<sup>th</sup> to April 1<sup>st</sup>, 2015.

To compare and assess the performance of the Hunter Douglas cellular shades relative to the baseline windows, energy use was compared on an average daily basis. During the heating season, the Hunter Douglas window attachments showed an improvement in average daily HVAC energy use, compared to the baseline home with no window attachments, of  $3,441 \pm 1,249$  Wh or  $17.6 \pm 8.1\%$ . These numbers were found by taking the average of the HVAC savings over the total experimental period. The large margin of

<sup>1</sup> Blower door testing equipment measures flow with an accuracy of  $\pm 3\%$ .

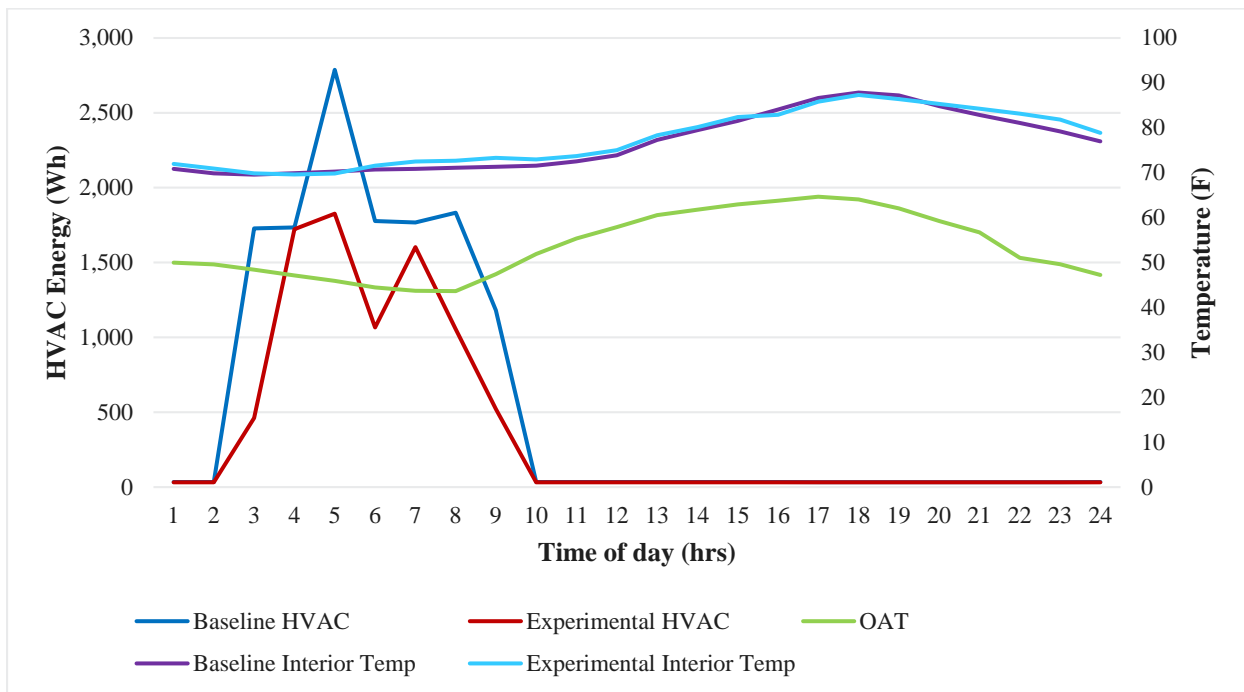
<http://www.energyconservatory.com/products/automated-blower-door-systems-and-accessories>

error, within the 95% confidence interval, is due to the increased standard deviation seen within the HVAC savings over the experimental period.

