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Energy Savings from Window Attachments

October 2013

Prepared for:

Building Technologies Office
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Prepared by:

Lawrence Berkeley National Laboratory

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TABLE OF CONTENTS:

1. EXECUTIVE SUMMARY

This study presents energy-modeling results for a large number of window combinations with window attachments in typical residential buildings and in varied climates throughout the United States. Studied window attachments include a range of products, from indoor-mounted to outdoor-mounted window attachments, including products such as shades, blinds, storm window panels, and surface applied films. Recent improvements in computer simulation of optically and thermally complex products (LBNL 2013, DOE 2013) enabled this quantitative study to be based on a comprehensive database of simulated results.

Four types of typical houses, located in 12 characteristic climatic zones were analyzed for the range of three baseline windows, eleven window attachment product categories, four product “qualities” for each product category, and three different attachment deployment positions (for those attachments that were operable). For some of the attachment products, such as louvered blinds, expanded deployment options were considered, because of their dual operability (e.g., level of retraction and slat angle). The resulting matrix amounted to more than 16,000 energy analysis runs.

Based on an occupant behavioral study conducted earlier this year (DRI 2013), typical operational (deployment) patterns were identified for three different regions in the country (North, Central, and South), for heating and cooling seasons, and time of day (morning, afternoon, and evening/night). These schedules were then used to weight energy use for the three simulated deployment scenarios (open, half open, and closed) on an annual basis.

Baseline windows with the matrix of window attachment options were first modeled in WINDOW and THERM software tools (LBNL 2013) and the resultant window/attachment combined properties were exported to EnergyPlus IDF input files. These were then incorporated into the EnergyPlus models of typical residential buildings and energy analysis performed for the 12 cities, representing all major climate types in the United States.

Annual energy use results are presented in tables and graphs, with selected data presented in the main body of this report and additional tables and an extended set of graphs presented in the Appendices. Conclusions and recommendations from the energy analysis are presented at the end of the main body of the report. All of the energy use and energy savings reporting in this study are reported in site energy terms, which treats all energy sources equally (e.g., electric energy use of 1 GJ is identical to natural gas energy use of 1 GJ).

The base window energy performance can be significantly improved in many cases with the use of operable attachments. The actual use of the operable attachment, or its deployment states, can have a large effect on energy performance. For example when operable shades are used by occupants in a “typical manner,” some shades provide energy savings in specific climates, but not all operable shades save energy in all climates. Results are climate dependent. In cooling dominated climates, all window attachments save energy. In northern and many central climate zones, heating energy is higher than cooling energy, so a combination of insulating properties and balanced solar control saves the most energy. Several window attachments provide little to no energy benefit in heating dominated climates and some perform worse than unshaded windows in terms of total energy use.

2. INTRODUCTION

Window attachments represent a wide range of products that are commonly attached to windows in a house as an “add-on” device. The most common and widely used types of attachments are window coverings and fashions that are typically used to control glare, to provide privacy, and for aesthetic purposes. Drapes are a typical example of this attachment type. Some types of coverings are traditionally used to control solar heat gain in conditioned and unconditioned houses. When they are used in unconditioned houses, they are used to create more comfortable living conditions. Examples of these products are outdoor-mounted louvered shutters, roller shutters and awnings. For the most part, indoor-mounted coverings and window fashions are used more for aesthetic reasons, privacy, and glare control, although some energy benefits of their use is recognized.

While we understand that different types of coverings have varying effects on energy performance of the windows they are installed over, generally their energy performance is not as well understood as that of prime windows. This is because their mounting and occupant use impacts their performance, and their energy impact can be orientation and climate dependent. Some limited measurements were done over the past few decades for both indoor and outdoor-mounted shades. These measurements were done for specific window combinations and in specific climates. Due to the high cost involved in measurements and the uncertainty and lack of standardization of these measurements, it is only possible to observe broader trends from them.

Simulation methods for window coverings and other optically complex systems, including complex glazing, have been steadily advancing over the past decade and now cover a large range of products. With support from U.S. Department of Energy (DOE) over the last two years, Lawrence Berkeley National Laboratory (LBNL) has significantly expanded the modeling capabilities of a suite of energy performance assessment tools originally developed for the window industry. LBNL completed the development and implementation of a generalized Bi-Directional Scattering Distribution Function (BSDF) methodology (Klems 1994a and 1994b, DOE 2013b), which enabled SHGC and Tv of an expanded range of products and devices to be modeled. The BSDF methodology was first implemented in LBNL’s WINDOW and THERM programs for calculating thermal and optical performance of windows with coverings and later was extended to EnergyPlus to allow for the calculation of energy impacts of these products on a commercial or residential building.

The selection of attachments included in this study covers both fixed and operable window attachments. In order to properly account for operational schedule of operable attachments, a separate behavioral study was carried out to determine typical use of operable window attachments (DRI 2013). Based on this typical deployment schedule, results of energy analysis are weighted in order to compare them among themselves and to the fixed attachments.

Window attachment products on the market today include a wide range of performance features and styles. To provide wide applicability to the U.S. residential stock, selected product categories are modeled as a set of parameters. The parameters include four building types, three baseline windows, 12 climate zones, four window attachment qualities and three deployment states (cellular shades, roller screens, solar screens, drop-arm awnings) or eight deployment states for louvered blinds (horizontal louvered blinds, also known as venetian blinds, and vertical louvered blinds). Four "qualities" (or solar and thermal performance levels) represent a wide range of performance, including products typically available on the market today but also speculative new high performance products. This choice gives a theoretical range of energy performance. For some window attachments, this range is closer to the performance of available attachments and for some this range is beyond what is currently available. Although the parameters for each quality are developed with the intent that quality A has the most favorable characteristics (e.g., low-e, high insulation, high reflectance, low absorptance) and qualities B, C, and D are progressively "worse," it is recognized that the overall energy outcomes are not necessarily going to be "Best" to "Worst," since in different climates and even in the same climate zone, a combination of parameters might be beneficial and in some cases might be detrimental. Therefore, generic A, B, C, and D quality designations are used to present the range of attachment properties. The complete set of parametric options resulted in 16,486 energy simulation runs.

Energy modeling results of these options are expressed in terms of energy use and energy savings, and presented in graphs and tables. All of the energy use and energy savings reporting in this study is done in terms of site energy, which treats all energy sources equally. Another type of comparison could be done in terms of source energy, where electrical energy, for example, is multiplied by conversion factor representative of source fuels used to produce electric energy. As the mix of energy sources used in producing electricity substantially change over time, this factor also may change, and would need to be updated in the future. The most important graphs and results are presented in the main body of the report, while an extended set of graphs and tables is presented in the appendices. The full set of results, including the WINDOW 7.1 database, all modeling assumptions, and the EnergyPlus input files are provided on the website: http://windows.lbl.gov/Attachments/Parametrics.

3. BUILDING MODELING ASSUMPTIONS

The EnergyPlus model of typical residential buildings was developed from the DOE EnergyPlus Residential Prototype Building Models (http://www.energycodes.gov/development/residential/iecc_models). This model was updated from the past residential models used for calculating energy effects of windows, because the DOE2.1E engine used for those calculations is no longer supported by the DOE, and EnergyPlus is now the tool being actively developed by DOE. More significantly, the advanced modeling capabilities for optically complex window systems have been developed for and implemented in EnergyPlus only.

The typical residential building consists of a two story, 2,400 ft^2 building with an unconditioned attic. There are four 44.7 ft^2 windows per floor, distributed evenly and centered on the wall. A summary table with modeling assumptions is presented in Appendix C. A more detailed description of assumptions, comparisons with prior models, etc. can be found in LBNL (2102).

The second-story floor (first-story ceiling) is assumed to be adiabatic. Infiltration was calculated using the Sherman-Grimsrud infiltration model which uses Effective Leakage Area coupled with the outdoor air temperature to calculate the infiltration load.

For this study, two different foundation options were considered:

1. Unheated basement
2. Slab-on-grade

Also, two HVAC systems were considered:

1. Gas furnace and electric A/C
2. Heat pump for heating and cooling

In order to size the HVAC system, 144 EnergyPlus autosize runs were made (12 locations, three windows, two HVAC systems, and two foundation models). The sizing parameters were:

- Air flow rate [m^3/sec]
- Cooling capacity [W]
- Rated sensible heat ratio
- Heating capacity [W]
- Supplemental heating capacity [W] – for heat pumps only

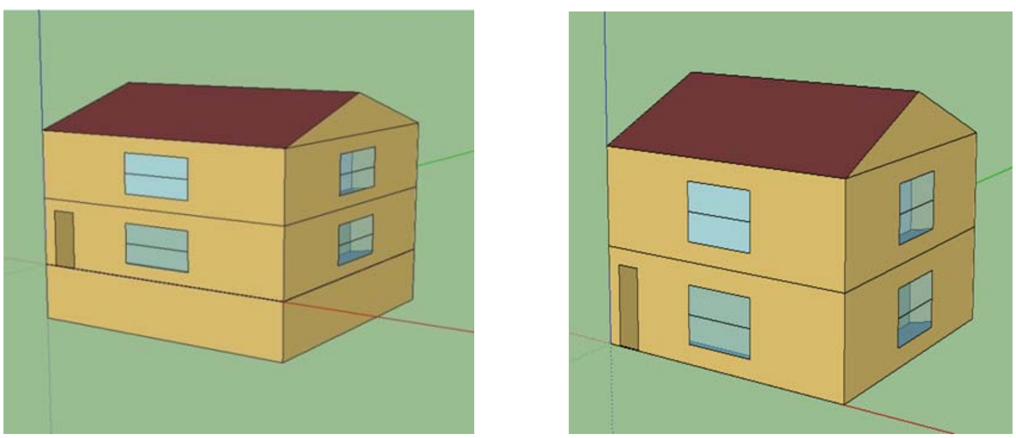
After the HVAC system was sized for each of 144 unique combinations, the sizing values were used for attachment runs. This approach represents typical situation in which original HVAC system is not replaced or modified when attachments are added to windows.

The other important task was to accurately calculate the ground temperatures for each foundation model. It is difficult to link ground heat transfer calculations to EnergyPlus since the conduction calculations in EnergyPlus are one-dimensional and the ground heat transfer calculations are two or three-dimensional. This causes severe modeling problems for the ground heat transfer calculation. In order to compute appropriate ground temperatures at the exterior side of any surface that is in contact with the ground, two utility programs were used, Slab.exe and Basement.exe, included with EnergyPlus distribution, to calculate monthly outside boundary condition (temperature) for a particular surface in contact with the ground. These schedules were calculated for all 12 locations and were added to the input file.

Figure 1 shows the models used in this study. Part (a) of this Figure shows image of the building that appears to be three stories, but what appears to be the bottom floor is actually unheated basement. Main, conditioned part of the house is identical two story residential building. Figure 2 shows inside of the building. Even though the house looks like it is perimeter and core zoned (i.e., 5 zones), the division inside is done to simulate internal partitions that prevent solar radiation transmitted from one window reaching the back side of another window. The house has single HVAC zone (single thermostat).

The EnergyPlus input file (IDF file) was divided into several files, to allow for parameterization of the EnergyPlus runs. Macro parameters, needed for parametric runs, were also added to those input files.

See Appendix D for more details about the modeling assumptions.



(a) (b)

Figure 1. Illustration of EnergyPlus Residential Building Models: (a) Basement and (b) Slab

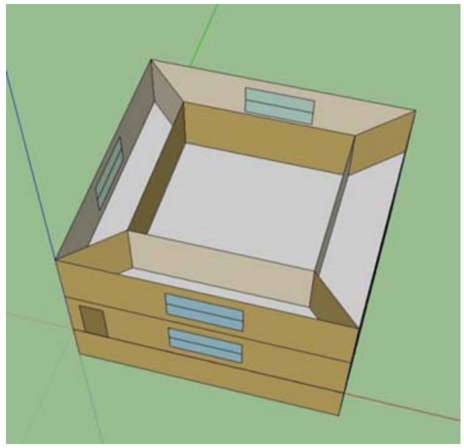


Figure 2. Illustration of Internal Partitions in Residential Building

4. WINDOW ATTACHMENT PARAMETRICS

In order to represent a broad range of different window attachment products, four different sets of performance parameters, called "qualities" were developed for each window attachment category. These "qualities" do not necessarily represent real products and for some options, they will be quite different than what is presently offered. However, in order to analyze a full range of performance options, these theoretical limits were explored. The four different product 'qualities' are denoted by A, B, C, and D and are explained later in the section. The following eleven window attachment categories were considered:

Outdoor-mounted window attachments:

1. Solar screens
2. Awnings – fixed
3. Awnings – drop-arm
4. Storm panels
5. Surface applied films

Indoor-mounted window attachments:

6. Horizontal louvered blinds
7. Vertical louvered blinds
8. Cellular shades
9. Roller shades
10. Surface applied films
11. Interior fixed Panel

Several categories of window attachments were not included in this study due to the current lack of reliable simulation models. Many of these models are now under development or validation and should be available later in fiscal year 2014 (FY 2014) or FY 2015. While it is difficult to predict energy effects of these attachment categories, it is believed that they are within the ranges of products analyzed here, with respect to their location (i.e., outdoor and indoor). The following window attachment categories were not considered in this study:

Excluded outdoor-mounted window attachments

1. Roller shutters
2. Louvered shutters

Excluded indoor-mounted window attachments

3. Sheer shades
4. Window quilts
5. Roman shades
6. Drapes

4.1 Baseline Windows

Baseline windows are defined from the selection of typical windows installed in existing or new homes. They range in performance from very poor to very good. Three baseline windows are selected for this study:

1. Single clear glazing and aluminum alloy frame
2. Double clear glazing and wood frame
3. Double low-e glazing and vinyl frame

For all three baseline windows, a vertical sliding window (also known as "double-hung") was modeled at the standard NFRC size of 1200 mm x 1500 mm. In order to model partially deployed window attachments in EnergyPlus (this functionality is currently not available in EnergyPlus), baseline windows were divided vertically into two equal halves, with each half being covered or not covered, thus emulating these three conditions:

a) Fully retracted shade – both window halves not covered
b) Half-retracted – upper half covered, lower half not covered
c) Fully deployed – both halves covered

Figure 3 to Figure 5 show the window layout and frame dimensions.

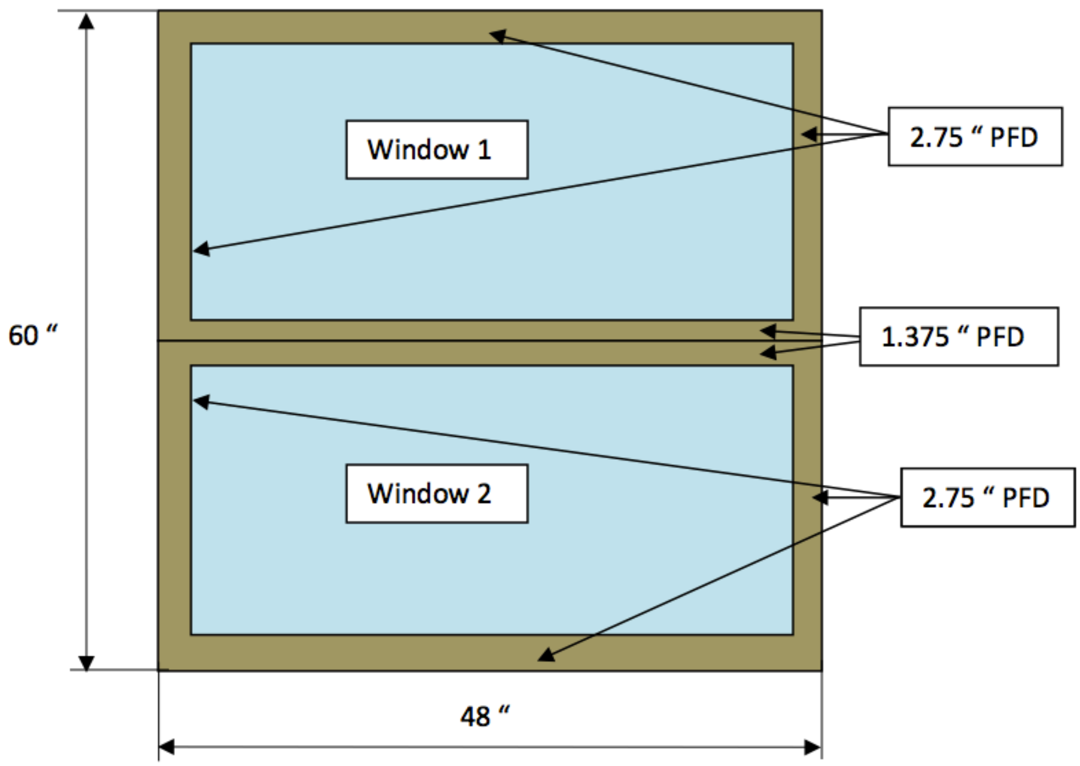


Figure 3. Wood Frame Double-Hung Window Subdivision into Two Equal Windows

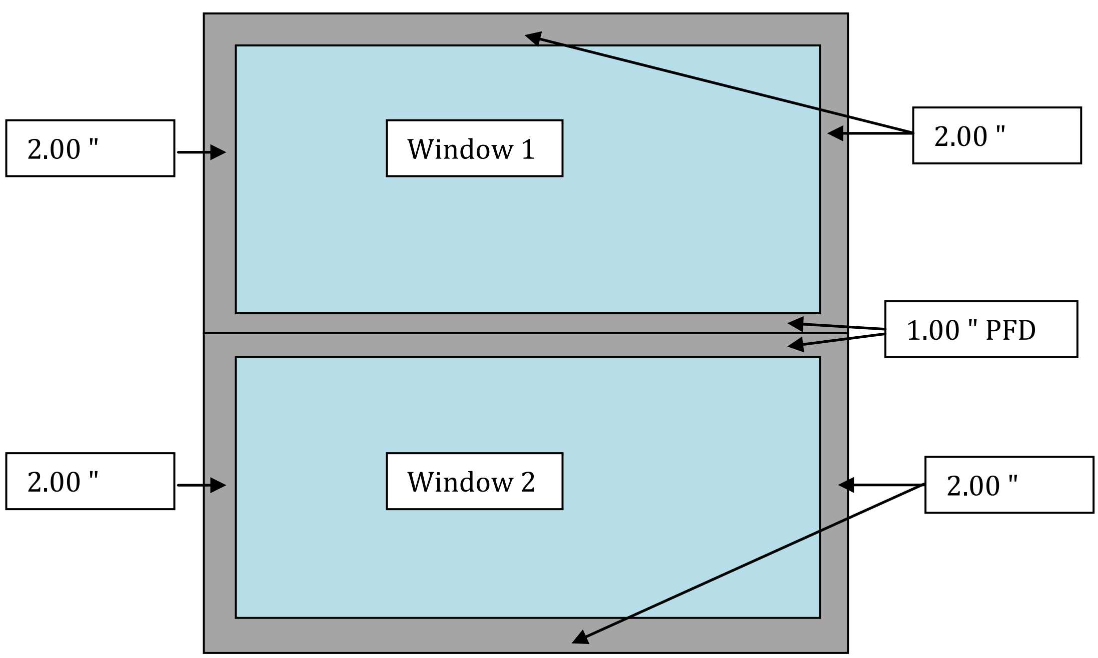


Figure 4. Vinyl Frame Double-Hung Window Subdivision into Two Equal Windows

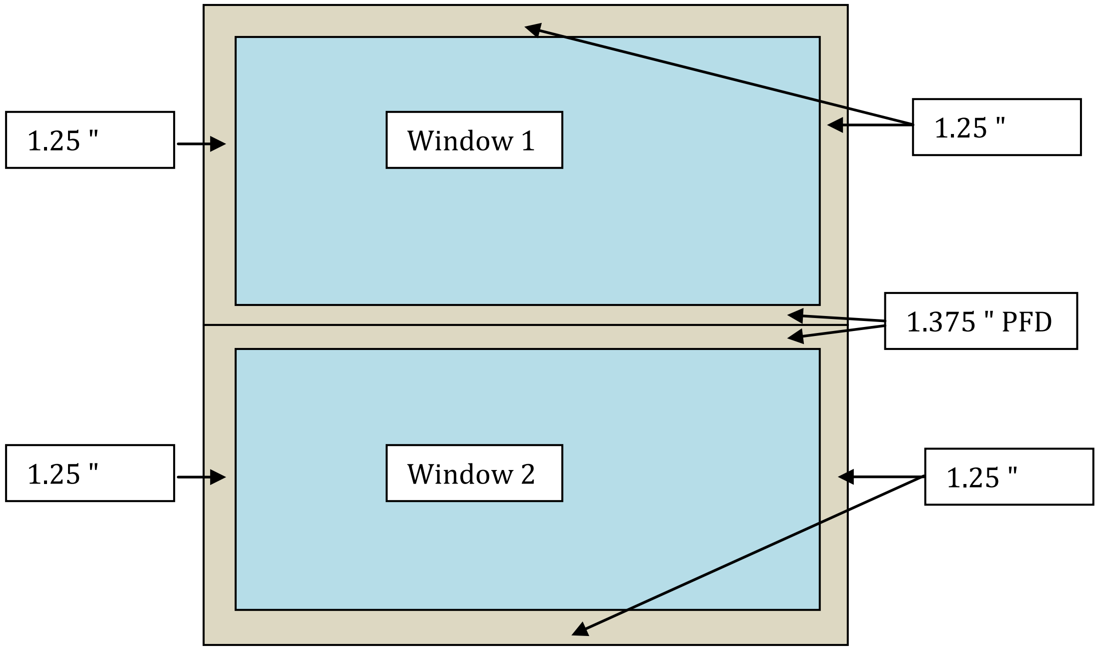


Figure 5. Aluminum Frame Double-Hung Window Subdivision into Two Equal Windows

4.2 Window Attachments Deployment

For some window attachments deployment schedules do not apply due to their fixed nature. The attachments that are fixed and are modeled in one position only are:

1. Interior fixed panel
2. Exterior storm panel
3. Interior surface-applied film
4. Exterior surface-applied film
5. Fixed awnings

Six other categories of window attachments are operable and they all can be classified as "shades" (operable shades).

1. Horizontal louvered blinds
2. Vertical louvered blinds
3. Cellular shades
4. Roller shades
5. Solar screen
6. Drop-arm awnings

Those operable shades are modeled in their three deployment states, open, half-open, and closed, using the following combinations of window coverage:

Table 1. Deployment Options for All Operable Shades

	Window 1	Window 2
Open (O)	No shade	No shade
Half-Open (H)	Fully deployed	No shade
Closed (C)	Fully deployed	Fully deployed

For louvered blinds, horizontal and vertical, definition of open and half-open is more complicated because of the dual adjustability (level of retraction and slat angle), so for these categories of shades, the following combinations are modeled and then averaged in post-processing to create the three main deployment options:

Table 2. Expanded Deployment Options for Louvered Blinds (Horizontal and Vertical Blinds)

	No.	**Window 1**	**Window 2**	**Behavioral Study Designation**
Open (O)	1	0° slat angle	0° slat angle	Fully deployed 0° slat angle
	2	No shade	No shade	Fully retracted (Baseline window)
Half-Open (H)	3	45° slat angle	45° slat angle	Fully deployed 45° slat angle
	4	-45° slat angle	-45° slat angle	Fully deployed -45° slat angle
	5	90° slat angle	No shade	Half retracted 90° slat angle
	6	45° slat angle	No shade	Half retracted 45° slat angle
	7	-45° slat angle	No shade	Half retracted -45° slat angle
Closed (C)	8	90° slat angle	90° slat angle	Fully deployed 90° slat angle

Slat angle definition and their illustration for louvered blinds (both horizontal, also known as Venetian blind, and vertical) are shown in Figure 6.

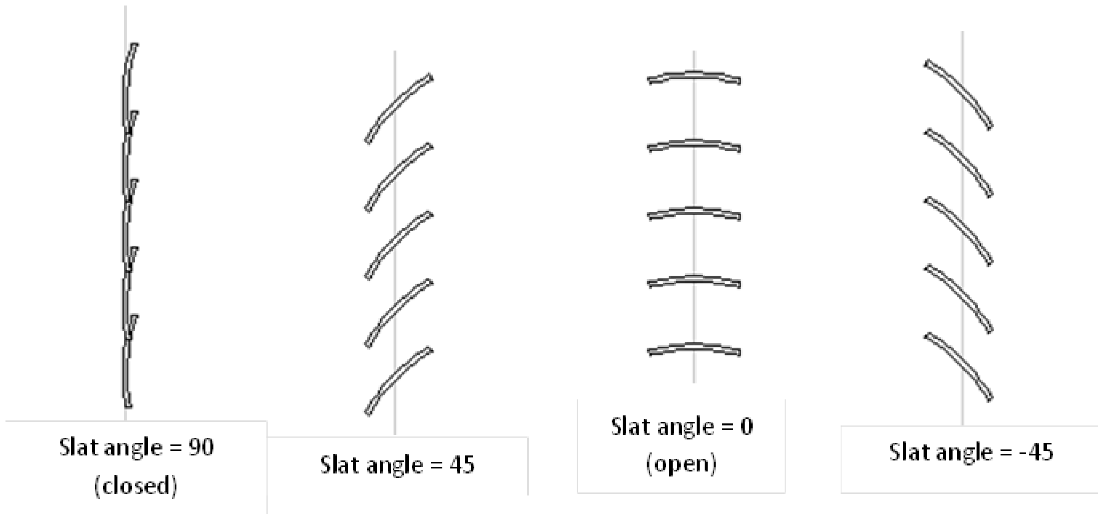


Figure 6. Louvered Blind (Horizontal and Vertical) Slat Angle Definitions with Outdoor Environment on the Left

4.3 Window Attachment Properties

To accomplish energy analysis of the range of performance for each window attachment, four sets of attachment "qualities" were developed. Each attachment quality consists of the set of input parameters that defines a range of energy related performance from "high" to "low" parameters. In some cases, this range in qualities would directly translate to a range from the best to worst performing products, but because the window system (window with attachment) may perform differently in different climates, what is energetically best in one climate, might even be worst in a different climate. Therefore the properties were not classified using best and worst terminology, but rather simply labeled Types A, B, C, and D. From the detailed listing of input parameters below, and rating type levels of performance (i.e., single U-Factor, SHGC, VT for each quality) one can better understand the performance strength and weaknesses for each quality.