### 4.3.1 Heating Season – Optimum Operation

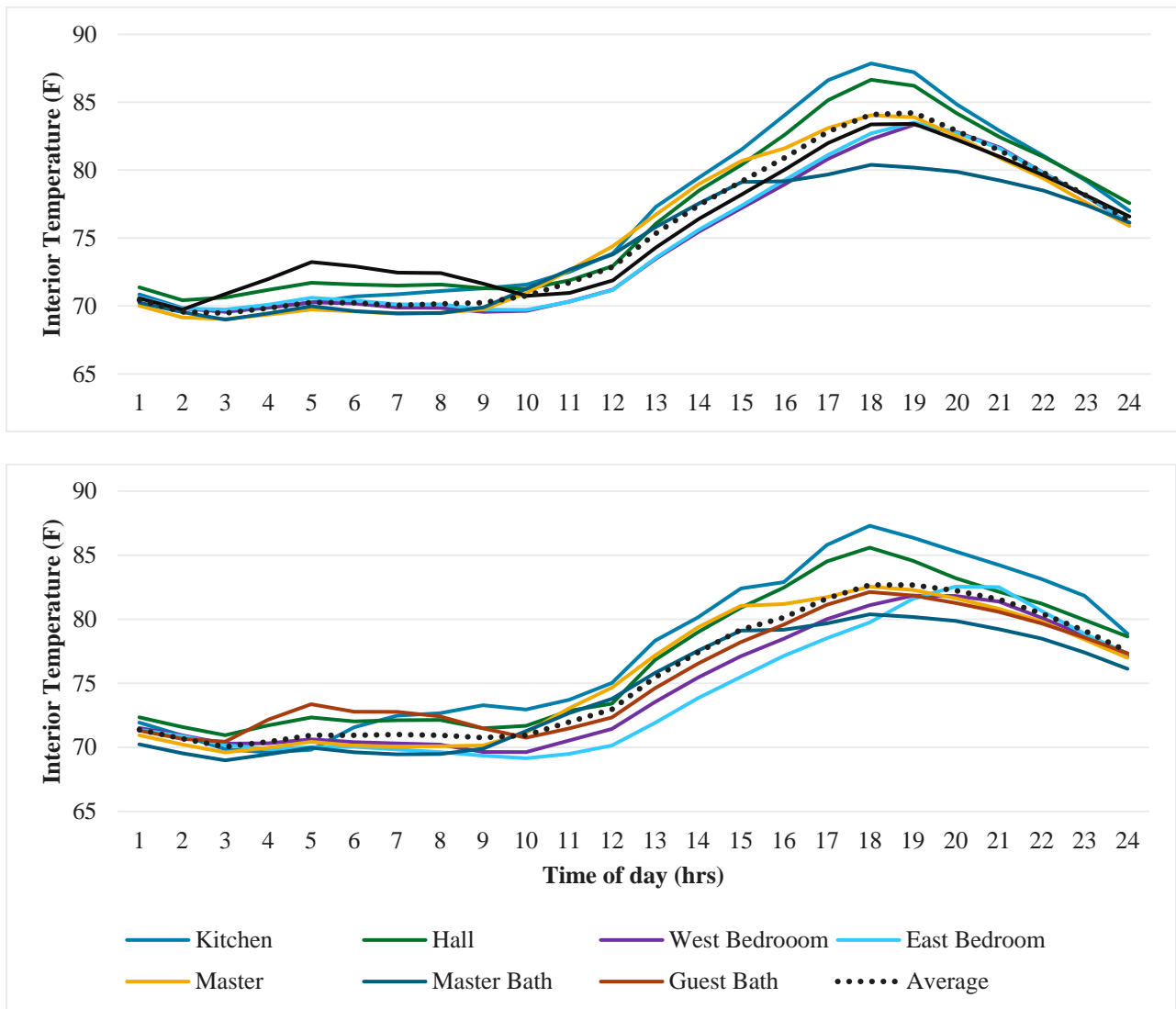
HVAC savings through the implementation of the HD Green Mode operational schedule was compared between the experimental home with the Hunter Douglas cellular shades and the baseline home with no window attachments installed over a series of 9 experimental days between March 4, 2015 and March 19, 2015. Over this experimental period, the average outdoor air temperature was 49.3°F. The HVAC energy usage was cataloged to determine the total peak reduction in HVAC use between the two lab homes due to the Hunter Douglas cellular shades with optimum schedule implementation. During the heating season, the HD Green Mode operation schedule is specifically designed to optimize the amount of solar heat gain and ensure adequate light enters the interior, but also uses the cellular shade’s insulating properties to reduce the amount of heat loss through windows. In the experimental home, wirelessly controlled motors within the Hunter Douglas shades followed the pre-programmed schedule. Verification of the scheduled operation was done by PNNL engineers. During this experimental period, the cellular shades reduced the HVAC energy use by  $3,441 \pm 1,249$  Wh or  $17.6 \pm 8.1\%$  compared to no blinds.

Figure 4.3 details a single day, March 18, 2015, during the experimental period where the window attachments followed the HD Green Mode operational schedule detailed in Appendix A. On this day, the average outdoor air temperature was 51.8°F. The internal set point of each of the Lab Homes was 71°F. The HVAC energy use in watt-hours for baseline home (dark blue) and experimental home (red) are shown along with the outdoor air temperature (green) and representative indoor special temperature for the baseline home (purple) and experimental home (turquoise). The HVAC load profile is the total HVAC energy usage averaged over each hour. The HVAC savings for each experimental day is averaged over the total experimental period to develop the average daily HVAC energy consumption.



**Figure 4.3.** HVAC Usage during the Implementation of the HD Green Mode Optimum Schedule between Hunter Douglas Cellular Shades in Experimental Home (red) Compared to No Window Attachments in Baseline Home (blue)

During the heating season, the majority of the HVAC load was in the early morning. The reduction in peak HVAC energy use can be seen between the Lab Homes. This is due to the insulating properties of the Hunter Douglas cellular shades reducing the amount of internal heat escaping the envelope. The ambient temperature began to increase at 9:00 a.m. and the effect of thermal gains on the envelope can be seen throughout the remainder of the day. The envelope heated to a point where the internal temperature was above the thermostat set point and no HVAC operation was needed. After the cellular shades were closed at 5:00 p.m., the internal temperature of the experimental home remained higher than that of the baseline home. The added insulating value of the shades allowed for the solar heat gains achieved during the day to cascade into the night. This ultimately reduces the HVAC load the following day. Figure 4.4 details the temperature distribution throughout each home on this experimental day.



**Figure 4.4.** Interior Temperature of Baseline Home (Top) Compared to Experimental Home (Bottom) during the March 18<sup>th</sup> 2015 HD Green Mode Optimum Operation

The large window-to-wall ratio within each of the lab homes allows for solar heat gains to greatly affect the internal temperature within the space. Though the HD Green Mode schedule is designed to optimize solar heat gain, the amount of heat seen during this day increased interior temperature to a point that was well above the set point and would affect the thermal comfort of occupants. At 5:00 p.m., all Hunter Douglas cellular shades were closed in the experimental home. The average temperature of the baseline home continued to increase until sunset. As the envelope began to cool, the slope of the average internal temperature between the two homes was significantly different. The insulating properties of the cellular shades in the experimental home allowed for the heat to be retained within the space for an extended period of time compared to the baseline home.

## 4.4 Cooling Season Cellular Shades Energy Performance Results

After retrofitting the experimental home with the cellular shades, experimental data was collected from August 19 to September 15, 2015, to characterize the energy and thermal performance of the cellular shades during the cooling season. Cooling during the summer was provided by a 2.5-ton seasonal energy-efficiency ratio (SEER) 13 heat pump. To compare and assess the performance of the cellular shades relative to the baseline windows, energy use was compared on an average daily basis.

### 4.4.1 Cooling Season – Static Operation

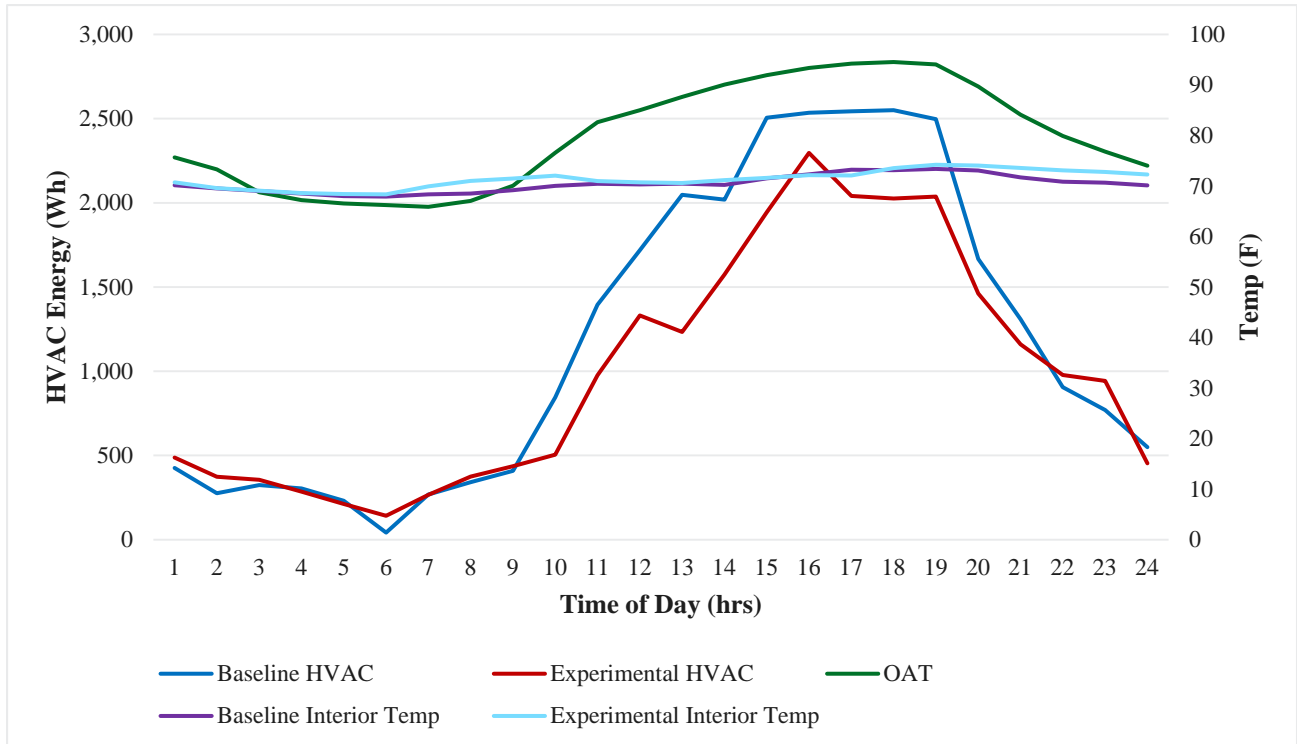
Comparison of the insulating values of the cellular shades to the typical horizontal vinyl binds was completed over 14 experimental days between August 19, 2015 and September 2, 2015. The HVAC energy usage was cataloged and compared to determine the total peak reduction in HVAC use during this time. The insulating values associated with cellular shades reduce the HVAC energy usage by  $2,880 \pm 517$ Wh or  $13.3 \pm 2.8\%$  when compared to the standard vinyl blinds. These numbers were found by taking the average of the HVAC savings over the total experimental period. The large margin of error, within the 95% confidence interval, is due to the increased standard deviation seen within the HVAC savings over the experimental period.