4.4 Outdoor-Mounted Window Attachments

4.4.1 Solar Screens

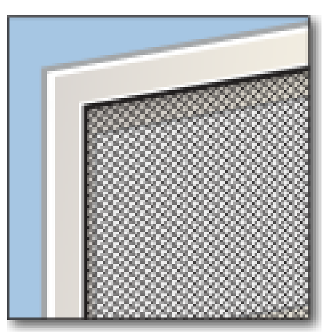


Table 3. Outdoor-Mounted Solar Screen Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Openness [-]	Conductivity k, [W/m·K]	Gap [mm]	Deployed	DRI Def
A	0.1	0.8	0.1	0	0.10	0	Full	Closed
							Half	Half Open
B	0.9	0.7	0.1	0.02	0.10	0	Full	Closed
							Half	Half Open
C	0.9	0.5	0.2	0.05	0.15	3	Full	Closed
							Half	Half Open
D	0.9	0.05	0.5	0.3	1.0	12	Full	Closed
							Half	Half Open

Where:

Emissivity – Emissivity of the surface [Ratio 0 to 1]

Reflectance – Reflectance of the surface [Ratio 0 to 1]

Transmittance – Transmittance of the layer [Ratio 0 to 1]

Openness – Openness of the shade material. Openness is normally calculated as a ratio of holes to the overall area of the shade [Ratio 0 to 1]

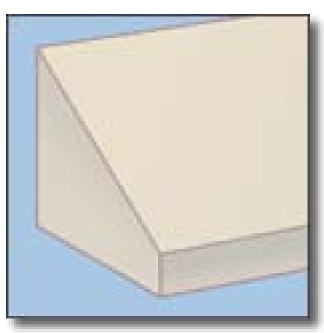
Conductivity – Conductivity of the attachment material, [W/m·K]

Gap – Gap around the edge of the attachment, [mm]. 0 mm is considered tight fit, 3 mm is considered loose fit and 12 mm is considered extra loose fit

Deployed – Level of deployment of the window attachment. See Table 1 for the description of deployment states. Open deployment is not included in the table, because it corresponds to no-shade case (i.e., baseline window)

DRI Def – Behavioral study (DRI 2013) definition

4.4.2 Awnings – Fixed

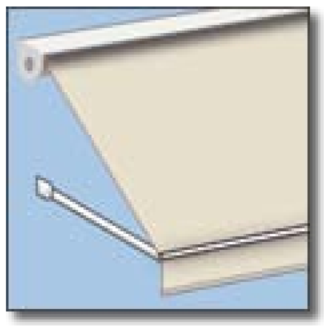


Fixed awnings are always fully deployed. Note that fixed awnings and drop-arm awnings are applied directly in E+, while baseline windows are imported from WINDOW software tool (LBNL 2013). This is due to an inability of WINDOW to model non-coplanar window attachments at this time. Fixed awnings have closed sidess

Table 4. Fixed Awnings Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Deployed	DRI Def
A	0.1	0.8	0.0	Full	N/A
B	0.9	0.6	0.0	Full	N/A
C	0.9	0.4	0.05	Full	N/A
D	0.9	0.02	0.50	Full	N/A

4.4.3 Awnings – Drop-Arm



Drop-arm awnings are operable shades, where fabric is mounted over the swinging arm mechanism, pivoting around the arm anchor, located at the window's half-height point. In fully retracted, drop-arm awning position, arm is angled fully upward, making 0° angle between the arm and the wall and the window is completely unshaded. In half-retracted position, the drop-arm awnings arm is at 90° angle with the wall, so that fabric makes a 45° angle with the wall. In fully deployed position, the pivoting arm forms a 165° angle with the wall, so that fabric makes 172.5° angle with the wall.

Drop-arm awnings were not part of the behavioral study, so we do not have survey data about their typical operation, but we have made an assumption that drop-arm awnings are operated using the same schedule as other operable shades.

Table 5. Drop-Arm Awnings Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Deployed	D&R Def
A	0.1	0.8	0.0	Full	N/A
				Half	N/A
B	0.9	0.6	0.0	Full	N/A
				Half	N/A
C	0.9	0.4	0.05	Full	N/A
				Half	N/A
D	0.9	0.02	0.50	Full	N/A
				Half	N/A

4.4.4 Storm Window Panels

Exterior storm window panels are always fully deployed. They are considered to be tightly attached to the baseline window with no gaps around the edges. Gap definition in the table below refers to the space between the baseline window and storm panel.

Table 6. Outdoor-Mounted Storm Window Panels Definition of Range of Qualities

Quality	Emissivity (Ext/Int) [-]	Reflectance [-]	Transmittance [-]	Conductivity (k) of pane(s) [W/m·K]	# Panes	Gap Size / Gas Fill [mm]	Deployed
A	0.05 / 0.1	0.6	0.2	1.0	2	12.7 / Argon	Full
B	0.07/0.15	0.2	0.5	1.0	2	12.7 / Air	Full
C	0.84	0.3	0.6	1.0	1	25.4 / Air	Full
D	0.9	0.11	0.7	0.15	1	25.4 / Air	Full

4.4.5 Surface-Applied Films

Exterior (Outdoor-Mounted) surface applied films are always fully deployed. This means that the film is applied to the window and remains there throughout all seasons. The properties below are for the film applied to 3mm clear glass.

Table 7. Outdoor-Mounted Storm Window Panels Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Conductivity k, [W/m·K]	Deployed
A	0.02	0.5	0.2	1.0	Full
B	0.15	0.2	0.6	1.0	Full
C	0.9	0.5	0.3	1.0	Full
D	0.9	0.1	0.5	1.0	Full

4.5 Indoor-mounted Window Attachments:

4.5.1 Horizontal Louvered Blind

In addition to parameters that were varied for the rest of shades (except for awnings, where conductivity and openness were not considered due to their absence of any effect), such as emissivity, reflectance, transmittance, and conductivity of the slat material, for louvered blinds thickness and tilt angle, were also varied as follows:

- **Emissivity:** varied from 0.2 and 0.9, where 0.2 represents a low-emissivity material, and 0.9 is representative of vinyl or painted metal blinds
- **Reflectance:** varied from 0.9 to 0.1, where 0.9 is a highly reflective slat, that will have very little absorptance, and 0.1 is a very dark slat, with high absorptance
- **Transmittance:** 0 for most slats (as would be the case for an aluminum slat) but one system was modeled with a 0.05 transmittance which would be common for a vinyl slat
- **Conductivity:** ranges from 0.08 to 160. The lowest value (0.08 W/m-K) represents a insulating slat, such as a foamed faux-wood slat. 0.2 W/m-K represents vinyl slates, and 160 W/m-K is the conductivity of aluminum
- **Thickness:** Two slat thicknesses were modeled: 3 mm for a thick insulating slat, and 0.2 mm for regular thin slats

These five properties (emissivity, reflectance, transmittance, conductivity, thickness) can be combined into 96 unique combinations. For this project, only four combinations were modeled. These four are shows in the table below.

Four blind angles were modeled for the horizontal venetian blinds:

- 0°: horizontal slat
- 45°: a 'sun-blocking' angle, which does not allow direct solar radiation from the sky
- -45°: a 'sun-admitting' angle, which allows direct solar radiation from the sky at certain sun angles
- 90°: a closed blind. The blinds are closed as far as their thickness and angle allow (sometimes this might be less than 90 degrees)

The horizontal louvered blind systems were 1 in. miniblinds that were modeled had the following characteristics:

- Slat width: 25.4
- Slat spacing: 19 mm
- Rise: 2 mm
- An opening 3 mm top, bottom, left right for all cases

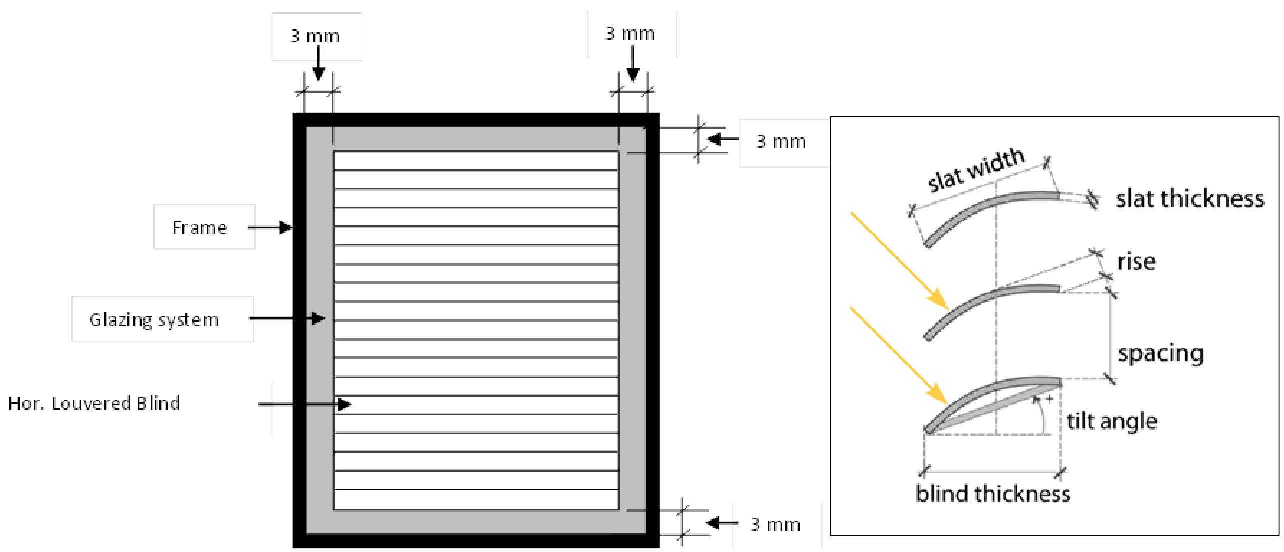


Figure 7. Horizontal Louvered Blinds Configuration Definitions

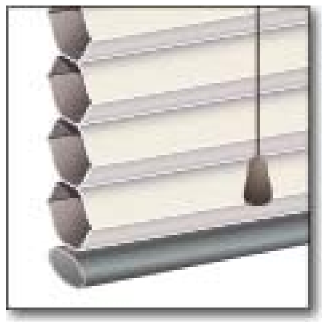
Table 8. Horizontal Louvered Blinds (Venetian Blinds) Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmit. [-]	Conductivity k, [W/m·K]	Thick [mm]	Tilt Angle	Depl.	Remark
A	0.2	0.9	0	0.08	3	0	Full	Fully deployed w/ open slats (0°)
							Half	Half deployed w/ open slats (0°)
						45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						-45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						90	Full	Fully deployed w/ closed slats (90°)
							Half	Half deployed w/ closed slats (90°)
B	0.9	0.75	0	0.2	0.2	0	Full	Fully deployed w/ open slats (0°)
							Half	Half deployed w/ open slats (0°)
						45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						-45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						90	Full	Fully deployed w/ closed slats (90°)
							Half	Half deployed w/ closed slats (90°)
C	0.9	0.6	0.6	0.2	0.2	0	Full	Fully deployed w/ open slats (0°)
							Half	Half deployed w/ open slats (0°)
						45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						-45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						90	Full	Fully deployed w/ closed slats (90°)
							Half	Half deployed w/ closed slats (90°)
D	0.9	0.1	0	160	0.2	0	Full	Fully deployed w/ open slats (0°)
							Half	Half deployed w/ open slats (0°)
						45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						-45	Full	Fully deployed w/ 45° slats
							Half	Half deployed w/ 45° slate
						90	Full	Fully deployed w/ closed slats (90°)
							Half	Half deployed w/ closed slats (90°)

4.5.2 Vertical Louvered Blinds

Vertical louvered blinds were run with the same parametric set as horizontal venetian blinds.

4.5.3 Cellular Shades



Fabric openness is 0 for all cellular shades. Transmittance, reflectance, and emissivity are used for each fabric layer on both the front and the back side of the material. Single cell and cell-in-cell honey comb cellular shades were modeled. The emissivity ranges from 0.1 to 0.9. The 0.1 emissivity represents a low emissivity surface that will increase the thermal resistance.

Table 9. Cellular (Honeycomb) Shades Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance (diffuse) [-]	Transmittance (spec/diff) [-]	Cell Side length [mm]	# walls	Gap [mm]	Deployed
A	0.1	0.8	0 / 0	19 mm	Double (cell in cell)	0	Full
							Half
B	0.9	0.65	0.2 (0.02 / 0.18)	19 mm	Double (cell in cell)	3	Full
							Half
C	0.9	0.45	0.25 (0.02 / 0.23)	15 mm	Single	3	Full
							Half
D	0.9	0.1	0.5 (0.2 / 0.3)	10 mm	Single	12	Full
							Half

Where:

Spec – Specular transmittance (incident and outgoing angles of solar radiation are the same)

Diff – Diffuse Transmittance

4.5.4 Roller Shades

The roller shades definitions for Energy Plus were developed using the woven shade model in WINDOW, which assumes that shade material is made of perfect cylindrical threads equally spaced in both weave directions.

Table 10. Indoor-Mounted Roller Shades Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Openness [-]	Conductivity k, [W/m·K]	Gap [mm]	Deployed
A	0.1	0.8	0.0	0	0.10	0	Full
							Half
B	0.9	0.7	0.1	0.02	0.10	0	Full
							Half
C	0.9	0.5	0.2	0.05	0.15	3	Full
							Half
D	0.9	0.05	0.5	0.3	0.5	12	Full
							Half

4.5.5 Surface Applied Films

Interior (indoor-mounted) surface applied films are always fully deployed. This means that the film is applied to the window and remains there throughout all seasons. The properties below are for the film applied to 3mm clear glass.

Table 11. Indoor-Mounted Surface Applied Films Definition of Range of Qualities

Quality	Emissivity [-]	Reflectance [-]	Transmittance [-]	Openness [-]	Deployed
A	0.02	0.5	0.2	1.0	Full
B	0.15	0.2	0.6	1.0	Full
C	0.9	0.5	0.3	1.0	Full
D	0.9	0.1	0.5	1.0	Full

4.5.6 Interior Window Panels

Interior (indoor-mounted) window panels are always fully deployed. They are considered to be tightly attached to the baseline window with no gaps around the edges. Gap of 1 in. between the prime glass and the interior window panel is considered for all qualities.

Table 12. Interior Window Panel Definition of Range of Qualities

Quality	Emissivity (Ext/Int) [-]	Reflectance [-]	Transmittance [-]	Conductivity k, [W/m·K]	#Panes	Deployed
A	0.05 / 0.1	0.6	0.2	0.15	2	Full
B	0.07/0.15	0.2	0.6	1.0	2	Full
C	0.84	0.3	0.6	1.0	1	Full
D	0.9	0.1	0.7	1.0	1	Full

4.6 U-factor / SHGC Characterizations

WINDOW 7.1 (LBNL 2013) was used to calculate the thermal and optical performance of the window system. Because of the nature of the BSDF methodology, the result of these calculations is a large matrix of thermal and optical properties, which are exported to EnergyPlus for accurate calculation of energy use in variable environmental conditions. However, in order to summarize results, a single angle of incidence (normal incidence) and single set of environmental and room conditions (NFRC standard conditions) were used to express results in terms of single U-factor and SHGC for each of the combinations of shades and baseline windows.

The tables below show the summary version of results of these calculations. For more details, the WINDOW 7.1 database and supporting files can be downloaded from: http://windows.lbl.gov/attachments/parametrics

Table 13. U-factor / SHGC for Attachment and Single Clear Glazing System Combinations

Product	Emissivity		Transmittance		Reflectance		Angle	U-factor (Btu/h-ft2-F)		SHGC	
	High	Low	High	Low	High	Low		Low	High	Low	High
Baseline window								1.06		0.78	
Horizontal blind	0.9	0.1	0.05	0	0.9	0.1	0	0.90	0.93	0.71	0.75
							45	0.83	0.91	0.36	0.59
							90	0.57	0.73	0.13	0.51
Vertical blind	0.9	0.1	0.05	0	0.9	0.1	0	0.92	0.94	0.77	0.77
							45	0.86	0.92	0.44	0.63
							90	0.53	0.72	0.10	0.51
Roller Shades	0.9	0.1	0.5	0	0.8	0.05	N/A	0.33	0.93	0.13	0.67
Cellular Shades	0.9	0.1	0.5	0	0.8	0.1	N/A	0.24	0.81	0.16	0.56
Interior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	0.64	1.09	0.22	0.58
Storm Windows	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.24	0.54	0.23	0.60
Interior Window Panel	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.24	0.54	0.28	0.64
Exterior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	1.04	1.06	0.23	0.62
Exterior Solar Screens	0.9	0.1	0.5	0.1	0.8	0.05	N/A	0.41	0.66	0.12	0.45

Table 14. U-factor / SHGC for Attachment and Double Clear Glazing System Combinations

Product	Emissivity		Transmittance		Reflectance		Angle	U-factor (Btu/h-ft2-F)		SHGC	
	High	Low	High	Low	High	Low		Low	High	Low	High
Baseline window								0.49		0.59	
Horizontal blind	0.9	0.1	0.05	0	0.9	0.1	0	0.45	0.46	0.55	0.58
							45	0.43	0.45	0.33	0.51
							90	0.36	0.42	0.12	0.46
Vertical blind	0.9	0.1	0.05	0	0.9	0.1	0	0.46	0.46	0.59	0.59
							45	0.44	0.46	0.38	0.52
							90	0.36	0.42	0.12	0.46
Roller Shades	0.9	0.1	0.5	0	0.8	0.05	N/A	0.29	0.46	0.14	0.54
Cellular Shades	0.9	0.1	0.5	0	0.8	0.1	N/A	0.20	0.43	0.15	0.48
Interior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	0.39	0.49	0.23	0.51
Storm Windows	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.20	0.37	0.19	0.46
Interior Window Panel	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.20	0.37	0.24	0.51
Exterior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	0.48	0.49	0.18	0.46
Exterior Solar Screens	0.9	0.1	0.5	0.1	0.8	0.05	N/A	0.32	0.40	0.10	0.34

Table 15. U-factor / SHGC for Attachment and Double Low-e Glazing System Combinations

Product	Emissivity		Transmittance		Reflectance		Angle	U-factor (Btu/h-ft2-F)		SHGC	
	High	Low	High	Low	High	Low		Low	High	Low	High
Baseline window								0.31		0.29	
Horizontal blind	0.9	0.1	0.05	0	0.9	0.1	0	0.29	0.30	0.28	0.29
							45	0.29	0.29	0.18	0.27
							90	0.26	0.28	0.08	0.26
Vertical blind	0.9	0.1	0.05	0	0.9	0.1	0	0.29	0.30	0.29	0.29
							45	0.29	0.29	0.20	0.27
							90	0.26	0.28	0.08	0.25
Roller Shades	0.9	0.1	0.5	0	0.8	0.05	N/A	0.17	0.30	0.09	0.28
Cellular Shades	0.9	0.1	0.5	0	0.8	0.1	N/A	0.14	0.28	0.10	0.26
Interior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	0.27	0.31	0.15	0.27
Storm Windows	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.14	0.26	0.17	0.32
Interior Window Panel	0.9	0.05	0.7	0.2	0.6	0.1	N/A	0.14	0.27	0.18	0.28
Exterior Applied Film	0.9	0.02	0.6	0.2	0.6	0.1	N/A	0.30	0.31	0.12	0.25
Exterior Solar Screens	0.9	0.1	0.5	0.1	0.8	0.05	N/A	0.19	0.23	0.05	0.18

5. METHODOLOGY

Energy use of windows and window attachments was modeled in EnergyPlus using the typical residential buildings described in the previous section. EnergyPlus can model a wide range of shading and otherwise complex systems when the complex optical radiation distribution is calculated in the WINDOW program (LBNL 2013). WINDOW can generate a Bi-Directional Distribution Function (BSDF) which can be exported to EnergyPlus using the IDF file format. BSDF files define a discrete set of incident and outgoing angles, which fully describe the optical performance of any system, simple or complex, limited only by the resolution of the angular discretization. In this method each layer, as well as the whole system, is described by a matrix of incident and outgoing angles. Further details about the BSDF method and its implementation In WINDOW and EnergyPlus software tools can be found in Klems (1994A and 1994B) and DOE (2013b)

The deployment schedule for window attachments was developed from the results of a behavioral study, funded jointly by DOE and the Window Attachment Industry (DRI 2013). Based on the results of the survey of 2,467 households in 12 markets (see Parametrics section for the list of cities), a deployment schedule was developed for 3 periods during the day, for two seasons, and for the three distinct climatic regions in the country. Of the 2,467 households surveyed, 397 households were removed from the dataset due to issues with data quality, leaving 2,100 households for analysis. The behavioral study considered three different attachment deployments and identified the percentage of products that were in one of these three positions at different times of day:

1. **O:** Open
2. **H:** Half-Open
3. **C:** Closed

The periods of day considered were:

1. **M:** Morning, including work hours (6:00 a.m. to 12:00 p.m.)
2. **A:** Afternoon (12:00 p.m. to 6:00 p.m.)
3. **N:** Evening/Night (6:00 p.m. to 6.00 a.m.)

For each deployment state, the heating and cooling energy use is calculated on an hourly basis for each of the parameters considered and labeled E_O, E_H, E_C for open, half-open, and closed, respectively. While energy use for each deployment state is calculated separately, post-processing is applied to the three deployment states to produce weighted energy use for an operable window attachment, representative of the behavioral study.

In order to describe the weighting calculation methodology, indices for hourly, daily, and weekly periods are used. Hourly energy values are labeled using τ_h. Different day in a week (i.e., weekday vs. weekends and holidays) is labeled using index τ_d, and different week in a season is labeled using index τ_w. Using this notation, the following equations are used to calculate weighted energy use from operable window shades.

$$E = E_O + E_H + E_C \qquad (1)$$

Where:

E_O = Energy use for open window attachment

E_H = Energy use for half-open window attachment

E_O = Energy use for closed window attachment

$$E_O = \sum_{\tau_w = S_1}^{S_N} \left(E_{SDO}(\tau_w) + E_{SEO}(\tau_w) \right) + \sum_{\tau_w = W_1}^{W_N} \left(E_{WDO}(\tau_w) + E_{WEO}(\tau_w) \right) \tag{2}$$

$$E_H = \sum_{\tau_w = S_1}^{S_N} \left(E_{SDH}(\tau_w) + E_{SEH}(\tau_w) \right) + \sum_{\tau_w = W_1}^{W_N} \left(E_{WDH}(\tau_w) + E_{WEH}(\tau_w) \right) \tag{3}$$

$$E_C = \sum_{\tau_w = S_1}^{S_N} \left(E_{SDC}(\tau_w) + E_{SEC}(\tau_w) \right) + \sum_{\tau_w = W_1}^{W_N} \left(E_{WDC}(\tau_w) + E_{WEC}(\tau_w) \right) \tag{4}$$

Where:

$$E_{SDO}(\tau_w) = \sum_{\tau_d = 1}^{5} \left(F_{SDMO} \cdot \sum_{\tau_h = 6}^{12} E_O(\tau_w, \tau_d, \tau_h) + F_{SDAO} \cdot \sum_{\tau_h = 12}^{18} E_O(\tau_w, \tau_d, \tau_h) + F_{SDNO} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_O(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{SEO}(\tau_w) = \sum_{\tau_d = 6}^{7} \left(F_{SEMO} \cdot \sum_{\tau_h = 6}^{12} E_O(\tau_w, \tau_d, \tau_h) + F_{SEAO} \cdot \sum_{\tau_h = 12}^{18} E_O(\tau_w, \tau_d, \tau_h) + F_{SENO} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_O(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{WDO}(\tau_w) = \sum_{\tau_d = 1}^{5} \left(F_{WDMO} \cdot \sum_{\tau_h = 6}^{12} E_O(\tau_w, \tau_d, \tau_h) + F_{WDAO} \cdot \sum_{\tau_h = 12}^{18} E_O(\tau_w, \tau_d, \tau_h) + F_{WDNO} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_O(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{WEO}(\tau_w) = \sum_{\tau_d = 6}^{7} \left(F_{WEMO} \cdot \sum_{\tau_h = 6}^{12} E_O(\tau_w, \tau_d, \tau_h) + F_{WEAO} \cdot \sum_{\tau_h = 12}^{18} E_O(\tau_w, \tau_d, \tau_h) + F_{WENO} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_O(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{SDH}(\tau_w) = \sum_{\tau_d = 1}^{5} \left(F_{SDMH} \cdot \sum_{\tau_h = 6}^{12} E_H(\tau_w, \tau_d, \tau_h) + F_{SDAH} \cdot \sum_{\tau_h = 12}^{18} E_H(\tau_w, \tau_d, \tau_h) + F_{SDNH} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_H(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{SEH}(\tau_w) = \sum_{\tau_d = 6}^{7} \left(F_{SEMH} \cdot \sum_{\tau_h = 6}^{12} E_H(\tau_w, \tau_d, \tau_h) + F_{SEAH} \cdot \sum_{\tau_h = 12}^{18} E_H(\tau_w, \tau_d, \tau_h) + F_{SENH} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_H(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{WDH}(\tau_w) = \sum_{\tau_d = 1}^{5} \left(F_{WDMH} \cdot \sum_{\tau_h = 6}^{12} E_H(\tau_w, \tau_d, \tau_h) + F_{WDAH} \cdot \sum_{\tau_h = 12}^{18} E_H(\tau_w, \tau_d, \tau_h) + F_{WDNH} \cdot \sum_{\tau_h = 18}^{6(+1day)} E_H(\tau_w, \tau_d, \tau_h) \right)$$

$$E_{WEH}(\tau_w) = \sum_{\tau_d=6}^{7} \left(F_{WEMH} \cdot \sum_{\tau_h=6}^{12} E_H(\tau_w,\tau_d,\tau_h) + F_{WEAH} \cdot \sum_{\tau_h=12}^{18} E_H(\tau_w,\tau_d,\tau_h) + F_{WENH} \cdot \sum_{\tau_h=18}^{6(+1day)} E_H(\tau_w,\tau_d,\tau_h) \right)$$

$$E_{SDC}(\tau_w) = \sum_{\tau_d=1}^{5} \left(F_{SDMC} \cdot \sum_{\tau_h=6}^{12} E_C(\tau_w,\tau_d,\tau_h) + F_{SDAC} \cdot \sum_{\tau_h=12}^{18} E_C(\tau_w,\tau_d,\tau_h) + F_{SDNC} \cdot \sum_{\tau_h=18}^{6(+1day)} E_C(\tau_w,\tau_d,\tau_h) \right)$$

$$E_{SEC}(\tau_w) = \sum_{\tau_d=6}^{7} \left(F_{SEMC} \cdot \sum_{\tau_h=6}^{12} E_C(\tau_w,\tau_d,\tau_h) + F_{SEAC} \cdot \sum_{\tau_h=12}^{18} E_C(\tau_w,\tau_d,\tau_h) + F_{SENC} \cdot \sum_{\tau_h=18}^{6(+1day)} E_C(\tau_w,\tau_d,\tau_h) \right)$$

$$E_{SWC}(\tau_w) = \sum_{\tau_d=1}^{5} \left(F_{WDMC} \cdot \sum_{\tau_h=6}^{12} E_C(\tau_w,\tau_d,\tau_h) + F_{WDAC} \cdot \sum_{\tau_h=12}^{18} E_C(\tau_w,\tau_d,\tau_h) + F_{WDNC} \cdot \sum_{\tau_h=18}^{6(+1day)} E_C(\tau_w,\tau_d,\tau_h) \right)$$

$$E_{WEC}(\tau_w) = \sum_{\tau_d=6}^{7} \left(F_{WEMC} \cdot \sum_{\tau_h=6}^{12} E_C(\tau_w,\tau_d,\tau_h) + F_{WEAC} \cdot \sum_{\tau_h=12}^{18} E_C(\tau_w,\tau_d,\tau_h) + F_{WENC} \cdot \sum_{\tau_h=18}^{6(+1day)} E_C(\tau_w,\tau_d,\tau_h) \right)$$