Figure 4.5 shows data from August 27, 2015, where the window attachments were left closed for the full day. On this day, the average outdoor air temperature was 79.8°F. The HVAC energy use in watt-hours for baseline home (dark blue) and experimental home (red) are shown along with the outdoor air temperature (green) and representative indoor special temperature for the baseline home (purple) and experimental home (turquoise). The HVAC load profile is the total HVAC energy usage averaged over each hour. The HVAC savings for each experimental day is averaged over the total experimental period to develop the average daily HVAC energy consumption.

During the early morning hours of the day, the HVAC systems performed similarly due to the fact that the ambient temperature was near 71°F and the sun had not yet risen. On August 27, 2015, sunrise was at 6:18 am. After this point, the envelope of the Lab Homes began to heat toward the set point and HVAC operation was almost identical. At about 9 a.m., the solar isolation and thermal intensity of the sun began to heat the envelope, and solar heat gains begins to drive up the HVAC energy use in both homes. With a the peak temperature of 96°F during this day, the baseline home HVAC system had a greater peak demand over a longer duration of time compared to the experimental home. It can be seen that the cellular shades reduce the peak HVAC energy use throughout the day by offering increased insulating values and reduced solar heat gain. The interior temperature distributions between the two homes can be seen in Figure 4.6.

The average internal temperature between the two homes is similar as it hovers near the 71°F set point. Overcooling can be seen in some rooms in both homes during the cooling season, probably due to the

location of the thermostat (in the hallway adjacent to the kitchen in both homes). Temperatures as low as 62°F are observed in both Lab Homes in the rooms closest to the air handler—the bathroom, west bedroom, and east bedroom receive the most air because of shorter duct runs. The master bedroom temperature is noticeably different between the two homes. The increased insulating value of the cellular shades in the experimental home reduces the solar heat gain through the window substantially. In turn, this allows for heat to flow more evenly from overcooled sections of the building to warmer areas, increasing the thermal comfort of the space.