Where:

τ_d = days of the week, where 1=Monday, and 7=Sunday. The weekend schedule is also applicable to holidays

τ_w = weeks of the year, where S_1 = first week of the cooling season, and S_N = last week of the cooling season, W_1 = first week of the heating season, and W_N = last week of the heating season. S1, SN, W1, and WN are defined in Table 20

τ_h = hours in a day, where 1=1:00 a.m., 12 = 12:00 p.m., and 24 = 12:00 a.m. For the evening/night period, the summation goes from 18 (6:00 p.m.) until 24 (12 a.m.), then the hours reset to 0 and go until 6 a.m. This is indicated in the equations as (+1 day) in the upper limit of the summation sign for the evening/night period

E_{SDO} = Energy use for weekdays, for open deployment during the cooling season

E_{SEO} = Energy use for weekends, for open deployment during the cooling season

E_{WDO} = Energy use for weekdays, for open deployment during the heating season

E_{WEO} = Energy use for weekends, for open deployment during the heating season

E_{SDH} = Energy use for weekdays, for half-open deployment during the cooling season

E_{SEH} = Energy use for weekends, for half-open deployment during the cooling season

E_{WDH} = Energy use for weekdays, for half-open deployment during the heating season

E_{WEH} = Energy use for weekends, for half-open deployment during the heating season

E_{SDC} = Energy use for weekdays, for closed deployment during the cooling season

E_{SEC} = Energy use for weekends, for closed deployment during the cooling season

E_{WDC} = Energy use for weekdays, for closed deployment during the heating season

E_{WEC} = Energy use for weekends, for closed deployment during the heating season

F_{SDMO} = Fraction of windows on weekdays, during morning and work hours with open deployment during the cooling season

F_{SDAO} = Fraction of windows on weekdays, during afternoon after work hours with open deployment during the cooling season

F_{SDNO} = Fraction of windows on weekdays, during night hours with open deployment during the cooling season

F_{SEMO} = Fraction of windows on weekends, during morning and work hours with open deployment during the cooling season

F_{SEAO} = Fraction of windows on weekends, during afternoon after work hours with open deployment during the cooling season

F_{SENO} = Fraction of windows on weekends, during night hours with open deployment during the cooling season

F_{WDMO} = Fraction of windows on weekdays, during morning and work hours with open deployment during the heating season

F_{WDAO} = Fraction of windows on weekdays, during afternoon after work hours with open deployment during the heating season

F_{WDNO} = Fraction of windows on weekdays, during night hours with open deployment during the heating season

F_{WEMO} = Fraction of windows on weekends, during morning and work hours with open deployment during the heating season

F_{WEAO} = Fraction of windows on weekends, during afternoon after work hours with open deployment during the heating season

F_{WENO} = Fraction of windows on weekends, during night hours with open deployment during the heating season

F_{SDMH} = Fraction of windows on weekdays, during morning and work hours with half-open deployment during the cooling season

F_{SDAH} = Fraction of windows on weekdays, during afternoon after work hours with half-open deployment during the cooling season

F_{SDNH} = Fraction of windows on weekdays, during night hours with half-open deployment during the cooling season

F_{SEMH} = Fraction of windows on weekends, during morning and work hours with half-open deployment during the cooling season

F_{SEAH} = Fraction of windows on weekends, during afternoon after work hours with half-open deployment during the cooling season

F_{SENH} = Fraction of windows on weekends, during night hours with half-open deployment during the cooling season

F_{WDMH} = Fraction of windows on weekdays, during morning and work hours with half-open deployment during the heating season

F_{WDAH} = Fraction of windows on weekdays, during afternoon after work hours with half-open deployment during the heating season

F_{WDNH} = Fraction of windows on weekdays, during night hours with half-open deployment during the heating season

F_{WEMH} = Fraction of windows on weekends, during morning and work hours with half-open deployment during the heating season

F_{WEAH} = Fraction of windows on weekends, during afternoon after work hours with half-open deployment during the heating season

F_{WENH} = Fraction of windows on weekends, during night hours with half-open deployment during the heating season

F_{SDMC} = Fraction of windows on weekdays, during morning and work hours with half-open deployment during the cooling season

F_{SDAC} = Fraction of windows on weekdays, during afternoon after work hours with closed deployment during the cooling season

F_{SDNC} = Fraction of windows on weekdays, during night hours with closed deployment during the cooling season

F_{SEMC} = Fraction of windows on weekends, during morning and work hours with closed deployment during the cooling season

F_{SEAC} = Fraction of windows on weekends, during afternoon after work hours with closed deployment during the cooling season

F_{SENC} = Fraction of windows on weekends, during night hours with closed deployment during the cooling season

F_{WDMC} = Fraction of windows on weekdays, during morning and work hours with closed deployment during the heating season

F_{WDAC} = Fraction of windows on weekdays, during afternoon after work hours with closed deployment during the heating season

F_{WDNC} = Fraction of windows on weekdays, during night hours with closed deployment during the heating season

F_{WEMC} = Fraction of windows on weekends, during morning and work hours with closed deployment during the heating season

F_{WEAC} = Fraction of windows on weekends, during afternoon after work hours with closed deployment during the heating season

F_{WENC} = Fraction of windows on weekends, during night hours with closed deployment during the heating season

Table 16 contains the variable names for the *F* fractions. They are calculated for each climatic zone

Table 16. Deployment Schedule Expressed in Terms of Variables (Fractions)

	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**
Open	F_{SDMO}	F_{SDAO}	F_{SDNO}	F_{SEMO}	F_{SEAO}	F_{SENO}	F_{WDMO}	F_{WDAO}	F_{SDNO}	F_{WEMO}	F_{WEAO}	F_{WENO}
Half-open	F_{SDMH}	F_{SDAH}	F_{SDNH}	F_{SEMH}	F_{SEAH}	F_{SENH}	F_{WDMH}	F_{WDAH}	F_{SDNH}	F_{WEMH}	F_{WEAH}	F_{WENH}
Closed	F_{SDMC}	F_{SDAC}	F_{SDNC}	F_{SEMC}	F_{SEAC}	F_{SENC}	F_{WDMC}	F_{WDAC}	F_{SDNC}	F_{WEMC}	F_{WEAC}	F_{WENC}

The following deployment schedules were developed from Tables 41, 42, and 43 in DRI (2013) for the three climatic zones; North, Central, and South (see definition of climatic zones and climatic locations in Table 20) and are presented in Table 17 to Table 19 in terms of percentages. In order to generate factors from Table 16, these percentages need to be divided by 100 (e.g., 36% becomes 0.36).

While the tables from DRI (2013) had summer and winter season breakdowns, this study adopts more inclusive and appropriate cooling and heating season periods, in order to account for annual energy use. The heating and cooling season hours always add up to the whole year hours (8,760).

The weekend schedule also applies to holidays. Each weather data file contains standard US holidays, which are assigned the weekend schedule in the EnergyPlus input.

Table 17. Deployment Schedule for North Climate Zone (Percentage)

	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**
Open	26	24	23	26	25	23	29	30	23	28	29	22
Half-open	35	34	32	36	36	33	32	33	28	32	33	29
Closed	39	41	45	38	39	44	39	38	49	40	38	49
Total	100	99	100	100	100	100	100	101	100	100	100	100

Table 18. Deployment Schedule for Central Climatic Zone (Percentage)

	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**
Open	23	21	20	23	22	20	25	25	19	24	24	18
Half-open	31	32	29	33	32	30	30	30	29	30	30	27
Closed	46	47	52	45	46	50	45	45	53	46	45	54
Total	100	100	101	101	100	100	100	100	101	100	99	99

Table 19. Deployment Schedule for South Climatic Zone (Percentage)

	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**	**M**	**A**	**N**
Open	17	15	13	18	17	14	23	23	17	23	23	17
Half-open	26	25	23	26	25	24	25	26	22	27	27	23
Closed	57	60	65	56	58	62	52	51	61	51	50	59
Total	100	100	101	100	100	100	100	100	100	101	100	99

For louvered blinds, the heating and cooling energy use is the result of averaging two retraction and slat angle combinations for the open deployment, and five retraction/slat angle combinations for the half-open deployment (see Parametrics section, Table 2). The above formulas are applied to each retraction and slat angle combinations. Numbers in the second column in Table 2 are used in subsequent equations as an index number (1-2 for open, 3-7 for half-open, and 8 for closed).

The energy use for open, half open, and closed deployment for louvered blinds is then calculated using the following formulas:

$$E_O = \frac{\sum_{i=1}^{2}\left(\sum_{\tau_w=S_1}^{S_N}\left(E_{SDO,i}(\tau_w)+E_{SEO,i}(\tau_w)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDO,i}(\tau_w)+E_{WEO,i}(\tau_w)\right)\right)}{2}$$

$$E_H = \frac{\sum_{i=3}^{7}\left(\sum_{\tau_w=S_1}^{S_N}\left(E_{SDH,i}(\tau_w)+E_{SEH,i}(\tau_w)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDH,i}(\tau_w)+E_{WEH,i}(\tau_w)\right)\right)}{5}$$

$$E_C = \sum_{\tau_w=S_1}^{S_N}\left(E_{SDC,8}(\tau_w)+E_{SEC,8}(\tau_w)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDC,8}(\tau_w)+E_{WEC,8}(\tau_w)\right)$$

The total weighted energy is then calculated using equation (1). An example of the application of formula to the calculation of $E_{SEO,1}$ is shown below. Other quantities are calculated in the same manner.

$$E_{SEO,1}(\tau_w) = \sum_{\tau_d=6}^{7}\left(F_{SEMO}\cdot\sum_{\tau_h=5}^{17}E_{O,1}(\tau_w,\tau_d,\tau_h)+F_{SEAO}\cdot\sum_{\tau_h=5}^{17}E_{O,1}(\tau_w,\tau_d,\tau_h)+F_{SENO}\cdot\sum_{\tau_h=5}^{17}E_{O,1}(\tau_w,\tau_d,\tau_h)\right)$$

These equations are applied separately to heating and cooling energy, so that the separate contributions for heating and cooling are reported and graphed in the Results section.

Fixed window attachments do not have an operational schedule associated with them, so for each unique window attachment combination, there is a single energy number.

Cooling and heating periods are defined for each climatic location in Table 20. Each location is represented by a standard weather data file, developed from climatic data for a typical year, based on long term observations and weather station data, collected across the United States and internationally. The most recent weather data files, which were used in this study, are “Typical Meteorological Year 3 (TMY3).”

Table 20. Climatic Zone Distribution and Cooling and Heating Season Definition for the 12 Climatic Locales

North

Minneapolis, 55111		
	Start	*End*
Winter	1, November	31, January
Spring	1, February	30, April
Summer	1, May	31, July
Autumn	1, August	31, October
Heating	15, September	16, March
Cooling	17, March	14, September

Boston, 02128		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Chicago, 60666		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Central

Washington, 20163		
	Start	*End*
Winter	1, November	31, January
Spring	1, February	30, April
Summer	1, May	31, July
Autumn	1, August	31, October
Heating	15, September	16, March
Cooling	17, March	14, September

Atlanta, 30320		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Denver, 80249		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

San Francisco, 94128		
	Start	*End*
Winter	1, January	31, March
Spring	1, April	30, june
Summer	1, July	30, September
Autumn	1, October	31, December
Heating	15, November	15, May
Cooling	16, May	14, November

South

San Antonio, 78216		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

New Orleans, 70126		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Tampa, 33607		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Phoenix, 85034		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

Fort Worth, 76177		
	Start	*End*
Winter	1, December	28, February
Spring	1, March	31, May
Summer	1, June	31, August
Autumn	1, September	30, November
Heating	16, October	14, April
Cooling	15, April	15, October

6. RESULTS

The parametric analysis gives total annual energy use for houses with each shading device in several configurations and climates. The total of 16,848 energy simulation runs were carried out for 12 climate zones, four house types, three baseline windows, 11 window attachment categories, four attachment qualities and varying number of deployment positions (one option for fixed, three options for cellular shades, roller screens, solar screens, and drop-arm awnings, and eight options for horizontal and vertical louvered blinds). This large set of data points is difficult to compare in tabulated, and even graphical form. This section outlines and discusses seven graphical comparison types that attempt to bring insight into the results.

The first set of graphs presents a larger set of data points in the form of a scatterplot. Instead of the total energy use, these graphs present results in the form of energy savings, where positive values are energy savings and negative values are energy penalty with respect to base window performance. The zero point represents energy use of the baseline window. Average savings of all window attachments analyzed in this study are shown as a dashed red line. While this kind of average is not representative of any single window attachment, it is useful for comparing effects of attachments in general over the baseline window. The scatterplot graphs show the effects of house type, baseline windows, and climate zones on energy savings. These graphs provide a high level view of the effects of house type, and choice of baseline window, so that the remaining graphs focus on single house type (basement, gas heating and A/C) and single baseline window (double-clear, wood window).

The second set of graphs show comparison between different attachments, whose energy performance is weighted by typical operational schedule from DRI (2013). These are bar graphs that show total energy use by a typical house employing particular type of window attachment. Cooling and heating are plotted separately in a stacked graph format, so that both total and cooling/heating performance can be compared in a single graph. These weighted graphs are presented in two different ways, one set where window attachments are compared to each other and grouped into four qualities, and the second where qualities are compared to each other and grouped by window attachment categories.

The third set of graphs compare different deployment states for louvered blinds. These window shades are different than other operable shades in that they have two degrees of freedom, slat angle, and level of retraction. Each louvered blind has eight deployment states, as described in the Parametrics section and each is compared in these graphs. Later on, deployment for louvered blinds is averaged into standard deployment states; open, half-open, and closed states and then compared with other operable shades that have these three deployment states.

The fourth set of graphs compares all operable shades using three main deployment states. For each shade three deployment states are plotted next to each other. This is done for the three climate zones.

Additional graphic results are in Appendix A and Appendix B and the tabulated data is made available in Appendix C. The full set of results, including WINDOW database and EnergyPlus files are located at http://windows.lbl.gov/Attachments/Paramterics.

It is important to note that window attachment qualities are developed as a range of performance between theoretical limits and that real shades, available on the market today, will be somewhere in-between. For some window attachments, the real products will be very close to one of qualities A to D and for some, the real performance will not come very close to one of the theoretical limits. These theoretical limits are not unphysical, but they may not be available on the market in those particular combinations.

All of the energy use and energy savings reporting in this study are reported in site energy terms, which treats all energy sources equally (e.g., electric energy use of 1 GJ is identical to natural gas energy use of 1 GJ). An alternate presentation that is sometimes used in similar studies could be done in "source energy", where conversion factors for each energy type are applied. In that case, all electrical energy would be roughly three times higher than gas energy. This would tend to emphasize savings from strategies that reduced cooling loads more than strategies that reduce heating loads. Although it would not change the underlying heating and cooling lend use, in some instances it could change the rankings of solutions relative to each other.

6.1 Scatterplot Graphs

6.1.1 House Type Comparison

Figure 8 through Figure 11 show a comparison of home energy use, by house configuration, of all attachments on all window types. Comparisons are done with the time weighted use results described in Methodology section. Use of different house types shows very little difference in the average performance of window attachments, as well as little change in any particular window attachment. Because of this, only one house type (basement) is presented in subsequent graphs.

Figure 8 and Figure 9 show energy savings for gas heating and electric A/C (GAC), while Figure 10 and Figure 11 show the same houses with heat pump heating and A/C (HP). Heat pump heating energy is lower than gas by approximately a factor of three in all cases due to heat pump's inherently much higher efficiency. This results in smaller heating energy savings (and thus overall energy savings) shown in Figure 10 and Figure 11. The difference in average energy savings for the houses is relatively small, though (up to 0.1 GJ), because both positive and negative energy savings have been reduced. In other words, points above and below the zero line are closer to zero (i.e., less spread), but the average remains roughly the same. These energy savings would be more pronounced (and much closer to GAC) if source energy was used instead of site energy, as it is done in this report.

Legend with abbreviations for different window attachment categories is given in tabular format and provided with each graph.

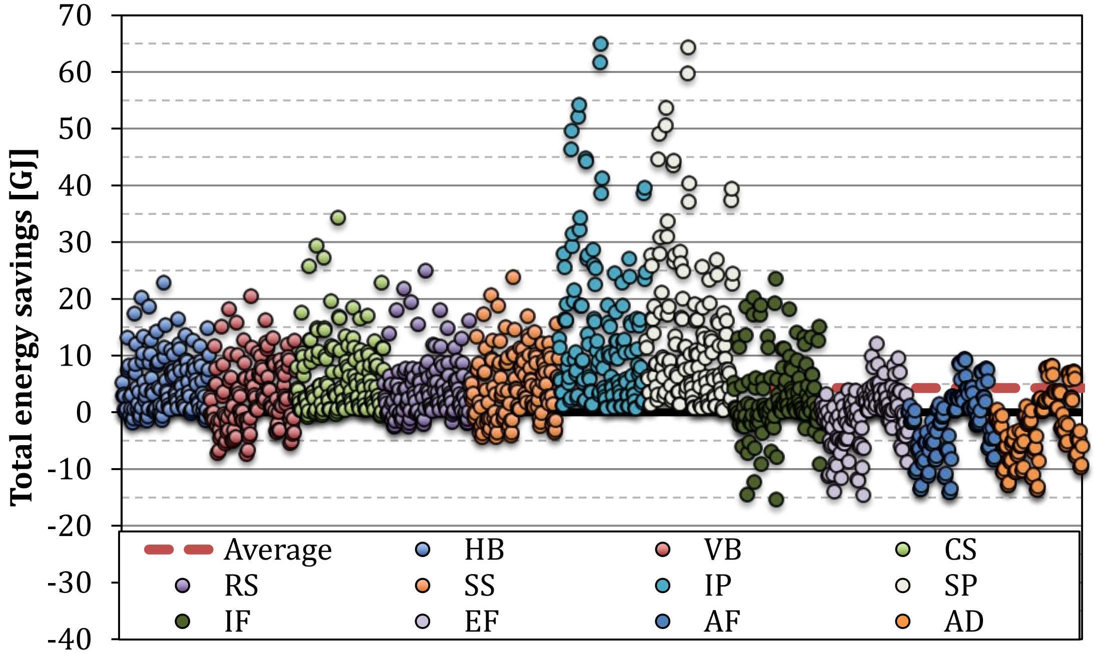


Figure 8. House Type: Basement, Gas Heating and Electric A/C. Average Savings: 4.31 GJ

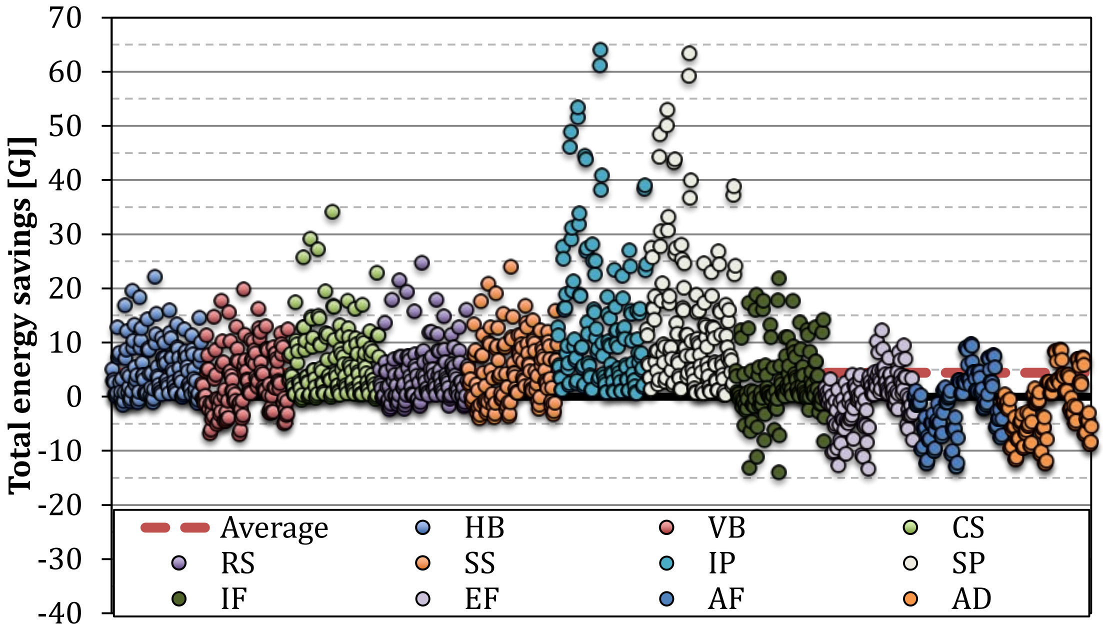


Figure 9. House Type: Slab, Gas Heating and Electric A/C. Average Savings: 4.41 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

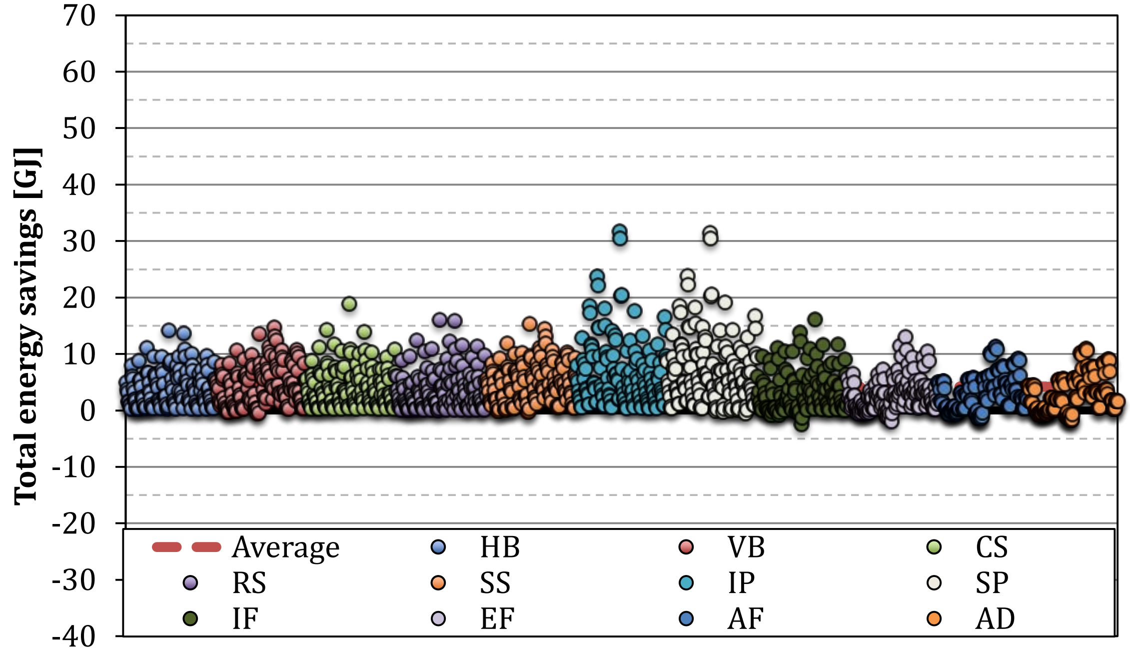


Figure 10. House Type: Basement, Heat Pump Heating and A/C. Average Savings: 4.21 GJ

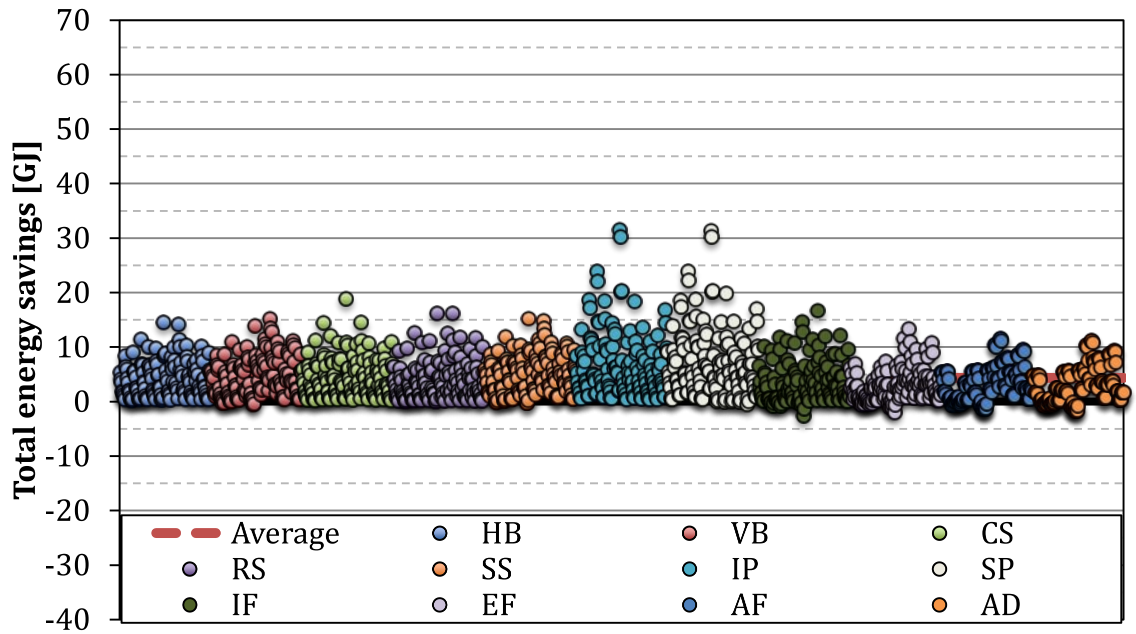


Figure 11. House Type: Slab, Heat Pump Heating and A/C. Average Savings: 4.36 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

6.1.2 Window Type Comparison

Figure 12 to Figure 14 show a comparison of home energy use by window configuration of all attachments. Comparisons are done with the time weighted use results described in the Methodology section. Use of different baseline windows show large differences in shows large differences in the energy savings of different window attachments, where energy savings are largest for single glazed Aluminum window and savings are lowest for the double pane low-e vinyl windows. This result is expected since the effects of window attachments on energy performance is expected to improve the performance of thermally poorer windows the most. These graphs also show that the relative ranking of different attachments does not change, so further graphs will show savings over just double pane clear wood window as a representative baseline.

Further examination of these graphs reveal that interior window panels and exterior storm window panels most consistently save energy, while for other window attachments, savings depends on a particular selection of attachment parameters. . This suggests the importance of operation over time.

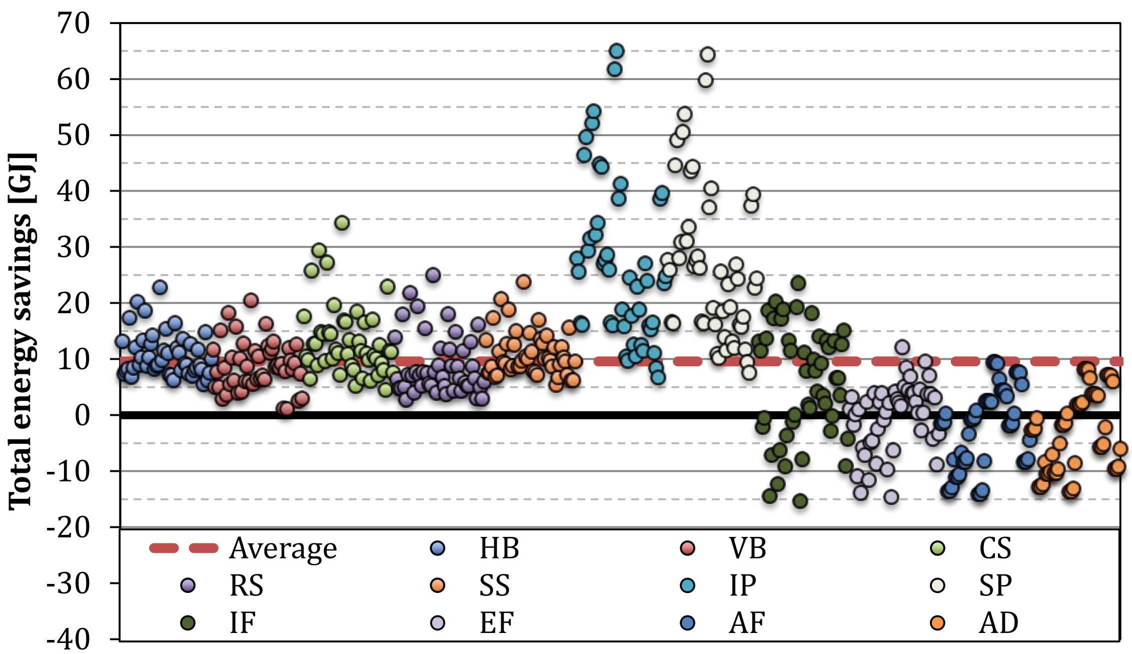


Figure 12. Baseline Window: Single Pane Aluminum. Average Savings: 9.61 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

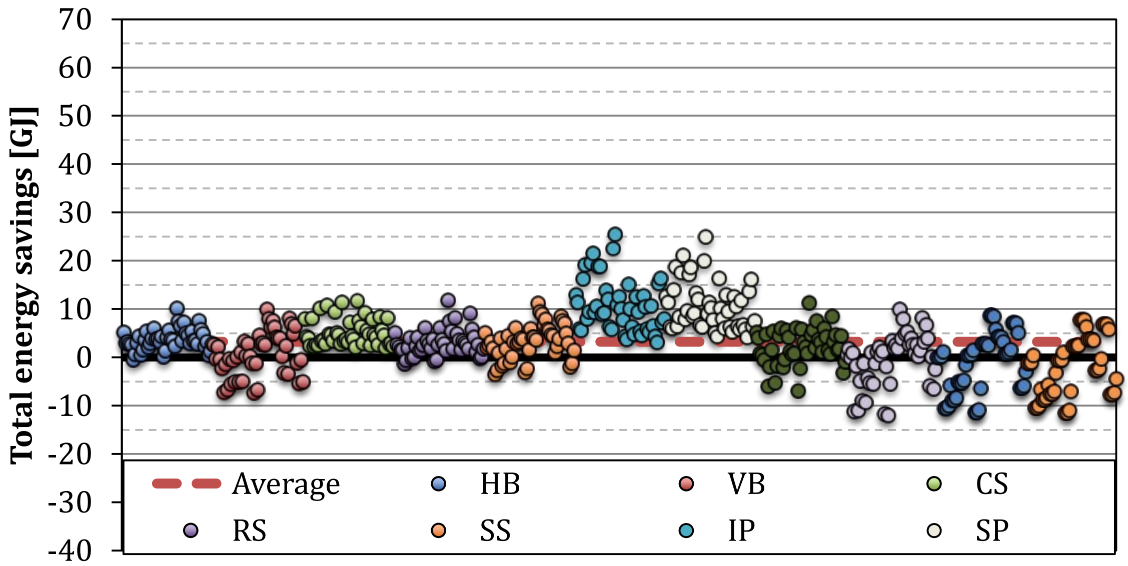


Figure 13. Baseline Window: Double Pane Clear Wood. Average Savings: 3.25 GJ

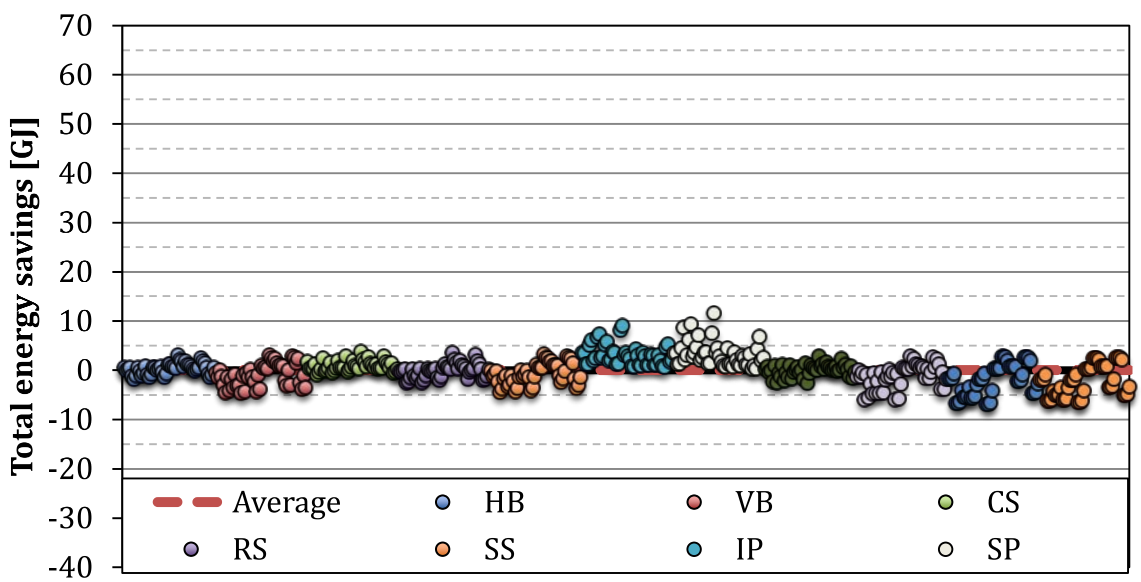


Figure 14. Baseline Window: Double Pane Low-e Vinyl. Average Savings: 0.05 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

6.1.3 Climate Zone Comparison

Figure 15 to Figure 17 show a comparison of home energy use, by climate zone, of all attachments over double pane clear wood window. All cities from each climate zone are represented; North (Boston, Chicago, Minneapolis), Central (Atlanta, Denver, San Francisco, Washington, DC), and South (Fort Worth, New Orleans, Phoenix, San Antonio, Tampa). Comparisons are done with the time weighted use results described in the Methodology section. Energy performance in different climate zones shows some interesting patterns. The North zone shows the largest scatter in the data and the highest potential for energy savings, followed by Central and South, where the distributions are tighter. However, South zone shows largest average savings, followed by North and Central. The difference in overall energy savings is not large and it sometimes skewed by the breakdown of heating and cooling energy, which will be shown later. While in the North zone there are many attachments which might increase energy use, in the South zone virtually all combinations studied had positive savings.

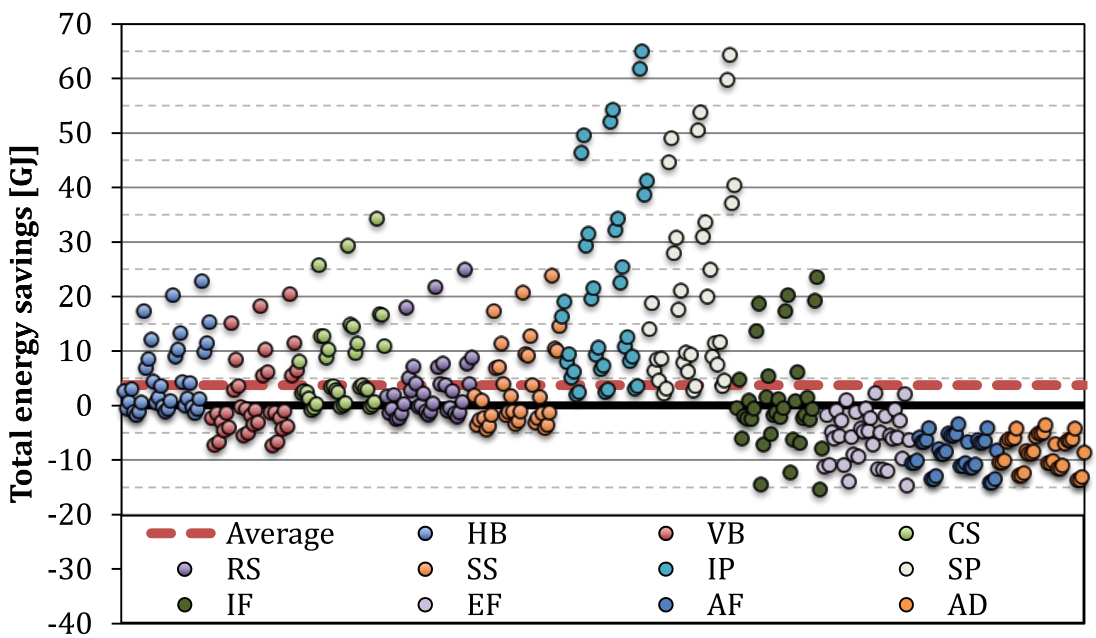


Figure 15. North Climate Zone. Average Savings: 3.72 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

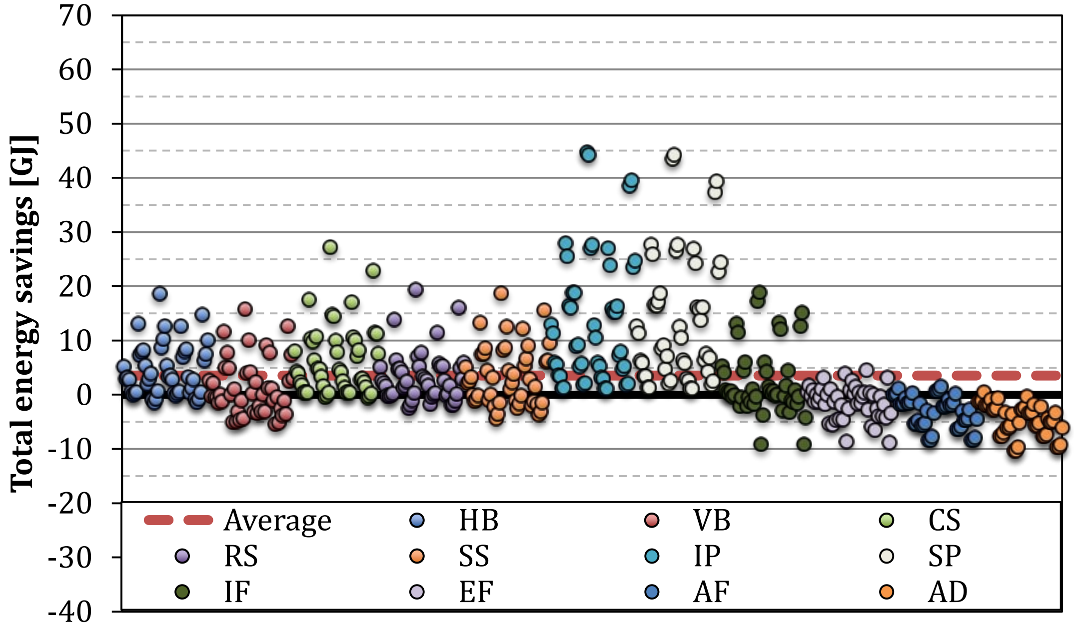


Figure 16. Central Climate Zone. Average Savings: 3.54 GJ

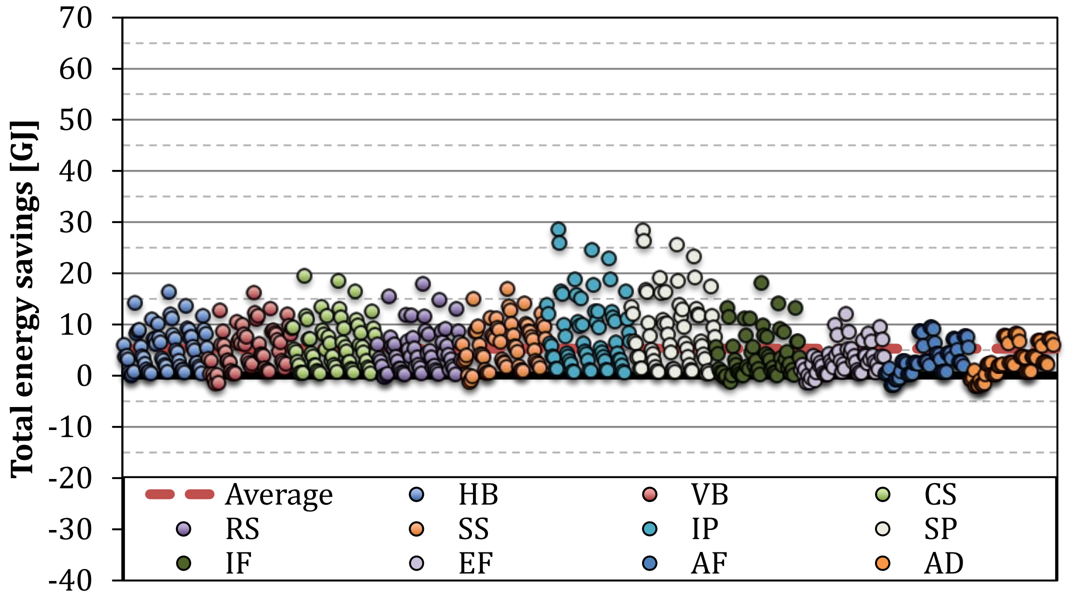


Figure 17. South Climate Zone. Average Savings: 5.25 GJ

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

6.2 Comparison by Shade Quality and Shade Category

Figure 18 to Figure 20 show side-by-side comparison of home energy use of all window attachments over double pane clear wood window. Each graph shows results for one climate zone, North, Central, and South, using the same representative cities for each zone; Minneapolis, Washington, DC, and Phoenix respectively. Comparisons are done with the time weighted use results described in Methodology section.

Window attachments are grouped by window attachment quality, where all window attachments are compared for each of the four qualities. Energy use is represented by horizontal bars consisting of heating (red) and cooling (blue) stacked bars. This allows display of individual contributions of heating and cooling as well as total energy use.

Figure 16 shows energy use in North zone (Minneapolis), where heating energy dominates cooling energy as evidenced by very long red bars and very short blue bars. The unshaded baseline window is shown at the top of the graph for reference. Looking at the distribution of energy use by different qualities it can be observed that the spread between different attachments is larger for quality A and B, which means that for some attachments the input parameters play a larger role than for others. Across all qualities in the North zone, interior window panels, and exterior storm panels consistently show lowest energy use. They perform well in both heating and cooling energy departments so their overall energy use is the lowest. Of all the shades, cellular shades show lowest energy use other than for quality D. Most savings comes from heating savings, although there are also some cooling savings, most pronounced for quality A. As expected, louvered blinds provide some savings in cooling energy for more reflective materials (qualities A and B) with slightly more cooling savings for vertical blinds (block more solar radiation). However, the heating energy penalty for vertical blinds is fairly high, making them worse then the baseline window. The presence of a low-e coating in quality A improves the heating energy slightly and for very dark venetian blinds, however the cooling energy penalty for darker blinds makes them only marginally better than the baseline window. Quality A of Roller shades and solar screens expectedly improves cooling performance and are almost neutral for heating energy, which is due to cancelling effects of low-e coating. The low-e increases insulation and lowers SHGC, decreasing the passive solar heating effect. Awnings, both fixed and operable, unsurprisingly substantially increase the use of heating energy while they substantially decrease cooling energy. However, because the cooling energy is quite small compared to heating energy they impose overall energy penalty across all four qualities. In a case like this a change in operating strategy (e.g., open awnings in winter, close in summer), would clearly improve annual performance.

In the Central climate zone, interior window panels and exterior storm panels again provide the largest overall energy savings across all qualities, however the overall level of savings is lower than in the Northern zone. This is primarily due to lower energy use by the baseline window in the central climate zone. Cellular shades again save energy, both heating and cooling, for quality A, and while they also save for other qualities, the level of energy savings is very small. Venetian blinds are marginally effective on the overall energy level, however they are effective in reducing cooling energy for qualities A and B. Vertical blinds are also effective in reducing cooling energy, but they again impose a penalty on heating energy, which is still substantial in the Central climate zone. Solar screens and roller shades are effective in saving cooling energy, but they impose a penalty on heating energy, making them largely ineffective in saving overall energy. Awnings are effective in saving cooling energy, but they impose a large heating penalty, resulting in higher overall energy use than the baseline window.

In the South zone, all window attachments save energy for all qualities. As expected, larger savings are observed for quality A. Interior window panels and exterior storm panels are most effective for quality A, but for other qualities, awnings and solar screens are more effective. Cellular shades are also more effective for quality A, while for other qualities they are only marginally effective.

Figure 21 to Figure 23 show the same data set as Figure 18 to Figure 20, but grouped by window attachment category with qualities A to D side by side. This set of graphs illustrates how different qualities affect each window attachment. In the north climate zone, only for cellular shades, roller screens and solar screens does quality A gives the lowest energy use. For interior and exterior surface applied films and for interior window panel and exterior storm panel, quality B gives the lowest energy use. For awnings, quality D gives the best performance. Similar observations can be made for the central zone in terms of relative performance. In the south climate zone, most window attachments have their energy performance ranked lowest to highest from quality A to D, with the exception of surface applied films and vertical louvered blinds, although only qualities B and C are reversed for films and quality C and D for vertical louvered blinds. See Appendix A for a similar set of graphs with single pane aluminum and double pane low-e vinyl windows.

Note that the “bundled” set of properties that comprise each ‘quality’ can be optimized for a specific climate and energy control function so it may be possible to achieve savings beyond the best results portrayed here for specific climates and operating assumptions.

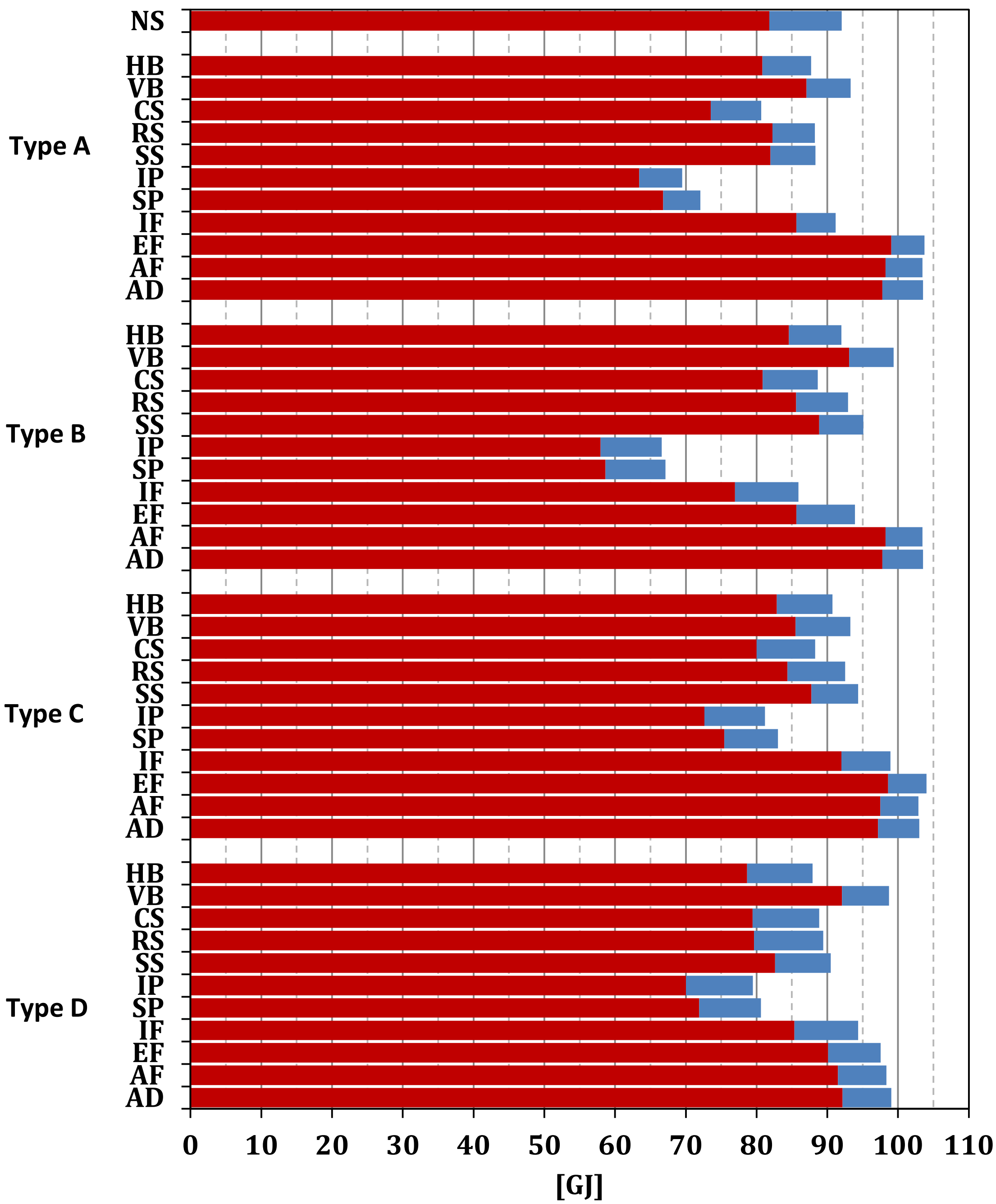
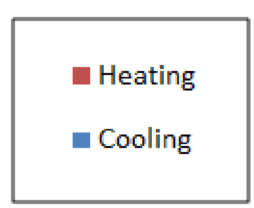