**Figure 4.5.** Insulating Value of the Hunter Douglas Cellular Shades Compared to Vinyl Blinds



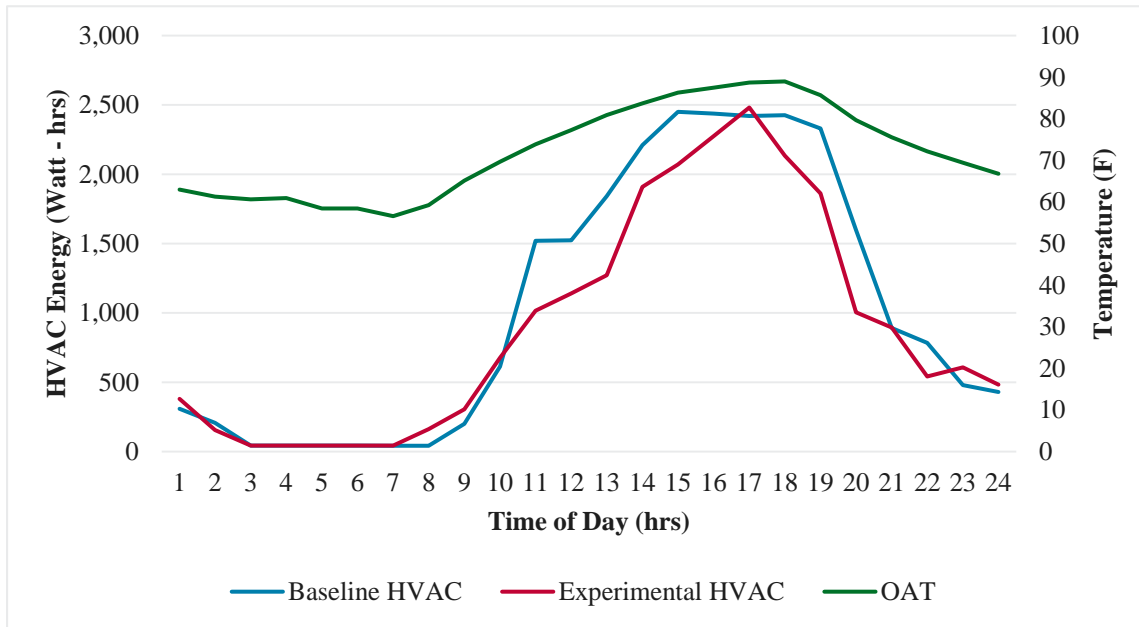
**Figure 4.6.** Interior Temperature of Baseline Home (Top) Compared to Experimental (Bottom) During the August 27<sup>th</sup> 2015 Static Window Attachment Comparison

#### 4.4.2 Cooling Season – Optimum Operation Comparison

During the Optimum Operation experiments, cellular shades and typical vinyl blinds were both operated according to the HD Green Mode operational schedule. This experiment was completed over a series of 7 days between September 3, 2015 and September 15, 2015. Over this experimental period, the average outdoor air temperature was 61.9°F. The decreased OAT over the experimental period greatly reduced the HVAC load. The HVAC energy usage was cataloged to determine the total peak reduction in HVAC