Figure 18 North Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



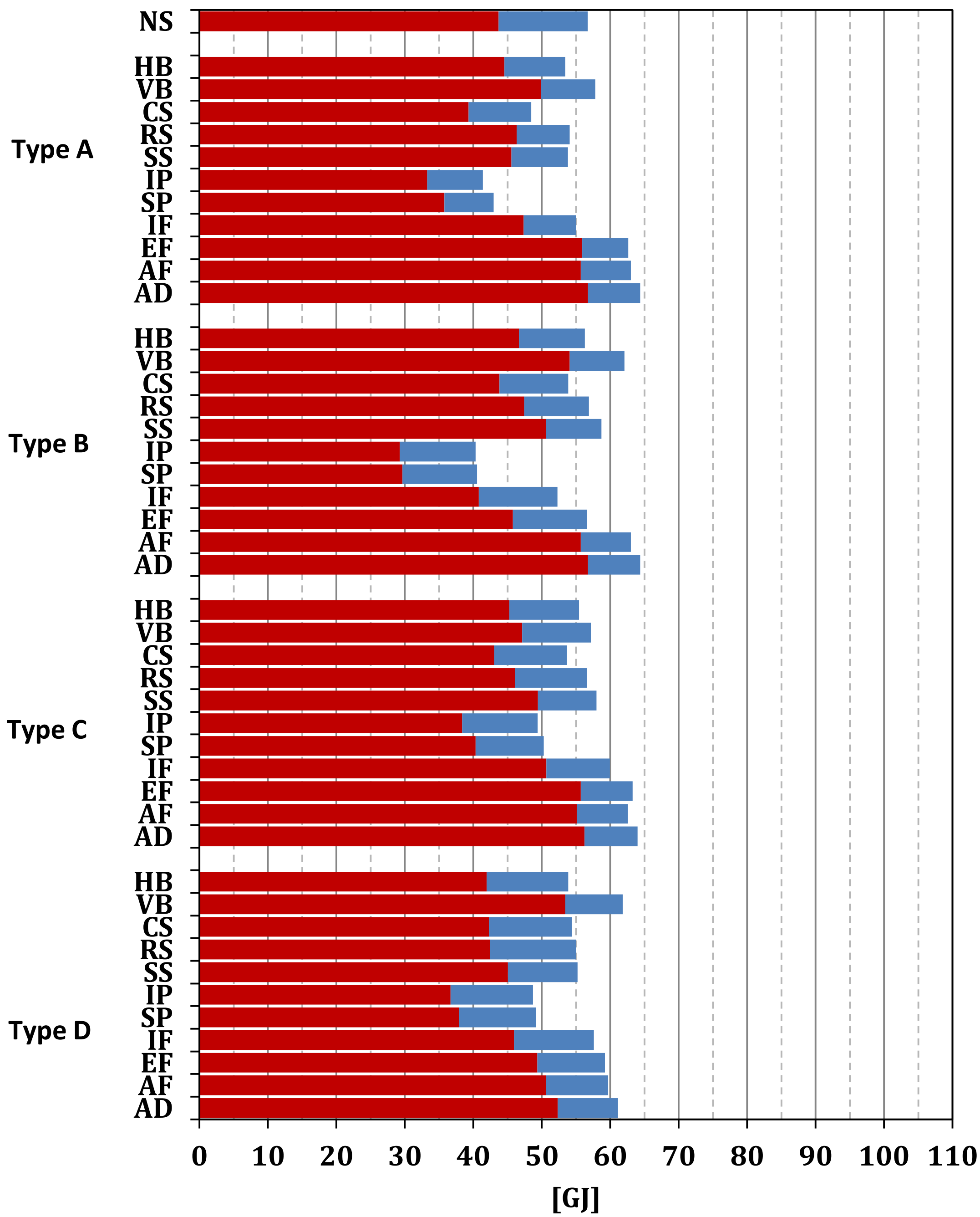


Figure 19 Central Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating

Cooling

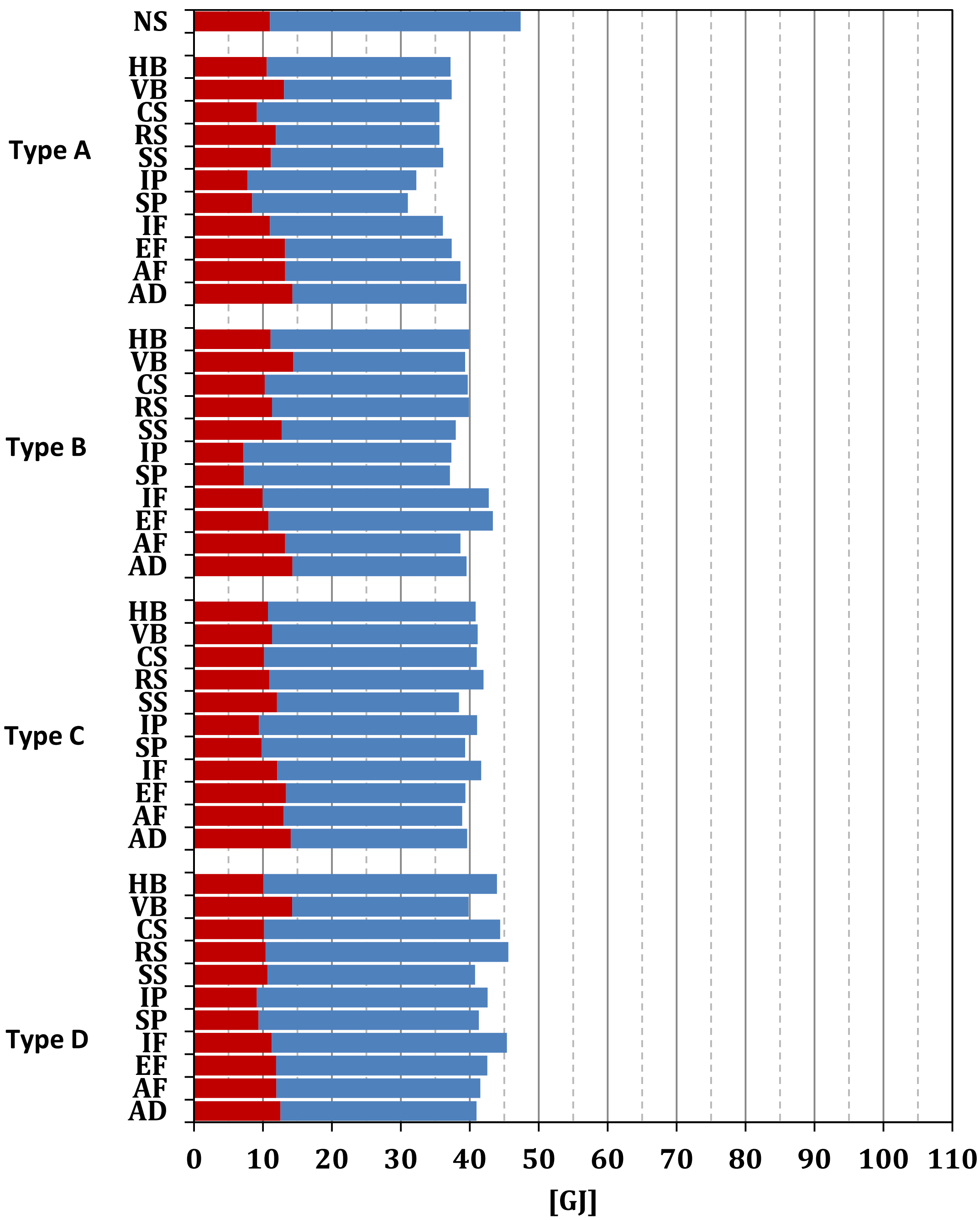


Figure 20. South Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating

Cooling

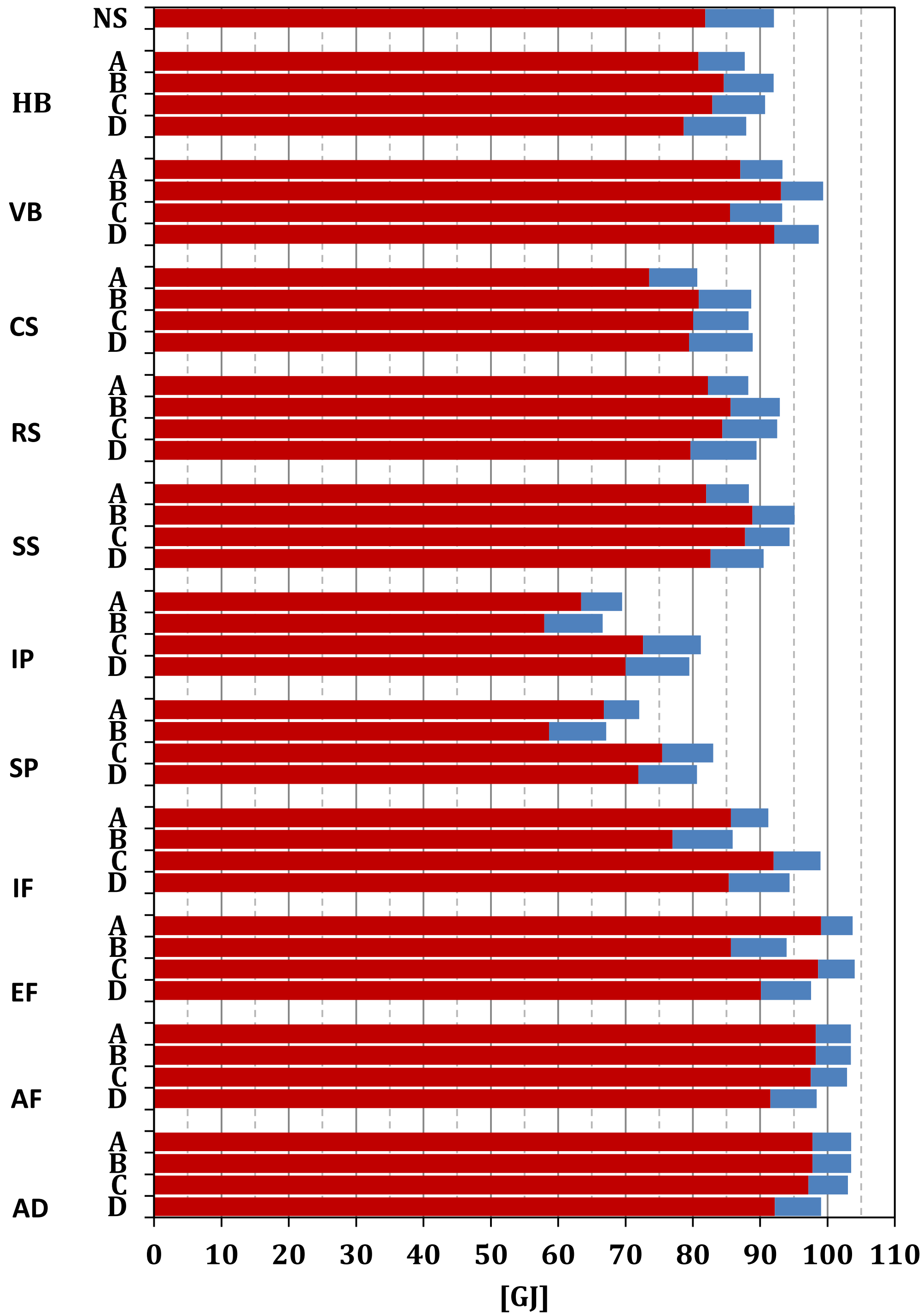


Figure 21. North Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating

Cooling

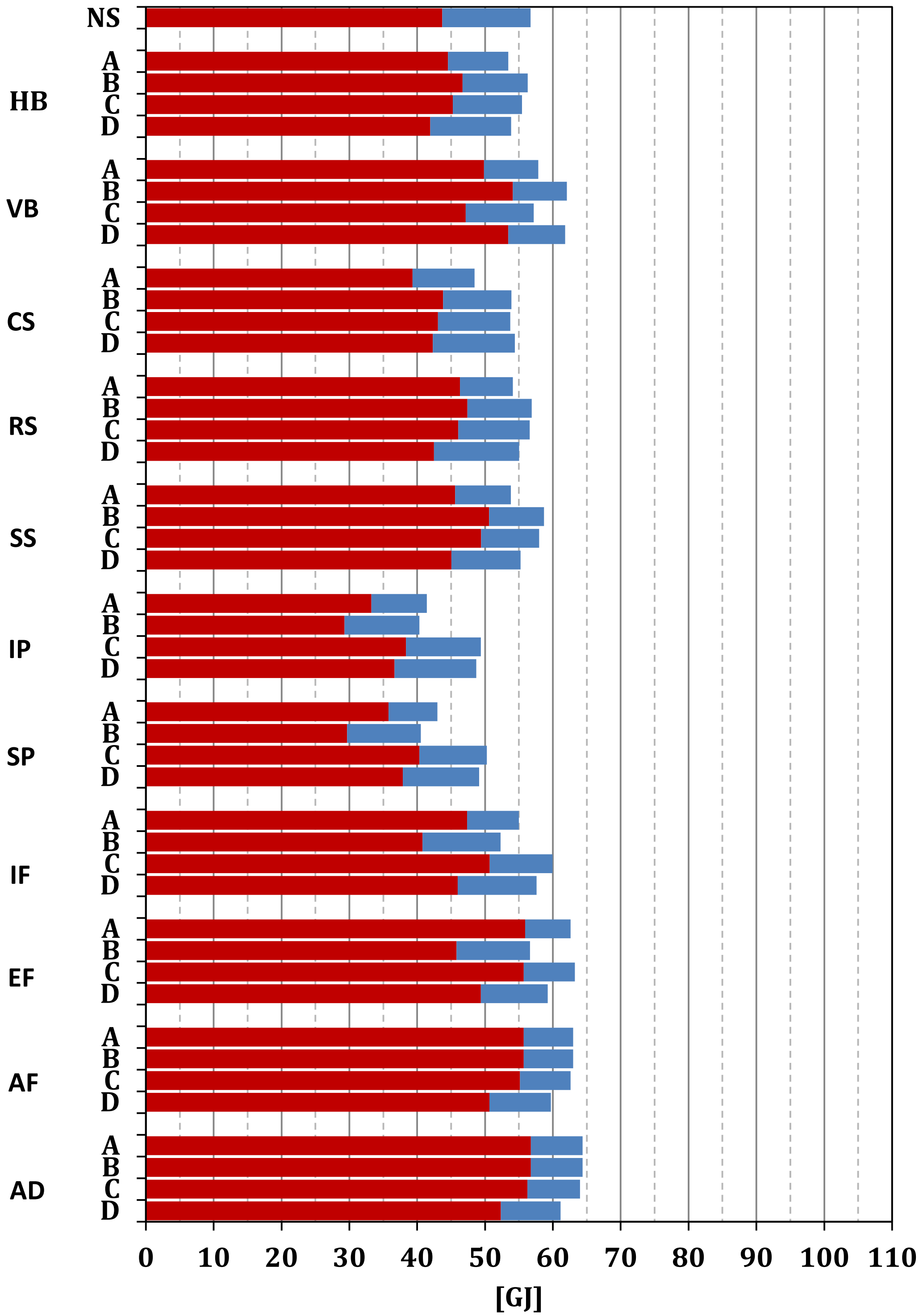


Figure 22. Central Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating
Cooling

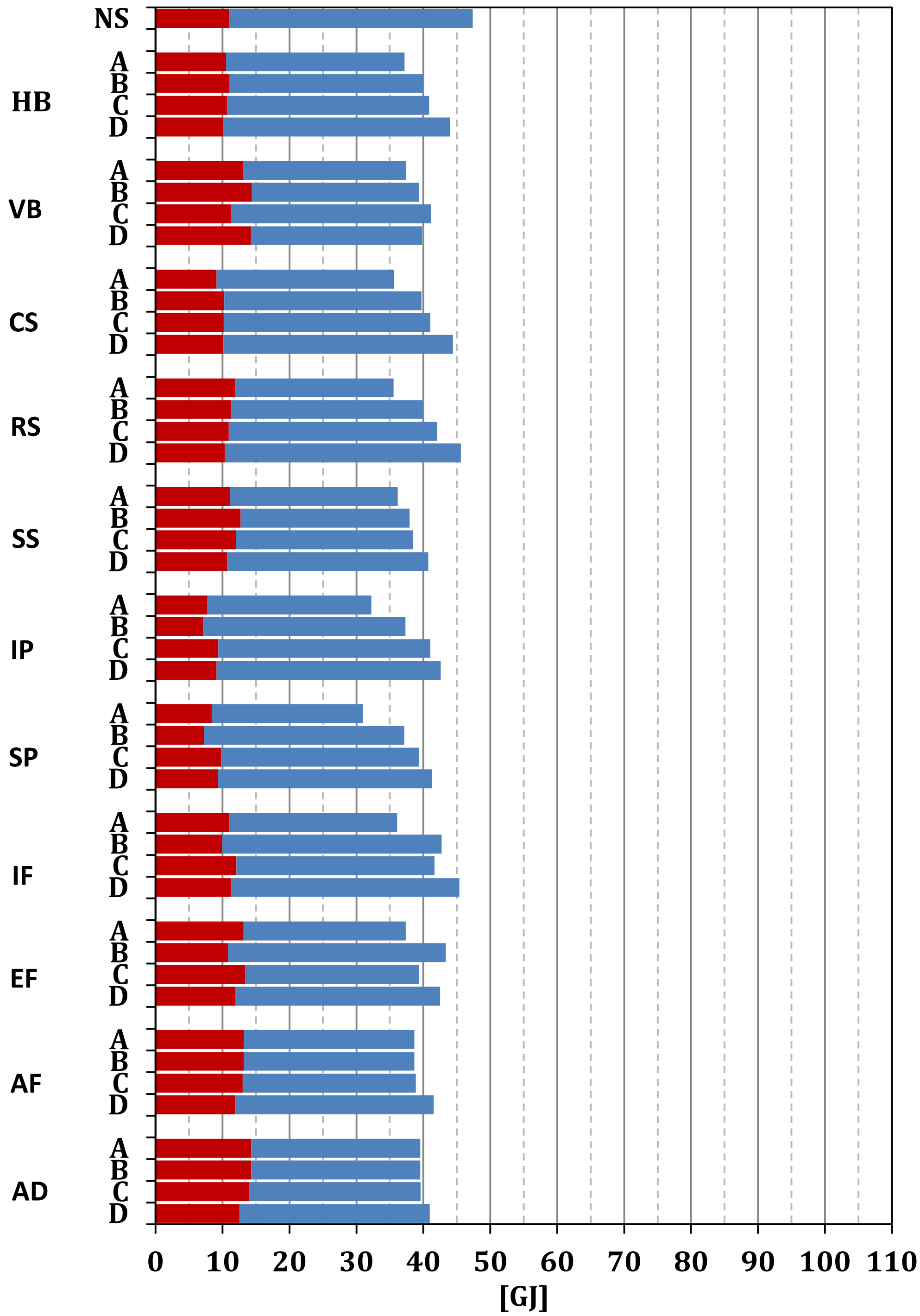


Figure 23. South Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating
Cooling

6.3 Energy Savings Tables

The following tables show energy savings compared to the baseline case without any attachment installed. The values displayed are for the following house type: slab, gas heating, and electric A/C. See Appendix A for results for all 12 cities.

Table 21. Single Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House with Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Attachment Type	Minn				Washington.DC				Phoenix			
	A	B	C	D	A	B	C	D	A	B	C	D
Horizontal Blind	22.8	9.8	11.5	15.4	16.4	12.0	11.2	8.0	14.8	6.3	7.5	10.1
Vertical Blind	20.5	5.5	11.4	6.4	16.3	12.3	11.1	11.8	12.7	2.6	7.4	3.0
Cellular Shade	34.3	16.9	16.7	10.9	18.5	13.1	11.5	6.5	22.9	11.4	11.3	7.6
Roller Shade	25.0	7.7	4.0	8.9	18.0	11.7	8.8	4.4	16.1	4.9	2.9	5.9
Solar Screen	23.8	10.4	10.1	14.6	17.0	13.6	12.8	10.1	15.6	6.2	6.3	9.6
Interior Window Panel	61.7	65.0	38.6	41.3	24.6	17.8	12.6	10.5	38.6	39.6	23.6	24.8
Storm Window	59.8	64.4	37.1	40.5	25.7	18.5	13.9	11.6	37.4	39.4	22.8	24.4
Interior Applied Film	19.3	23.6	-15.4	-7.9	18.2	9.9	7.9	4.2	12.7	15.1	-9.1	-4.2
Exterior Applied Film	-9.7	2.2	-14.6	-6.3	12.2	5.1	8.5	4.5	-4.2	3.2	-8.8	-3.3
Fixed Awning	-14.1	-14.1	-13.4	-8.2	9.5	9.5	9.2	6.4	-8.3	-8.3	-7.9	-4.5
Droparm Awning	-13.6	-13.6	-13.1	-8.5	8.2	8.2	8.1	6.7	-9.6	-9.6	-9.2	-6.0

Table 22. Double Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House with Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Attachment Type	Minn				Washington.DC				Phoenix			
	A	B	C	D	A	B	C	D	A	B	C	D
Horizontal Blind	4.3	0.1	1.3	4.1	10.2	7.4	6.5	3.4	3.3	0.4	1.3	2.9
Vertical Blind	-1.2	-7.3	-1.2	-6.7	10.0	8.0	6.2	7.5	-1.1	-5.4	-0.4	-5.1
Cellular Shade	11.4	3.4	3.8	3.2	11.8	7.6	6.3	2.9	8.3	2.9	3.0	2.3
Roller Shade	3.8	-0.9	-0.5	2.6	11.8	7.5	5.4	1.8	2.6	-0.2	0.1	1.7
Solar Screen	3.7	-3.0	-2.3	1.6	11.2	9.4	8.9	6.6	2.9	-2.0	-1.3	1.5
Interior Window Panel	22.6	25.5	10.9	12.6	15.1	10.0	6.3	4.8	15.3	16.4	7.3	8.0
Storm Window	20.0	24.9	9.0	11.4	16.4	10.2	8.1	6.0	13.8	16.2	6.4	7.6
Interior Applied Film	0.9	6.1	-6.9	-2.3	11.3	4.6	5.7	2.0	1.7	4.4	-3.2	-0.9
Exterior Applied Film	-11.7	-1.9	-12.0	-5.5	10.0	4.0	8.0	4.8	-5.9	0.1	-6.5	-2.5
Fixed Awning	-11.4	-11.4	-10.8	-6.3	8.7	8.7	8.5	5.8	-6.3	-6.3	-5.9	-3.0
Droparm Awning	-11.5	-11.5	-11.0	-7.0	7.8	7.8	7.8	6.4	-7.6	-7.6	-7.3	-4.4
No Shade	92.1	92.1	92.1	92.1	47.4	47.4	47.4	47.4	56.7	56.7	56.7	56.7

Table 23. Double Low-E Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House with Slab, Gas Heating, And Electric A/C, for Four Attachment Qualities (A, B, C, D).

Attachment Type	Minn				Washington.DC				Phoenix			
	A	B	C	D	A	B	C	D	A	B	C	D
Horizontal Blind	-0.3	-1.3	-0.6	1.2	3.0	2.1	1.8	0.8	-0.8	-1.3	-0.8	0.5
Vertical Blind	-2.3	-4.3	-1.0	-3.8	3.1	2.5	1.8	2.3	-2.5	-3.8	-1.1	-3.5
Cellular Shade	2.9	-0.2	0.1	0.7	3.8	2.1	1.7	0.8	1.4	-0.5	-0.2	0.2
Roller Shade	-1.5	-2.0	-1.2	0.6	3.6	2.1	1.6	0.4	-1.9	-1.8	-1.2	0.1
Solar Screen	-1.4	-4.1	-3.5	-1.3	3.3	2.6	2.5	1.7	-1.7	-3.6	-3.1	-1.4
Interior Window Panel	8.1	9.0	3.1	3.7	4.3	3.0	1.2	1.0	4.8	5.3	1.8	2.1
Storm Window	7.5	11.7	3.6	4.5	4.6	1.2	1.3	0.7	4.4	6.9	1.9	2.5
Interior Applied Film	-1.7	1.5	-2.6	-0.6	2.9	0.9	1.3	0.3	-1.3	0.8	-1.6	-0.3
Exterior Applied Film	-6.0	-0.7	-5.8	-2.8	2.9	0.8	2.4	1.3	-3.8	-0.3	-3.8	-1.8
Fixed Awning	-6.8	-6.8	-6.5	-4.1	2.8	2.8	2.7	2.0	-4.6	-4.6	-4.4	-2.7
Droparm Awning	-6.4	-6.4	-6.2	-4.2	2.5	2.5	2.5	2.1	-5.0	-5.0	-4.8	-3.3

6.4 Louvered Blinds Deployment Comparison

Louvered blinds have two modes of operation, adjustment of the slat angle and retraction. Because of this they have multiple definitions of open, half-open, and closed. In the following set of graphs, eight deployment states are compared for these shade types. These eight states are later grouped into the three main states that are used in the analysis of the rest of shades. The graphs on the following pages have codes representing the deployment state of the attachments, as shown below.

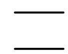
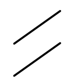
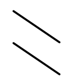
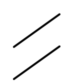
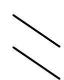
Code	Deployment state	Slat angle
NS	No Shade (Base case)	n/a
HR 0	Half Retracted, 0° slat angle (open)	
HR 45	Half Retracted, 45° slat angle	
HR -45	Half Retracted, -45° slat angle	
HR 90	Half Retracted, 90° slat angle (closed)	
FD 0	Fully Deployed, 0° slat angle (open)	
FD 45	Fully Deployed, 45° slat angle	
FD -45	Fully Depoloyed, -45° slat angle	
FD 90	Fully Depoloyed, 90° slat angle (closed)	

Figure 24 to Figure 26 show energy use from horizontal louvered blinds (venetian blinds) for the eight deployment positions along with baseline window case for each of the four shade qualities and for three climate zones. For the North climate zone, fully deployed blinds at 0 degrees and -45 degrees have the best overall performance due to lower heating energy. At the same time, the fully deployed shade with closed slats have the best cooling performance. Quality A blinds have lowest energy use. This same conclusion can be drawn for the central climate zone.

For the south climate zone, fully deployed shades with 45 degree tilt and closed slats have the best performance because of the dominance of cooling energy.

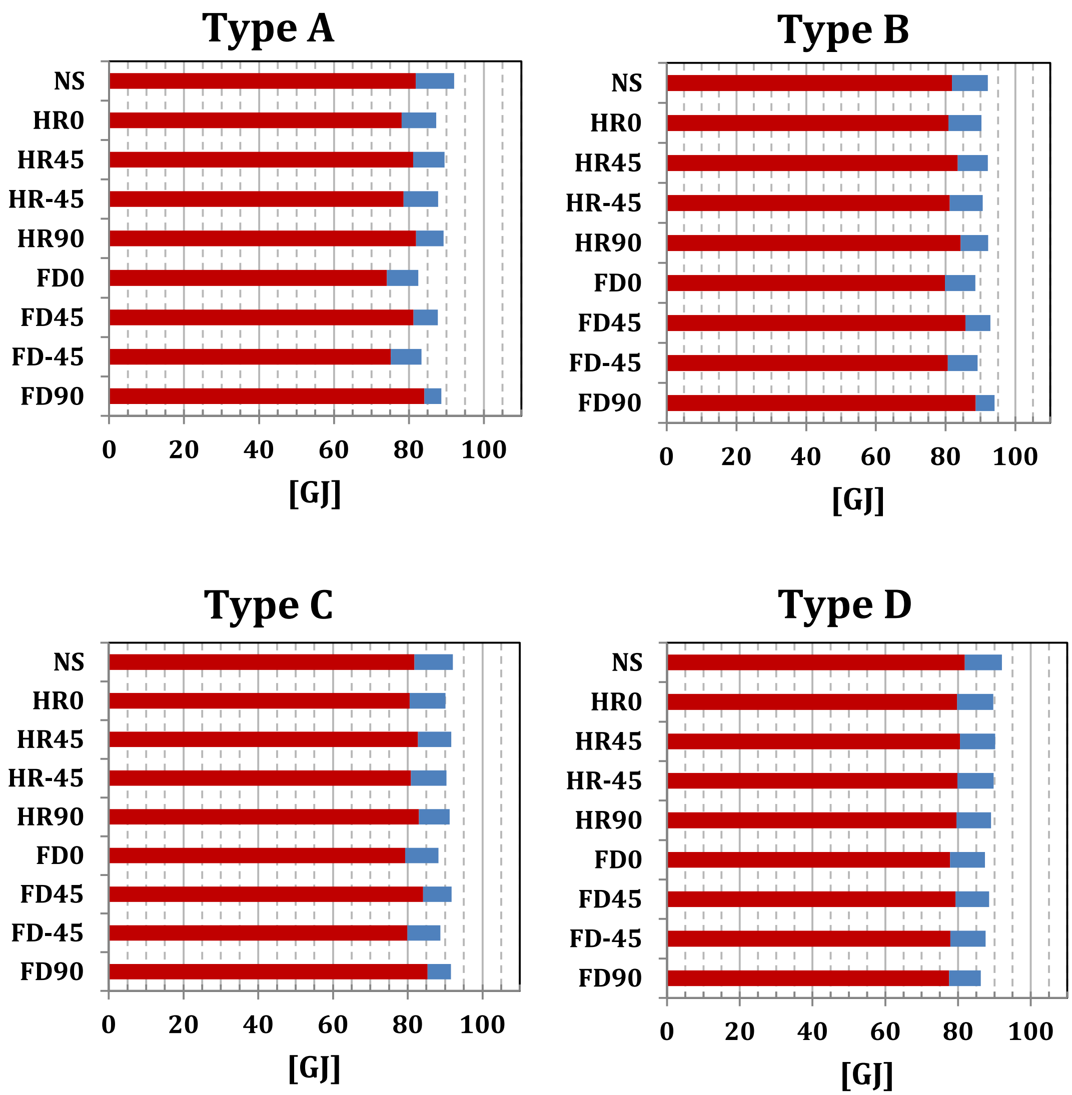
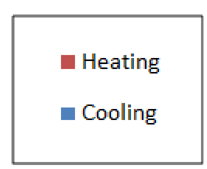


Figure 24. Deployment Comparison for Horizontal Louvered Blinds Grouped by Quality in North Climate Zone

NS	No Shade		
HR 0	Half Retracted 0° slat angle (open)	HR 0	Fully Deployed, 0° slat angle (open)
HR 45	Half Retracted, 45° slat angle	HR 45	Fully Deployed, 45° slat angle
HR-45	Half Retracted, -45° slat angle	HR-45	Fully Deployed, -45° slat angle
HR 90	Half Retracted, 90° slat angle (closed)	HR 90	Fully Deployed, 90° slat angle (closed)



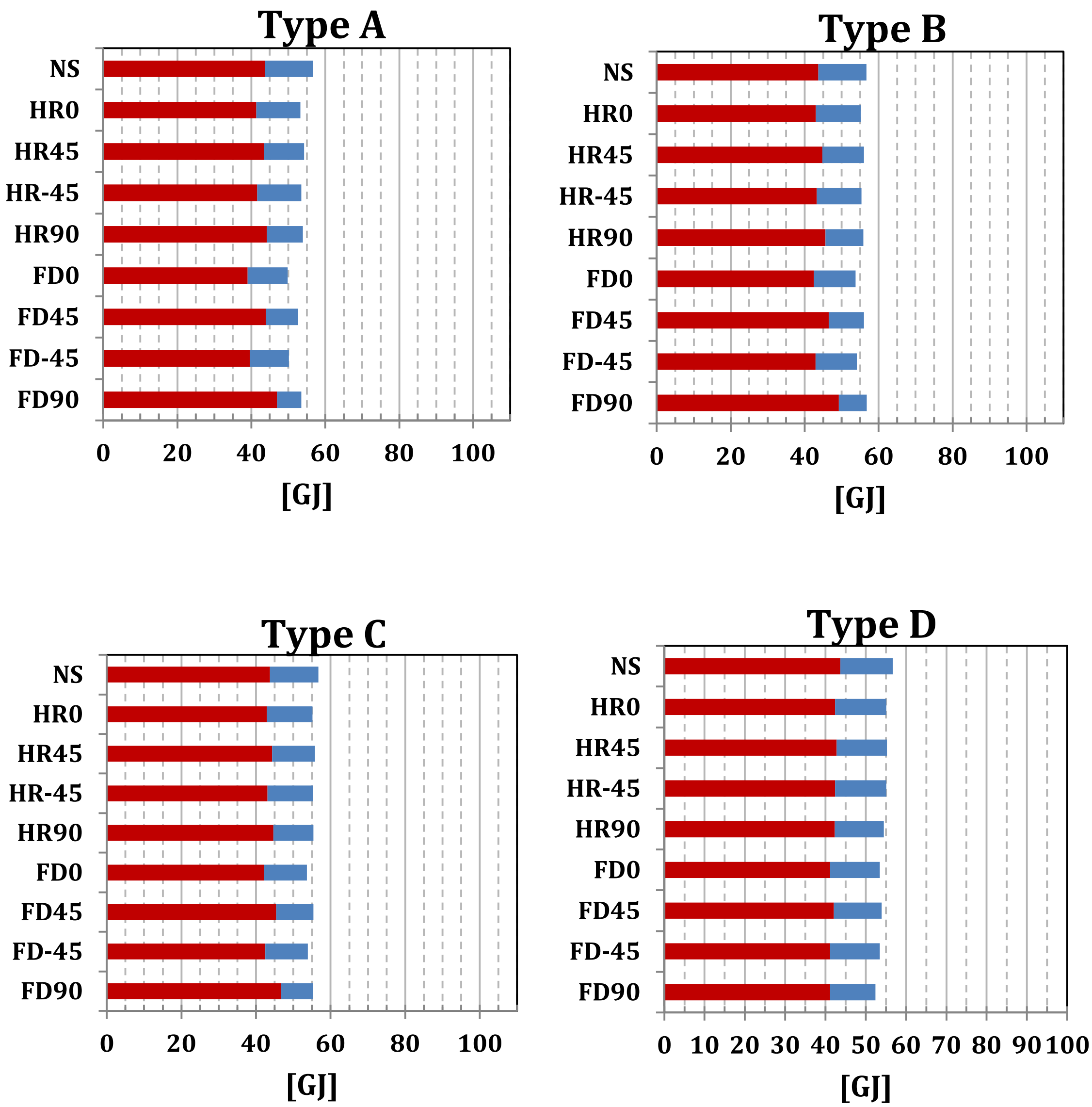


Figure 25. Deployment Comparison for Horizontal Louvered Blinds Grouped by Quality in Central Climate Zone

NS	No Shade		
HR 0	Half Retracted 0° slat angle (open)	HR 0	Fully Deployed, 0° slat angle (open)
HR 45	Half Retracted, 45° slat angle	HR 45	Fully Deployed, 45° slat angle
HR-45	Half Retracted, -45° slat angle	HR-45	Fully Deployed, -45° slat angle
HR 90	Half Retracted, 90° slat angle (closed)	HR 90	Fully Deployed, 90° slat angle (closed)

Heating
Cooling

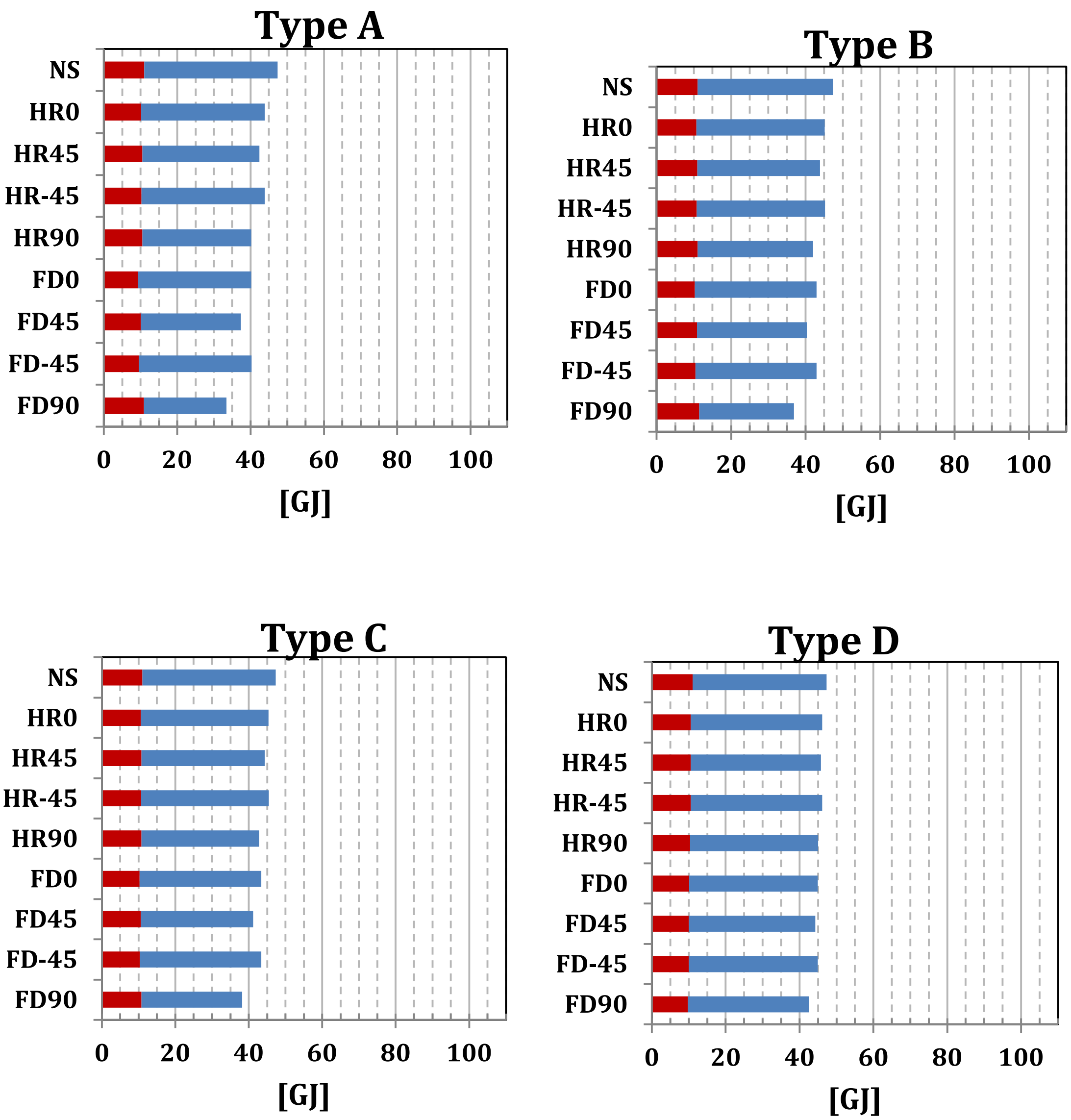
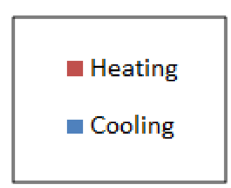


Figure 26. Deployment Comparison for Horizontal Louvered Blinds Grouped by Quality in South Climate Zone.

NS	No Shade		
HR 0	Half Retracted 0º slat angle (open)	HR 0	Fully Deployed, 0º slat angle (open)
HR 45	Half Retracted, 45º slat angle	HR 45	Fully Deployed, 45º slat angle
HR-45	Half Retracted, -45º slat angle	HR-45	Fully Deployed, -45º slat angle
HR 90	Half Retracted, 90º slat angle (closed)	HR 90	Fully Deployed, 90º slat angle (closed)



Similar conclusions can be drawn for vertical louvered blinds, where fully deployed shades show better performance across climate zones and shade qualities.

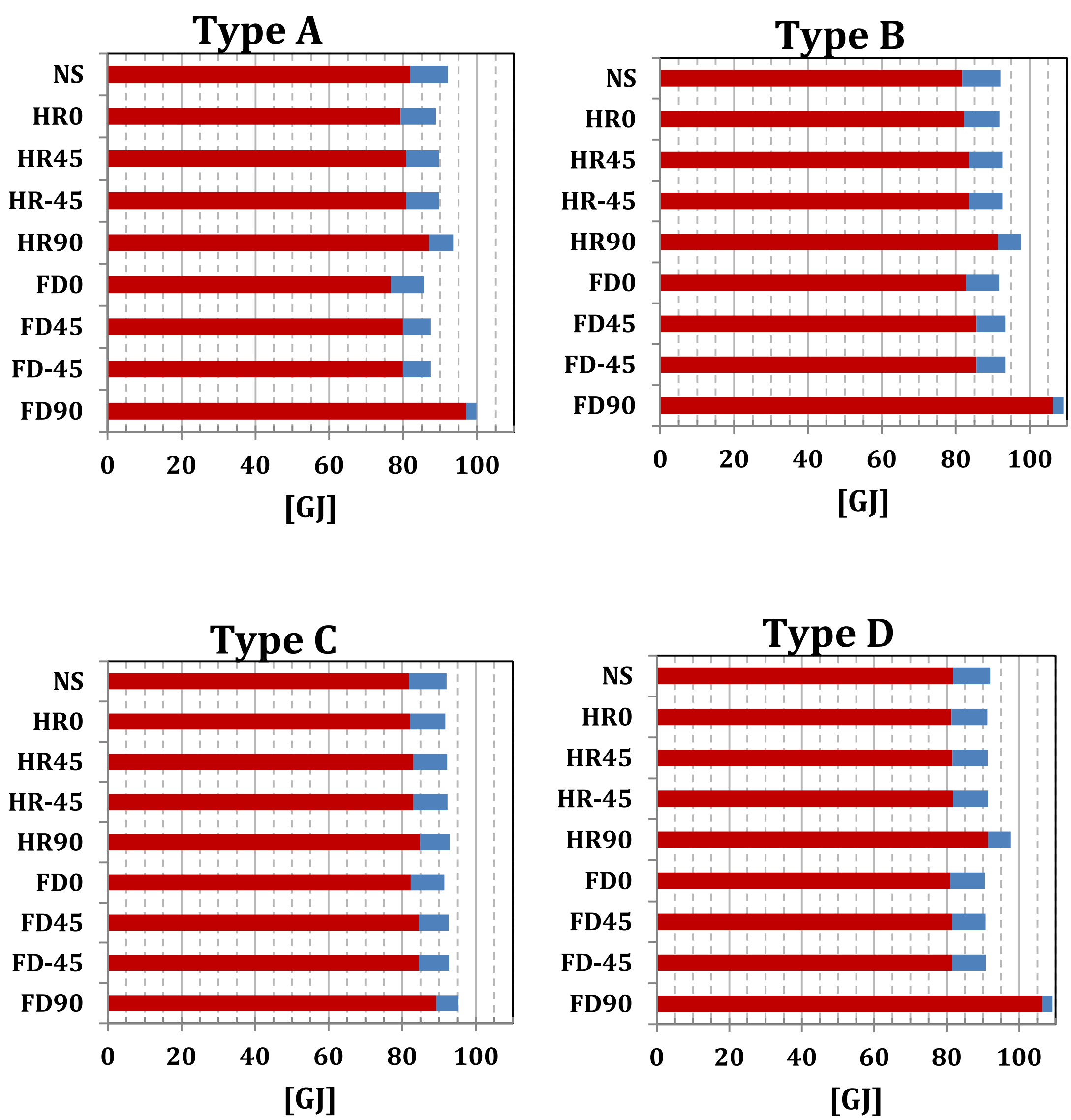
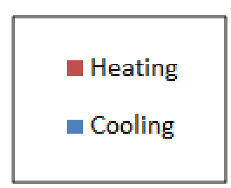


Figure 27. Deployment Comparison for Vertical Louvered Blinds Grouped by Quality in North Climate Zone.

NS	No Shade		
HR 0	Half Retracted 0° slat angle (open)	HR 0	Fully Deployed, 0° slat angle (open)
HR 45	Half Retracted, 45° slat angle	HR 45	Fully Deployed, 45° slat angle
HR-45	Half Retracted, -45° slat angle	HR-45	Fully Deployed, -45° slat angle
HR 90	Half Retracted, 90° slat angle (closed)	HR 90	Fully Deployed, 90° slat angle (closed)



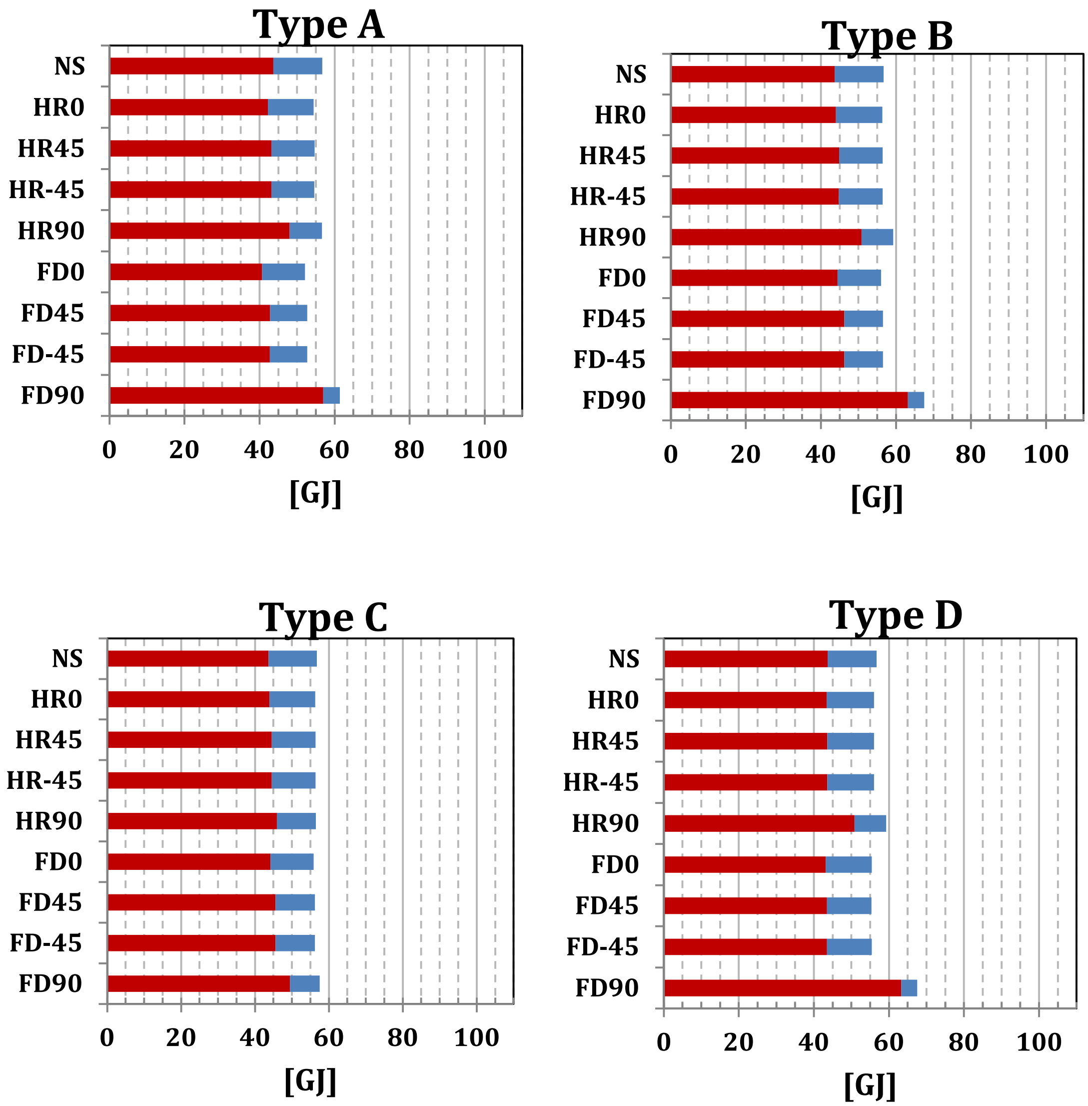
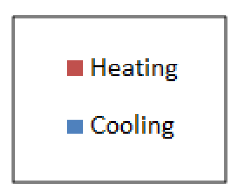


Figure 28. Deployment Comparison for Vertical Louvered Blinds Grouped by Quality in Central Climate Zone.

NS	No Shade		
HR 0	Half Retracted 0° slat angle (open)	HR 0	Fully Deployed, 0° slat angle (open)
HR 45	Half Retracted, 45° slat angle	HR 45	Fully Deployed, 45° slat angle
HR-45	Half Retracted, -45° slat angle	HR-45	Fully Deployed, -45° slat angle
HR 90	Half Retracted, 90° slat angle (closed)	HR 90	Fully Deployed, 90° slat angle (closed)



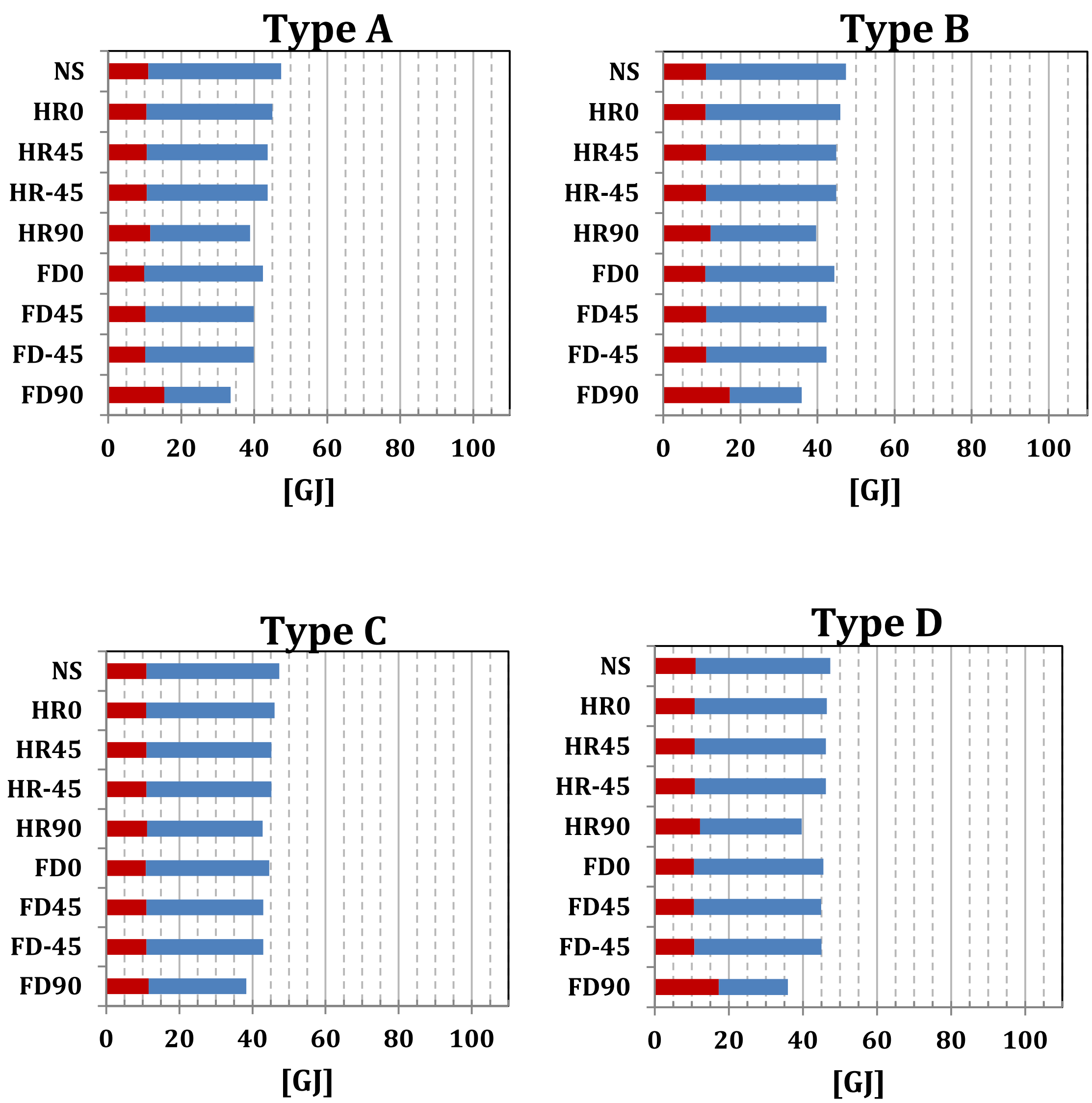


Figure 29. Deployment Comparison for Vertical Louvered Blinds Grouped by Quality in South Climate Zone.

NS	No Shade		
HR 0	Half Retracted 0° slat angle (open)	HR 0	Fully Deployed, 0° slat angle (open)
HR 45	Half Retracted, 45° slat angle	HR 45	Fully Deployed, 45° slat angle
HR-45	Half Retracted, -45° slat angle	HR-45	Fully Deployed, -45° slat angle
HR 90	Half Retracted, 90° slat angle (closed)	HR 90	Fully Deployed, 90° slat angle (closed)

Heating
Cooling

6.5 Operable Shades Deployment Comparison

The operational strategy of the shading system can have a major impact on overall energy use. In this set of graphs all operable shades are compared at their open (O), half-open (H), and closed (C) deployment states. Louvered blinds are here combined into the same three deployment states so that they can be compared with other shades. A description of how the expanded set of louvered blind deployment states are combined is given in the Parametrics and Methodology sections.

Figure 30 to Figure 32 show side-by-side comparisons of home energy use of different operable shade deployment options compared to double clear glazing for one foundation type (unheated basement), for one attachment quality (B), and one HVAC system type (gas heating / electric A/C). There is one graph for the representative city in each of the three climate zones.

In northern climates, for most of the shades, except for cellular shades, the open case has lowest overall energy use. This is primarily due to substantially lower heating due to a higher SHGC in the open deployment mode. Cooling energy is lower for the closed and half-open case, but because of the heating dominated climate, savings in cooling energy for those two deployment cases are not enough to achieve overall energy savings. For cellular shades, the trend is opposite because of the higher insulating value of cellular shades, compared to other analyzed shades. For the central climatic zone, trends are the same, although absolute energy use is different. This is due to heating energy still dominating cooling energy, although the ratio is lower than in the north climate zone.

In the south climate zone, this trend is completely reversed. Here, cooling dominates and energy use is lowest for the closed state, followed by half-open and open states. Cellular shades follow this same trend with the closed state being the best.

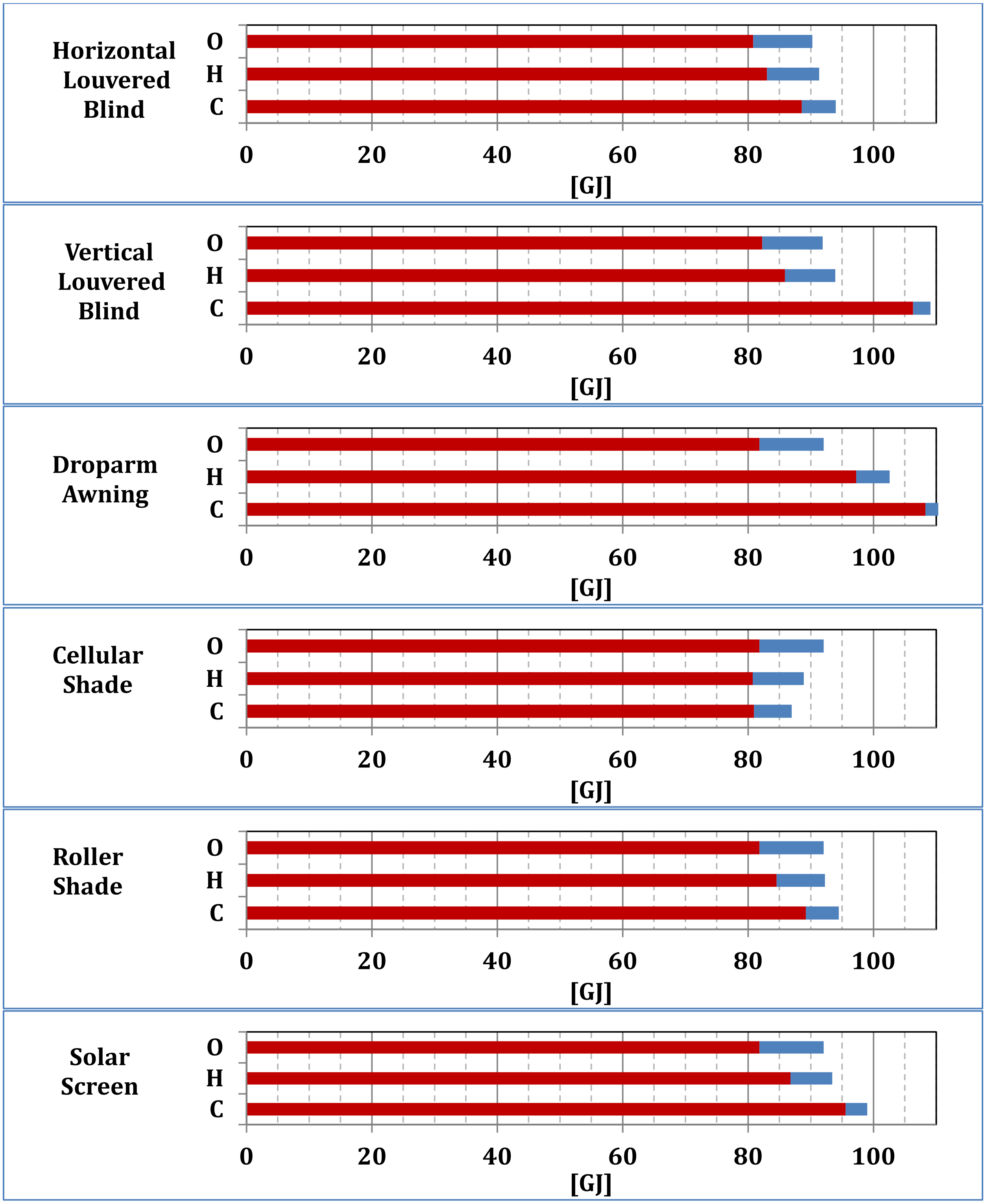
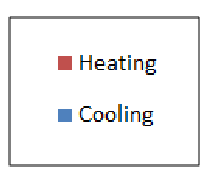


Figure 30. Operable Shade Deployment Comparison for the Quality B Case Over Double Clear Window in North Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade