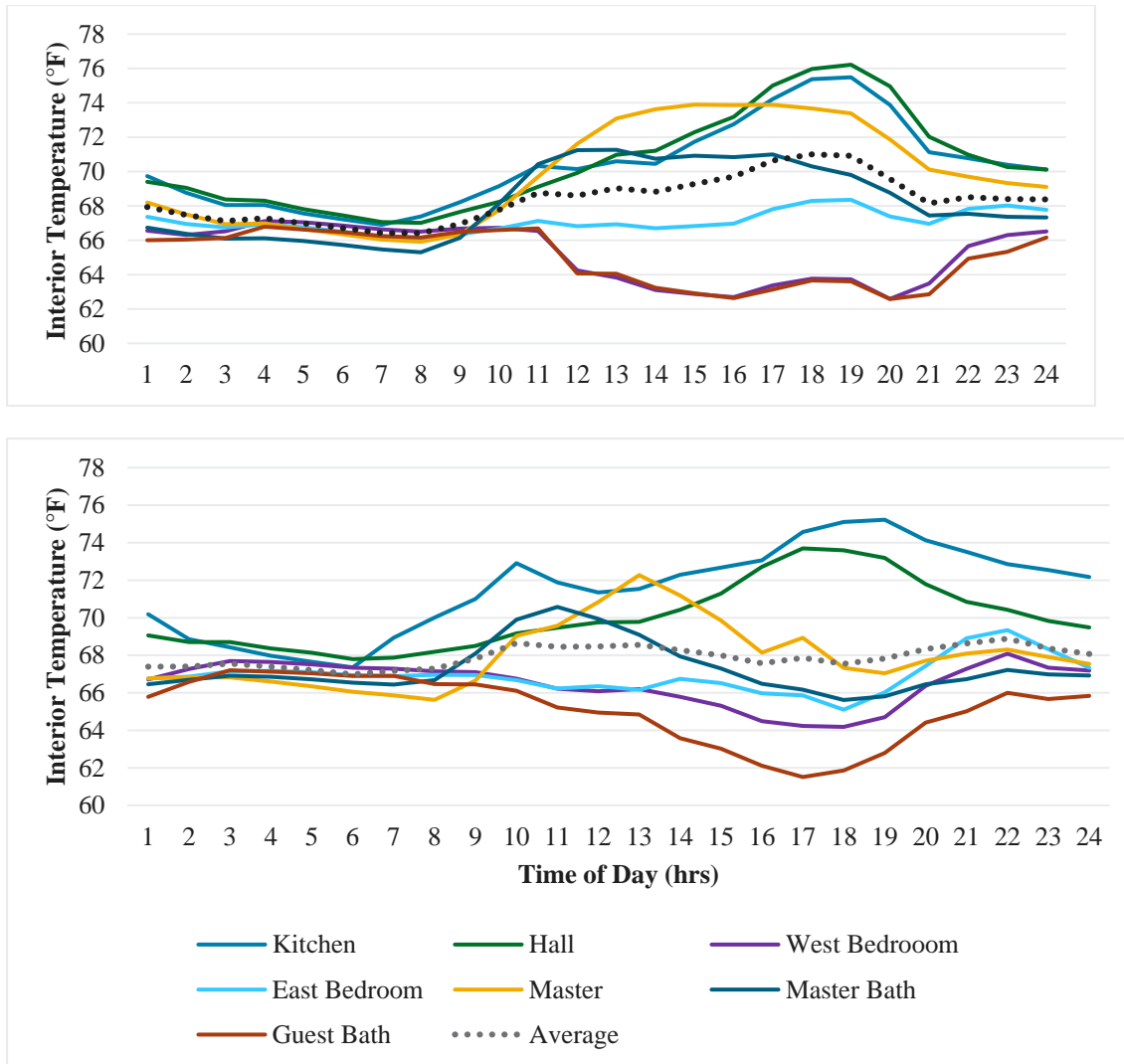
energy use between the two technologies during the schedule implementation. During the cooling season, the HD Green schedule was specifically designed to reduce the amount of solar heat gain while ensuring adequate light enters the interior. In the experimental home, wirelessly controlled motors within the cellular shades operated them according to the pre-programmed HD Green Mode schedule, and in the baseline home, the same operation schedule was implemented manually. Verification of the scheduled operation was done by PNNL engineers as the baseline home blinds changed state. When compared to typical vinyl blinds in the baseline home, the cellular shades reduced the peak HVAC load by 1,309  $\pm$ 708Wh or 10.4  $\pm$ 6.5%. These numbers were found by taking the average of the HVAC savings over the total experimental period. The large margin of error, within the 95% confidence interval, is due to the increased standard deviation seen within the HVAC savings over the experimental period.

Figure 4.7 details a single day, September 11, 2015, during the experimental period where the window attachments followed the HD Green Mode operational schedule detailed in Appendix A. On this day, the average outdoor air temperature was 72°F. The HVAC energy use in watt-hours for the baseline (blue) and experimental home (red) are shown along with the outdoor air temperature (green).



**Figure 4.7.** HVAC Usage during the Implementation of the HD Green Mode Optimum Schedule Between Hunter Douglas Cellular Shades Compared to Vinyl Blinds (September 11, 2015)

Figure 4.7 shows the lower HVAC energy use in the experimental home compared to the baseline home. This can be attributed to greater reductions in solar heat gain at critical times of the day when the window attachments were closed. The baseline home’s less insulative vinyl blinds allowed more heat to be transferred through the drawn window attachments into the home. The greater internal heat was then compensated for with increased HVAC energy use.



**Figure 4.8.** Interior Temperature of Lab Home A (Top) Compared to Lab Home B (Bottom) during the September 11<sup>th</sup> 2015 Optimum Operation Comparison

Unseasonably cold early morning weather cooled the envelopes of both homes and reduced the internal temperature of both homes below the 71°F set point. The location of the thermostat within the central hall allowed for overcooling in the guest bathroom and bedrooms. The solar heat gain in the master bedroom caused the most dynamic temperature change between the two homes. The shades on the south facing windows in the master bedroom were open from 8:00–10:00 a.m. and 4:00–5:00 p.m. The insulating value of the shades can be seen in the reduction in ambient temperature between the two homes.



## 5.0 Experimental Period and Future Work Discussion

Mild cooling and heating season temperatures caused the outdoor air temperature to hover around the internal set point of the thermostat during the experimental periods. This generated large amounts of HVAC load variability between differing experimental days. This variability increased the standard deviation and margin of error for each of the experimental periods. The large margin of error and limited experimental days in the Lab Homes made it difficult to generate statistically valid and robust results. The restricted timeframe also limited the amount of data that could be gathered, which increased the error associated with the savings confidence interval. Both of these challenges had an overall impact on the confidence of and statistical validity of the results, as shown in Table 5.1.