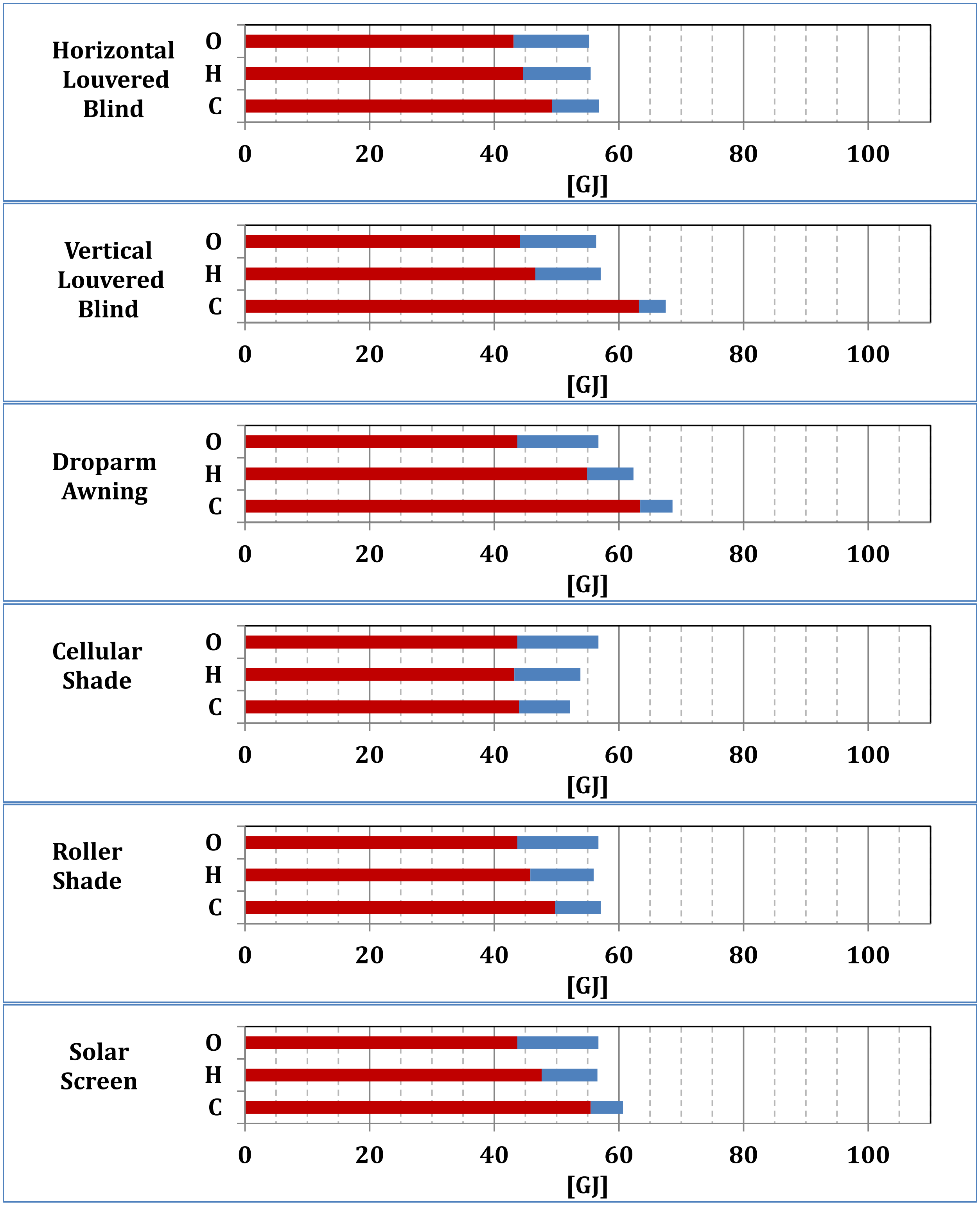


Figure 31. Operable Shade Deployment Comparison for the Quality B Case Over Double Clear Window in Central Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

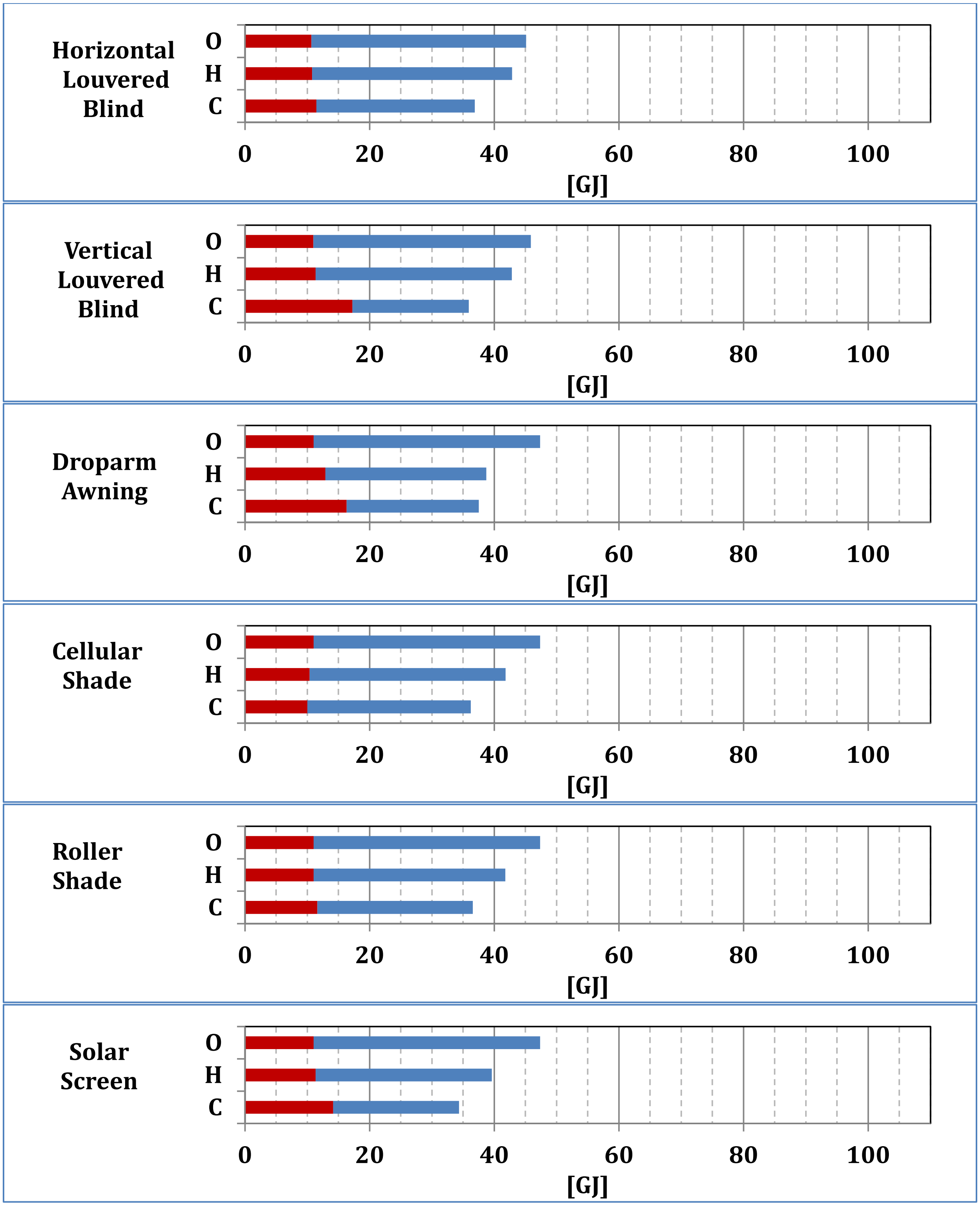


Figure 32. Operable Shade Deployment Comparison for the Quality B Case Over Double Clear Window in South Climate Zone.

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

7. CONCLUSIONS AND RECOMMENDATIONS

An extensive study of window attachment energy performance has been carried out. This is the first time that such a large selection of window attachments, including a large selection of window shading products, have been systematically modeled for a range of climates, window attachment properties, typical residential buildings, and baseline windows. This study was preceded by an occupant behavioral study (DRI 2013), which provided data used to develop typical operational schedules for use in the three distinct climate zones. A series of newly developed analytical models for WINDOW and EnergyPlus made it possible to simulate this range of products and operation far more accurately than in the past.

The study provides a comprehensive look at a wide range of interior and exterior systems. Even though the selection does not represent all window attachment categories sold on the market today, the extensive representation of outdoor and indoor-mounted attachments (roughly half each) and range of attachment thermal and optical characteristics ("qualities") provides confidence that the performance of a very wide range of all window attachments is covered.

The deployment states of operable window attachments (all shades in this study) have a large and differing effect on energy performance. This study has shown that when operable shades are used in a "typical" manner, (with an operational schedule developed from the behavioral study conducted earlier (DRI 2013)), some shades provide energy savings in specific climates, but not all operable shades save energy in all climates. The study includes a comparison of energy use when shades are held in a fixed position (half-open and closed). While this is not how operable shades are normally used in reality, it is useful to observe how they would impact energy use if they were fixed in a constant position. For some shades and in some climates the closed position saves energy, but for others it will increase energy use. This fundamental reversal of savings trends suggests the importance of better understanding how operable shading is used, and it suggests the value of efforts to improve manual operation or develop more cost effective approaches to automating operation.

The energy study shows mixed savings results in northern and central climates, due to variable insulating properties and the role of some systems in admitting or blocking solar gain. In cooling dominated climates, where solar control is very important, all window attachments save energy. This is due to their universal lowering of the Solar Heat Gain Coefficient (SHGC), which reduces solar gains in the building and thus reduces cooling energy use. Exterior (outdoor-mounted) attachments are generally more effective in saving cooling energy, but that does not always translate to the highest overall energy savings due to a potential increase (penalty) in heating energy.

In north and largely central climate zones, heating energy use is higher than cooling energy, so a combination of insulating properties and balanced solar control saves the most energy. Insulating interior window panels, exterior storm panels and cellular shades are most effective in these localities. Other insulating window attachments, such as window quilts and insulating roller shutters are expected to provide similar level of energy savings, although they were not included in this study. Several window attachments provide little to no energy benefit in heating dominated climates and some have higher energy use than unshaded windows based on the assumptions in the study. Example of such window attachments are vertical louvered blinds, awnings, and exterior films.

Many attachments have a number of critical design parameters that vary widely between products even of a similar type, in part because window coverings are providing visual comfort, privacy, fashion and other functions beside energy control. For example for a shade material the value of openness, reflectance, emittance, thickness, etc. could all vary over a wide range. Modeling the impact of all combinations of these properties is technically possible but not pragmatically achievable. For each attachment category, a range of sets of properties was defined that covered the range of available product properties and these were bundled into four performance “qualities”. The results of the study confirm the choice of a series of generic “qualities” A, B, C, and D rather than trying to define a consistent, robust set of properties that could be labeled “good-better-best” under all conditions. The data shows that in the north and central climate zones quality A is not necessarily the best nor is quality D the worst. In some instances quality A is worse than an unshaded window. For the south climate zone, all attachment qualities resulted in energy savings, albeit quality A was, for the most part, the best quality of the set.

This study largely bounds the performance limits we might expect from attachments and their impact on window energy use, although it doesn't include all types and all possible combinations. Further research will consider a wider range of actual products and a wider realistic range of their performance and compare their effects on residential building energy use. For this extension of the study, a survey of available products and measurements of material properties of representative products will be necessary.

Future extension of this work should also consider use of source energy for comparing energy savings and/or also introduce cost of energy as a basis for comparison.

Overall performance is highly dependent on “use” of the attachments – more intelligent and responsive use always improves energy performance. This study can be expanded to look at the energy savings of sensor-controlled motorized shading systems (e.g. automated shades). It is expected that such operation would maximize energy savings, since it would keep shades closed, partially open, or open depending on the environmental conditions and state of HVAC. These products are available in niche applications and better understanding of their performance benefits will spur market applications.

DOE is exploring the opportunity to further promote more extensive use of improved window attachments by working with industry to create a new entity to rate and certify the properties and performance of window attachments. This study provides a foundation for that effort that will no doubt need to evolve to meet the emerging needs of that activity.

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APPENDIX A: Expanded list of Graphs for Weighted Deployment

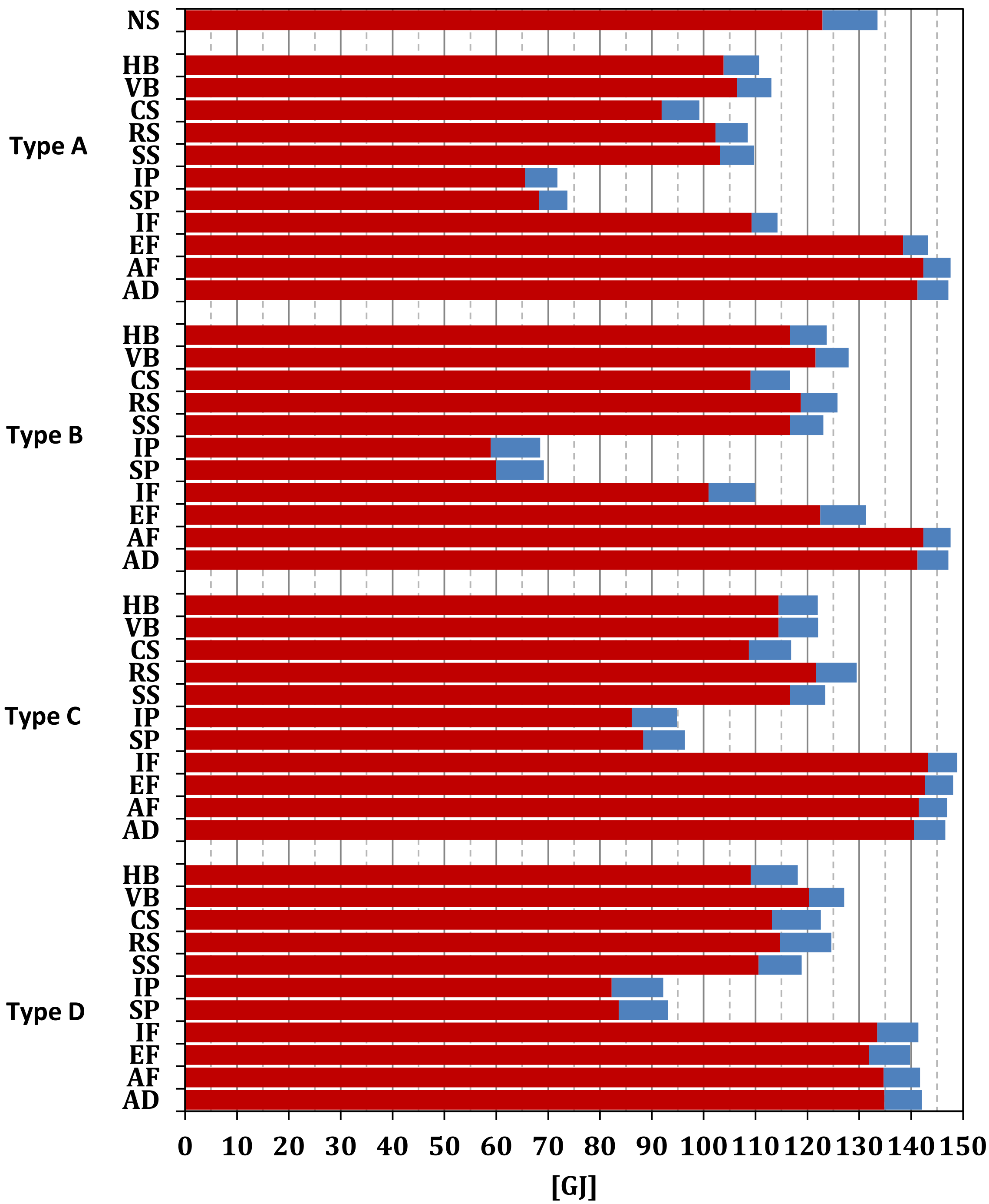
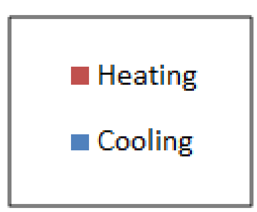


Figure 33. Baseline Window: Single Pane Aluminum. North Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



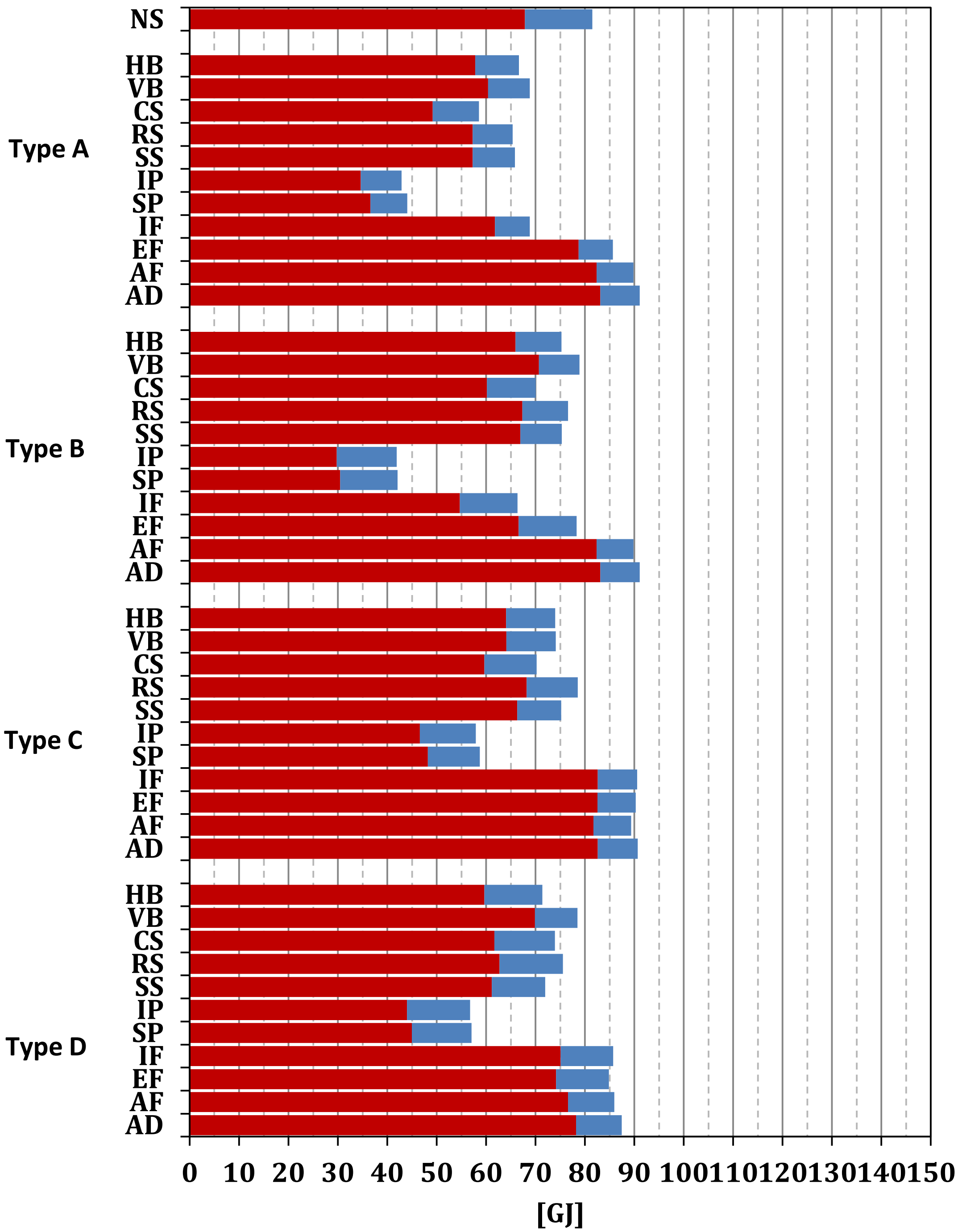


Figure 34. Baseline Window: Single Pane Aluminum. Central Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating

Cooling

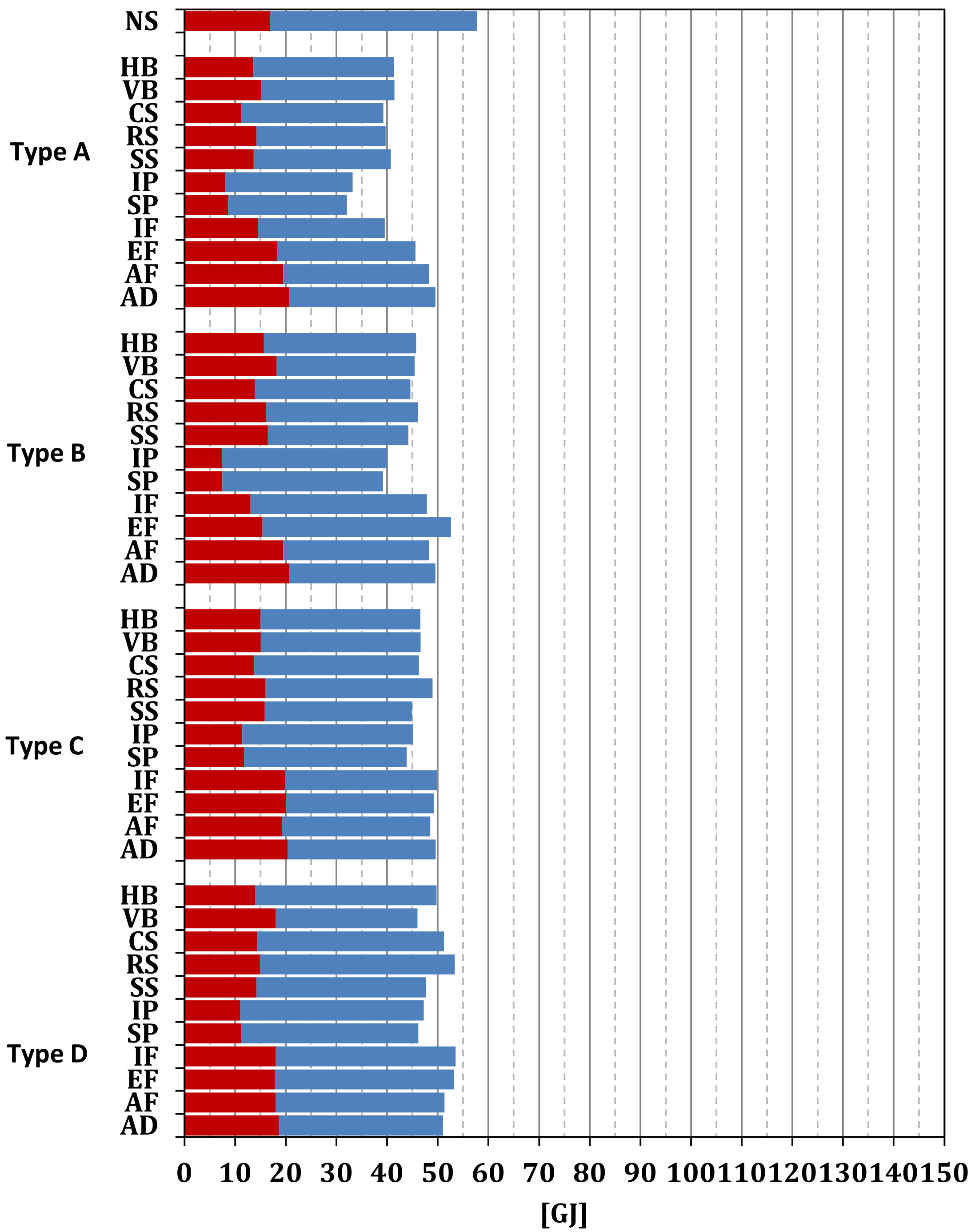


Figure 35. Baseline Window: Single Pane Aluminum. South Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating
Cooling

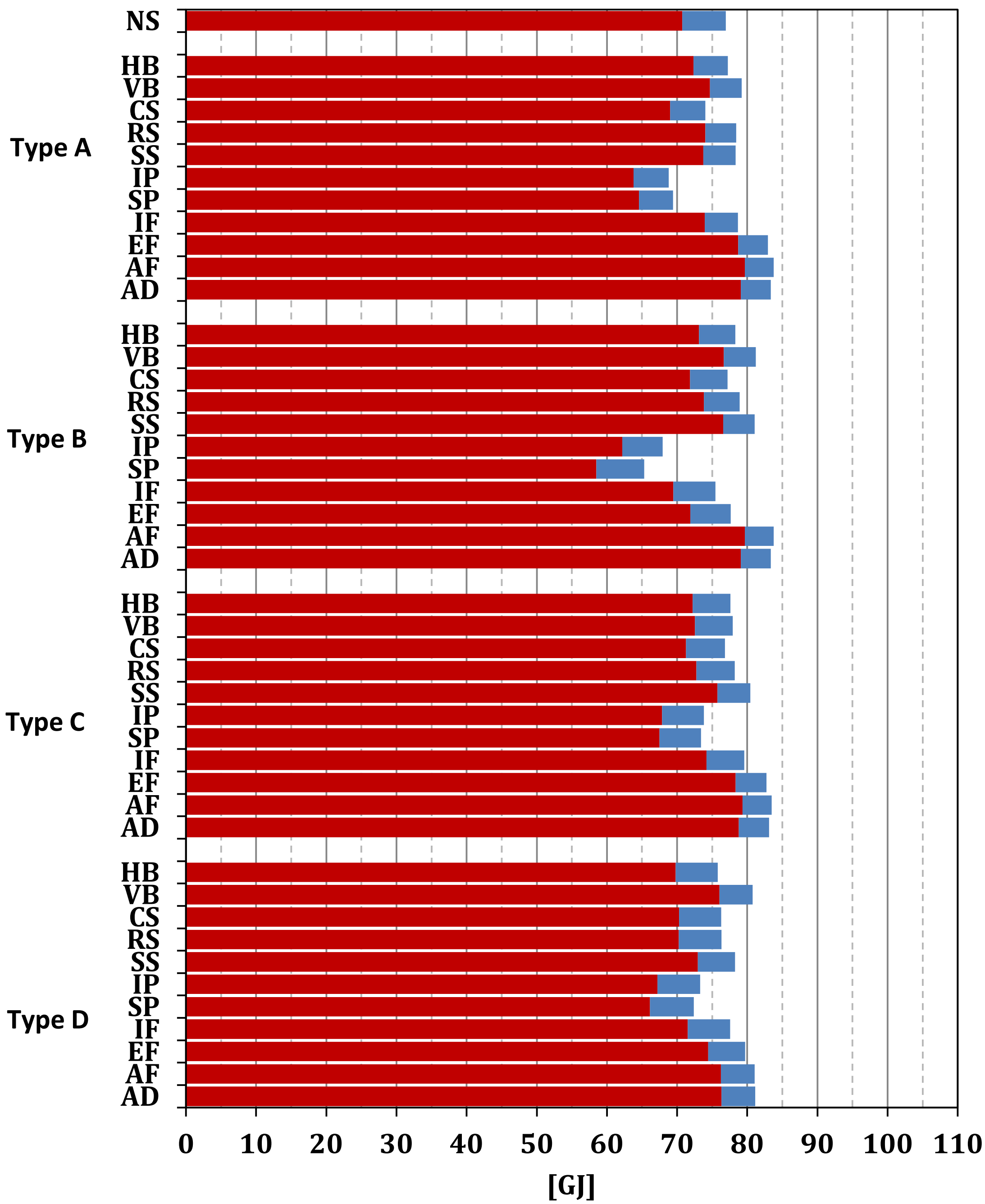


Figure 36. Baseline Window: Double Pane Low-e Vinyl. North Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating
Cooling