**Table 5.1.** Summary of Experimental Results of Cellular Shades Compared to a Baseline on the Same Schedule

Experiment	Number of Days	Baseline	Energy Savings
Heating Season – Optimum Operation	9	No Blinds	17.6 ± 8.1%
Cooling Season – Static Operation	14	Vinyl Blinds	13.3 ± 2.8%
Cooling Season – Optimum Operation Comparison	7	Vinyl Blinds	10.4 ± 6.5%

During the 2015–2016 heating and cooling seasons, the window attachment technology will be re-evaluated with a redefined experimental plan and procedure. Future research should focus on longer duration evaluation with an objective of providing seasonal impacts of cellular shade operation. Additional application of longer duration analysis would be to help calibrate energy-use models allowing for more informed annual energy use/savings analysis across building types and climate zones.

## 6.0 Conclusions

This experiment used two side-by-side Lab Homes on the PNNL campus to measure the potential energy savings of windows attachment products within different operational schedules in the experimental home compared to the baseline home equipped with standard double-pane clear-glass, aluminum-frame windows and sliding clear-glass patio doors. The primary windows in the baseline home are representative of many existing homes across the Pacific Northwest and much of the United States. Differing operational schedules were tested to help understand the effect of the window attachment technology on the HVAC energy use. The operational procedures that were completed in the 2015 heating and cooling season are detailed below with the associated HVAC energy savings. Based on the limited experimental period, the HVAC savings should be viewed as strictly preliminary and should not be annualized.

1. Optimum Operation – The “optimum” operation schedule follows the Hunter Douglas developed HD Green Mode operation schedule for the experimental period to maximize the energy savings from insulated window shades. The schedule is specifically designed to optimize HVAC operation and solar heat gain while allowing some daylighting to accommodate consumer needs for natural daylight. Following this operation schedule, the impact of the cellular shades on the HVAC system is compared to the baseline home with no window attachments installed. During the heating experimental period, the cellular shades reduced the HVAC energy use by  $17.6 \pm 8.1\%$  compared to no blinds.
2. Optimum Operation Comparison – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades in the experimental home and typical white vinyl horizontal blinds in the baseline home. The window coverings in both Lab Homes were set to follow the HD Green Mode operational schedule for the experimental period. When compared to the typical vinyl horizontal blinds during the cooling experimental period, the cellular blinds reduced the HVAC energy use by an estimated  $10.4 \pm 6.5\%$  when compared to typical vinyl horizontal blinds.
3. Static Operation – This experiment compares the impact on the conditioned space and HVAC energy savings between the insulated cellular shades and typical white vinyl horizontal blinds during the cooling season. No operational schedules were implemented and both sets of window coverings remained closed for the duration of the experiment. The cellular shades installed in the experimental home reduced the HVAC energy use by  $13.3 \pm 2.8\%$  in comparison to the vinyl blinds installed in the baseline home.

The automation benefit attributed to the Hunter Douglas cellular shades becomes apparent when comparing the static and optimum operation experiments. In these two experiments, the calculated reduction in HVAC energy consumption are statistically the same. The implementation of the HD Green Mode operational schedule optimizes the solar heat gain and natural light into the space without sacrificing HVAC performance when compared to the static operation. Further research is required to quantify the reduction in HVAC energy consumption attributed to each operational schedule.

This evaluation has added to the body of knowledge about window attachments by presenting measureable energy savings in a controlled setting. Results from this study clearly show that cellular shades are viable energy retrofits in single-family residences and should be explored further across a variety of building types and climate zones.

## 7.0 References

Aristo T and A Memari. 2013. *Evaluation of Residential Window Retrofit Solutions for Energy Efficiency*. Pennsylvania Housing Research Center (PHRC). No. 111, December 2013. University Park, Pennsylvania.

Center for Energy and Environment (CEE). 2014. *Window Retrofit Technologies*. Prepared for the Minnesota Department of Commerce, Division of Energy Resources. June 2014, COMM-0519012-53155.

Curcija DC, M Yazdanian, C Kohler, R Hart, R Mitchell, and S Vidanovic. 2013. *Energy Savings from Window Attachments*. Prepared for U.S. Department of Energy under DOE EERE award #DE-FOA-0001000. October 2013. Lawrence Berkeley National Laboratory, Berkeley, California. Available online at: [http://energy.gov/sites/prod/files/2013/11/f5/energy\\_savings\\_from\\_windows\\_attachments.pdf](http://energy.gov/sites/prod/files/2013/11/f5/energy_savings_from_windows_attachments.pdf).

Bickel S, E Phan-Gruber, and S Christie. 2013. *Residential Windows and Window Coverings: A Detailed View of the Installed Base and User Behavior*. Prepared for the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. September 2013. D&R International, Silver Spring, Maryland. Available online at: [http://energy.gov/sites/prod/files/2013/11/f5/residential\\_windows\\_coverings.pdf](http://energy.gov/sites/prod/files/2013/11/f5/residential_windows_coverings.pdf).

Garber-Slaght R and C Craven. 2011. *Evaluating Window Insulation Curtains, Blinds, Shutters & More*. Cold Climate Research Institute. Available online at: [http://www.cchrc.org/sites/default/files/docs/JGB\\_windows\\_article.pdf](http://www.cchrc.org/sites/default/files/docs/JGB_windows_article.pdf).

Huang J, J Hanford, and F Yang. 1999. *Residential Heating and Cooling Loads Component Analysis*. LBNL-44636, Building Technologies Department, Lawrence Berkeley National Laboratory, Berkeley, California.

Portland General Electric (PGE). 2015. "Energy Fixer: Window Coverings." Available online at: [https://www.portlandgeneral.com/residential/energy\\_savings/energy\\_fixer/docs/june\\_energy\\_fixer.pdf](https://www.portlandgeneral.com/residential/energy_savings/energy_fixer/docs/june_energy_fixer.pdf).

Zirnhelt H, B Bridgeland, and P Keuhn. 2015. *Energy Savings from Window Shades*. Prepared for Hunter Douglas by Rocky Mountain Institute.



# Appendix A

## HD Green Mode Operation Schedule

Developed by Hunter Douglas, the HD Green Mode operation schedule is based on the solar calendar and the latitude of the location at which the window attachments are installed. The schedule is specifically designed to optimize HVAC operation and solar heat gain while allowing adequate light into the conditioned space. During the heating season, the schedule is optimized by the solar heat gain to the conditioned space and provides insulating values for the envelope during the evening. During the cooling season, the schedule is optimized to minimize the solar heat gain to the space.

**Table A.1.** Optimum Efficiency Window Covering Timetable for Richland, Washington (46° Latitude)

Month	Hours Window Coverings Are Open (Raised or Stacked)			
	North Facing	South Facing	East Facing	West Facing
January	Closed All Day	9:00 a.m.–3:00 p.m.	8:00–11:00 a.m.	1:00–4:00 p.m.
February	Closed All Day	8:00 a.m.–4:00 p.m.	8:00–11:00 a.m.	1:00–4:00 p.m.
March	Closed All Day	8:00 a.m.–3:00 p.m.	7:00–11:00 a.m.	2:00–5:00 p.m.
April	Closed All Day	8:00 a.m.–4:00 p.m.	6:00–10:00 a.m.	3:00–6:00 p.m.
May	2:00–7:00 p.m.	9:00–11:00 a.m.	6:00–9:00 a.m.	11:00 a.m.–2:00 p.m.
June	11:00 a.m.–1:00 p.m.	8:00–11:00 a.m.	6:00–8:00 a.m. 1:00–7:00 p.m.	10:00 a.m.–1:00 p.m.
July	9:00 a.m.–12:00 p.m.	7:00–10:00 a.m.	6:00–7:00 a.m. 12:00–7:00 p.m.	8:00 a.m.–12:00 p.m.
August	9:00 a.m.–12:00 p.m.	6:00–10:00 a.m.	6:00–7:00 a.m. 12:00–6:00 p.m.	8:00 a.m.–12:00 p.m.
September	1:00–5:00 p.m.	8:00–10:00 a.m. 4:00–5:00 p.m.	7:00–8:00 a.m.	10:00 a.m.–1:00 p.m.
October	2:00–4:00 p.m.	8:00 a.m.–2:00 p.m.	8:00–10:00 a.m.	3:00–5:00 p.m.
November	Closed All Day	9:00 a.m.–3:00 p.m.	8:00–11:00 a.m.	1:00–4:00 p.m.
December	Closed All Day	9:00 a.m.–3:00 p.m.	9:00–11:00 a.m.	1:00–3:00 p.m.

All times for timetable operation assume direct sunlight. During cloudy hours when outside temperature is 60°F or less, all shades should be closed, overriding the time tables.

Heating season testing should be performed alternating between timetable operation (with adjustment for cloudy hours) and shades closed 24/7. We suggest 7–10 day periods for each method of operation.

Cooling season testing should alternate between timetable operation (no adjustment needed for cloudy hours) and shades closed 24/7. Again, 7–10 day test periods are recommended.







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