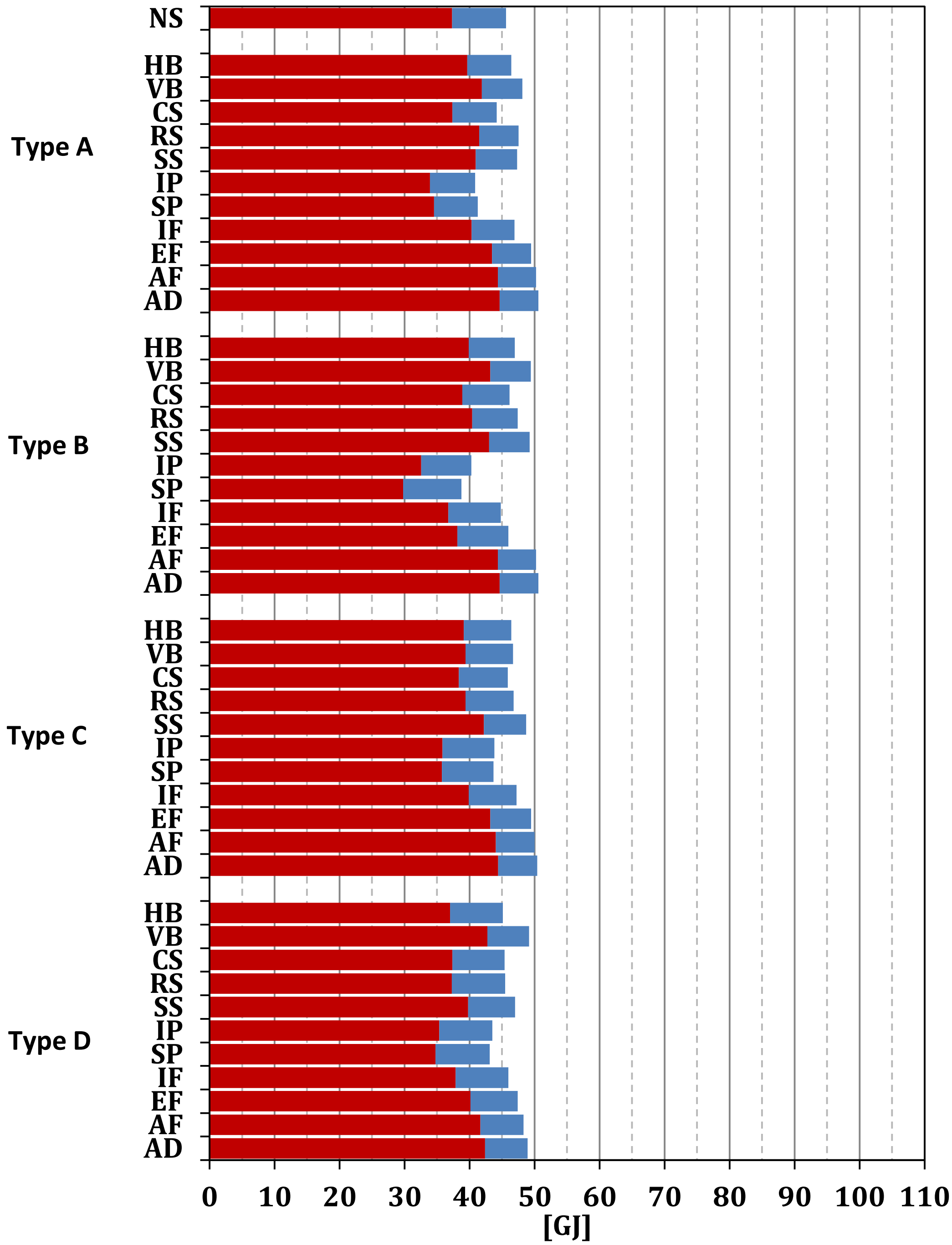


Figure 37. Baseline Window: Double Pane Low-e Vinyl. Central Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

Heating

Cooling

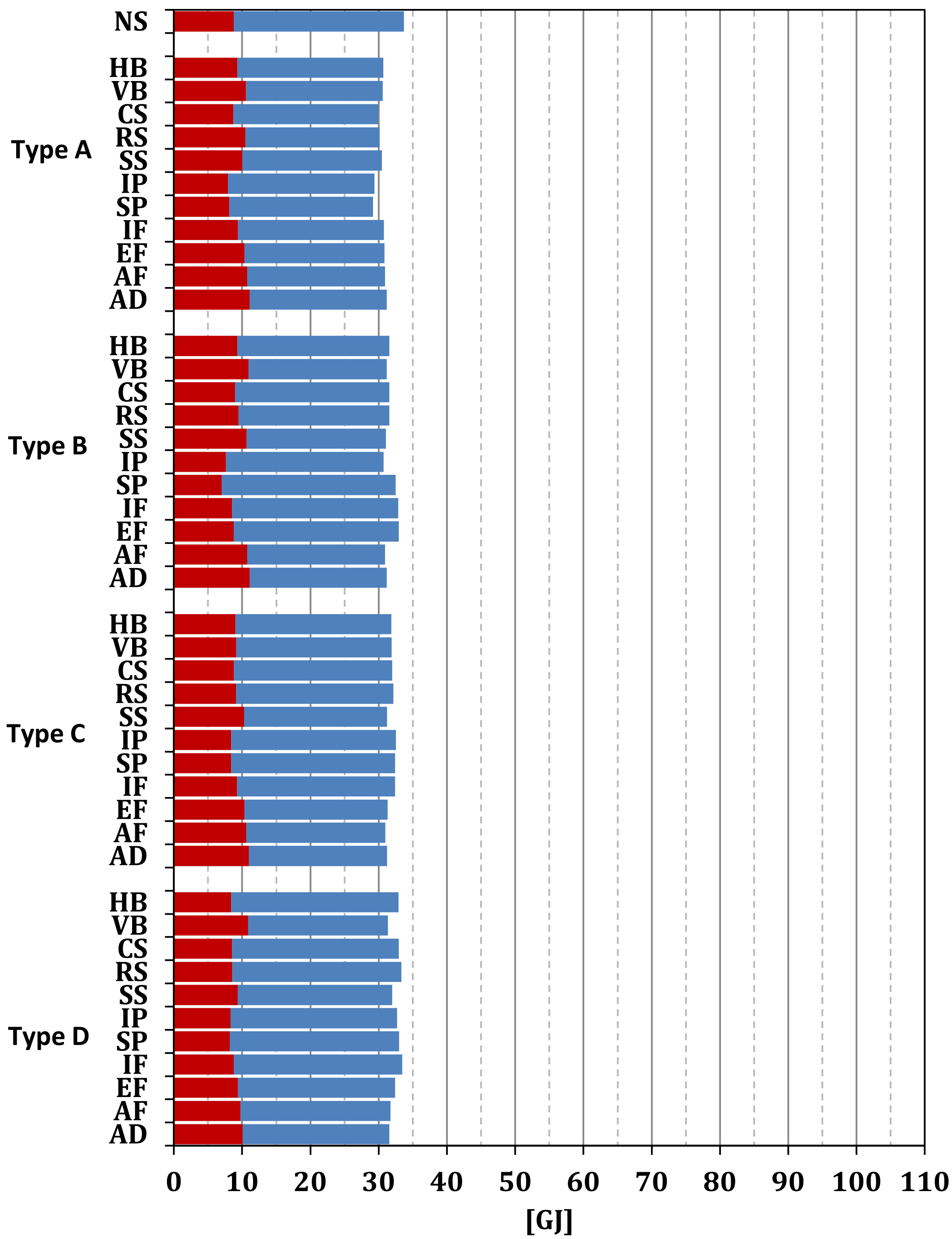
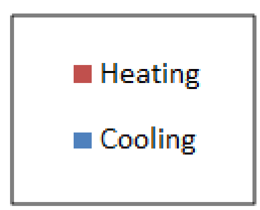


Figure 38. Baseline Window: Double Pane Low-e Vinyl. South Zone Weighted Deployment Schedule Grouped by Quality

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



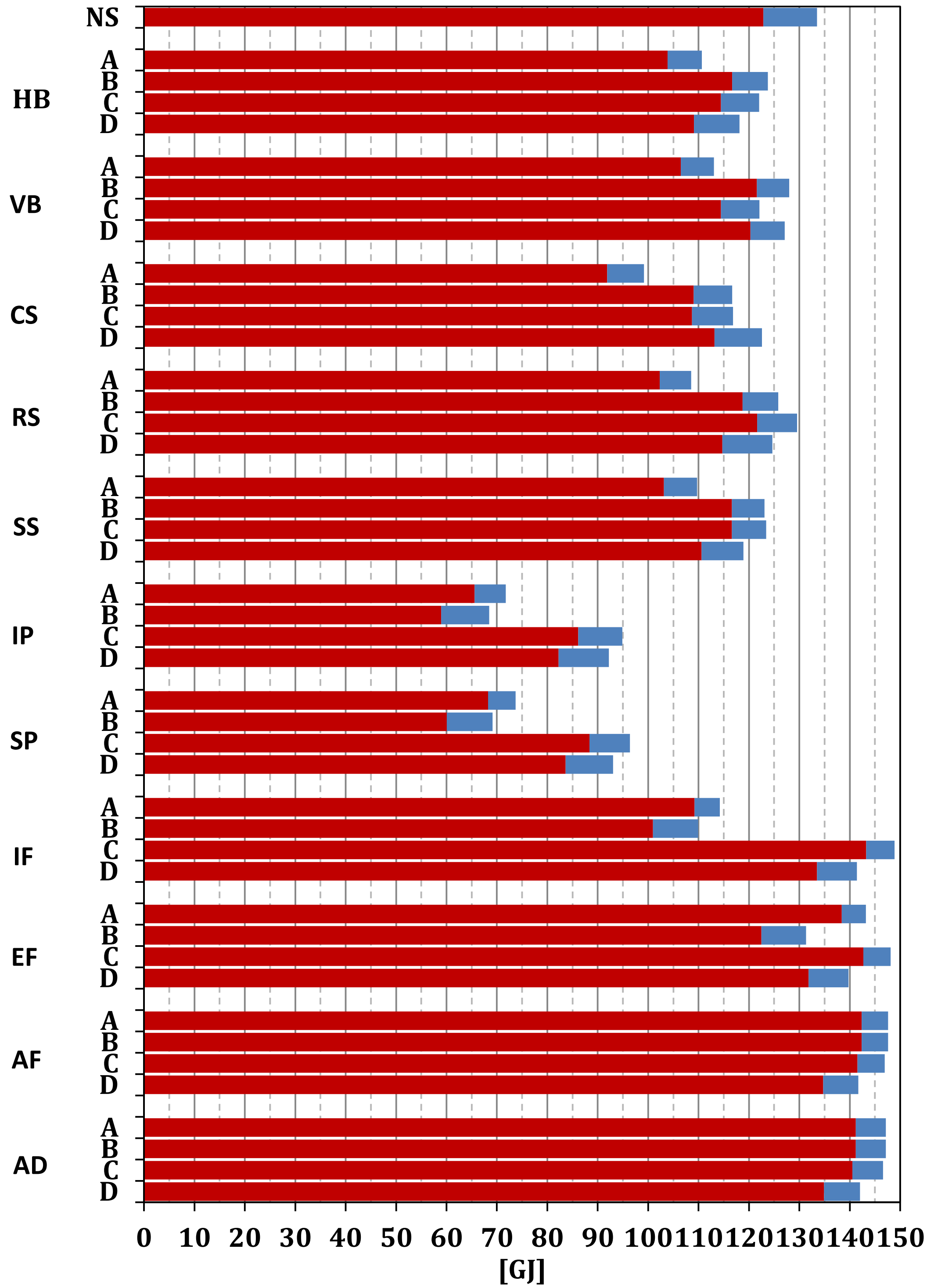
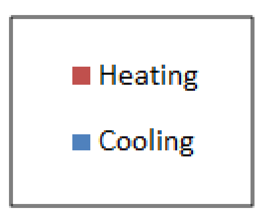


Figure 39. Baseline Window: Single Pane Aluminum. North Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



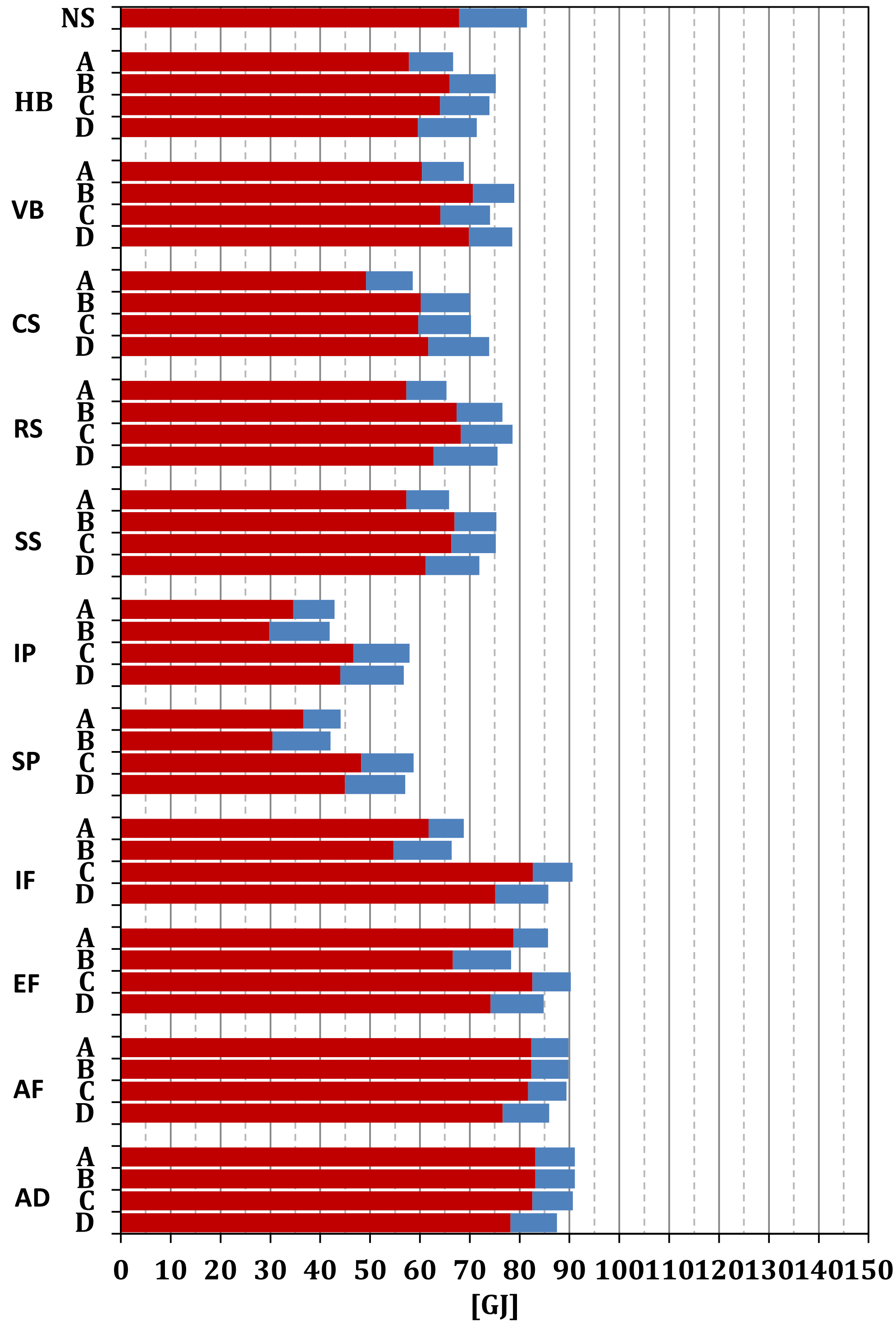
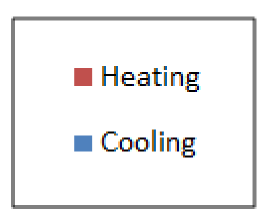


Figure 40. Baseline Window: Single Pane Aluminum. Central Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



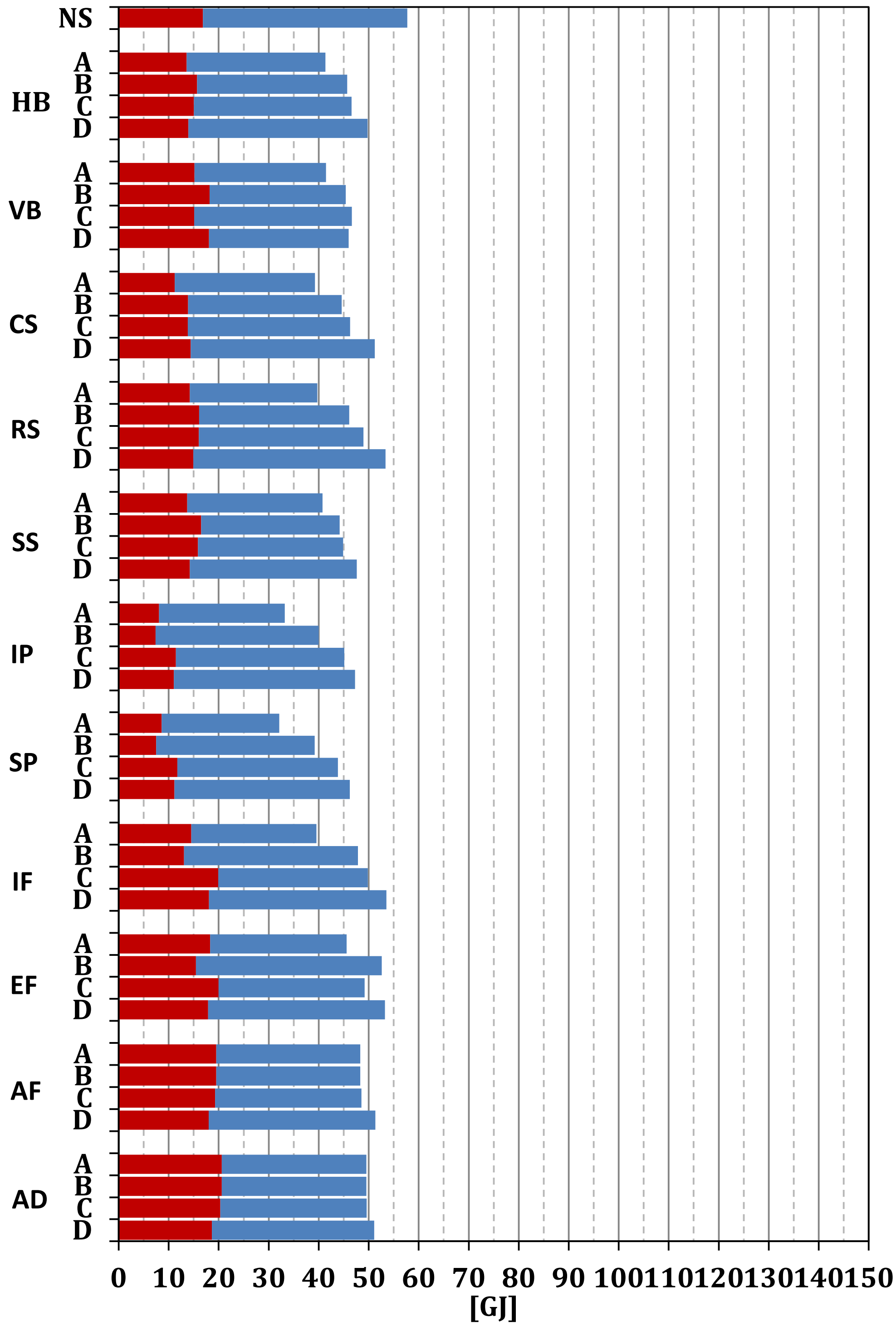
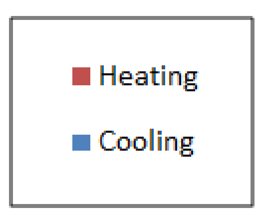


Figure 41. Baseline Window: Single Pane Aluminum. South Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



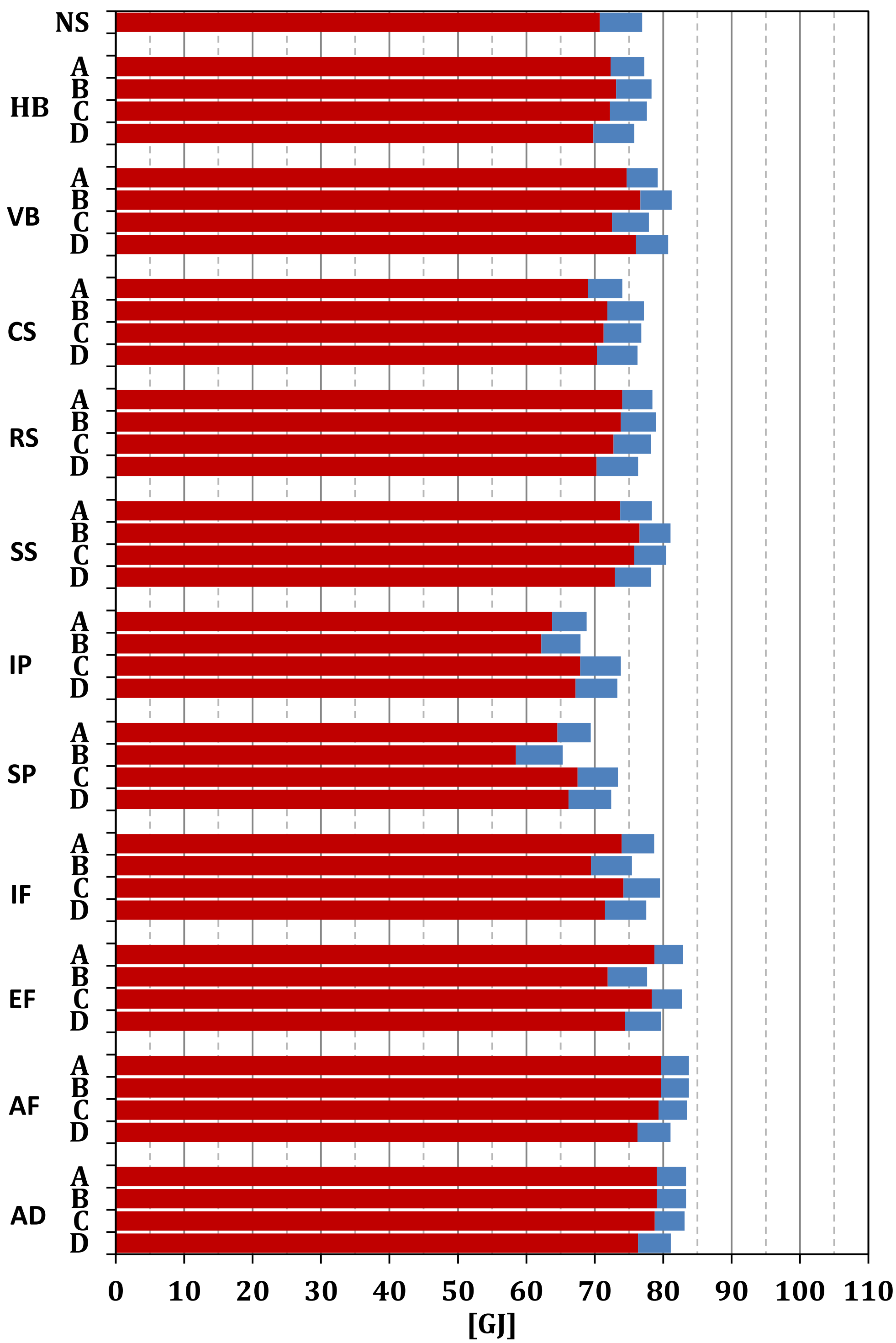


Figure 42. Baseline Window: Double Pane Low-e Vinyl. North Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning

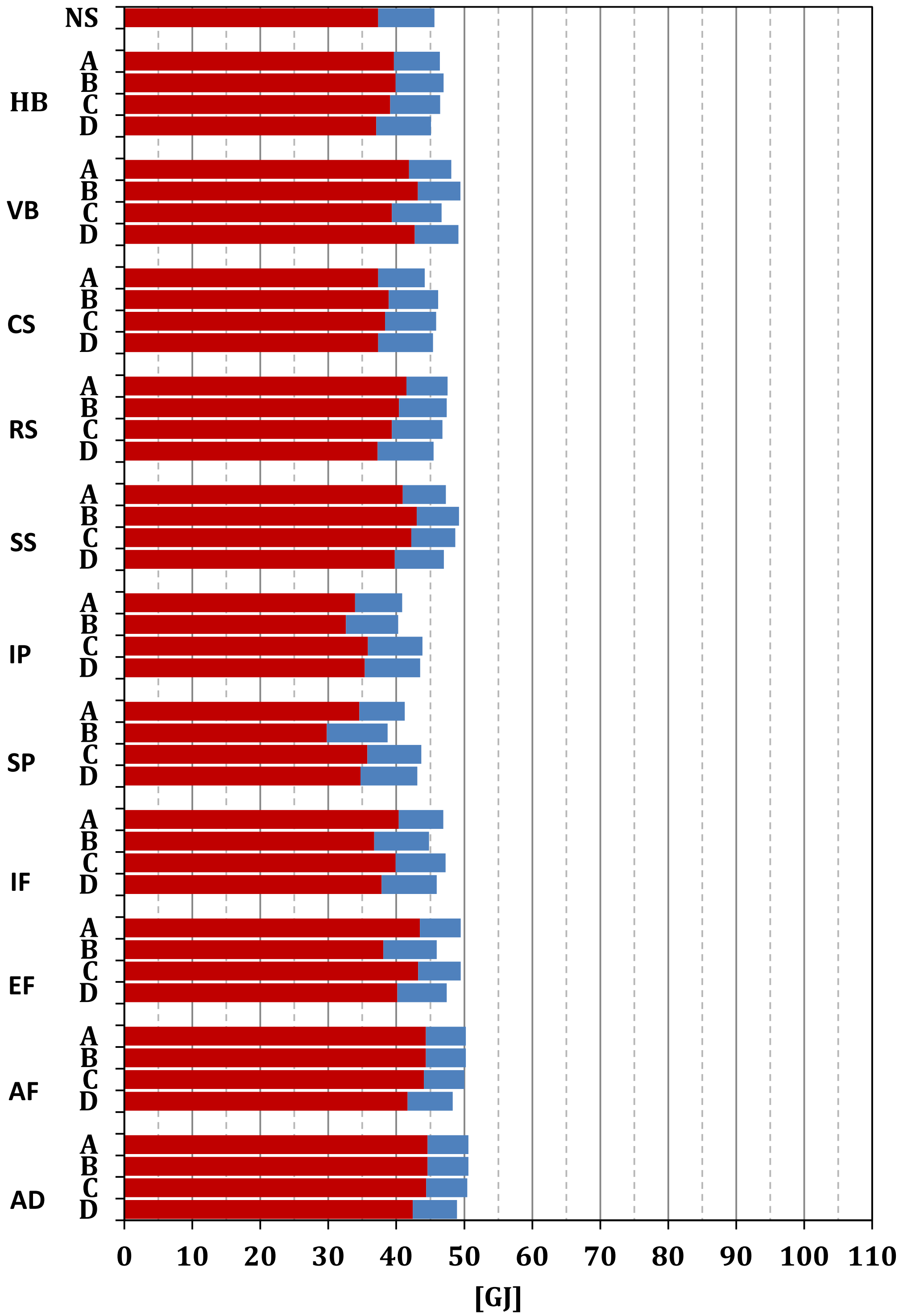
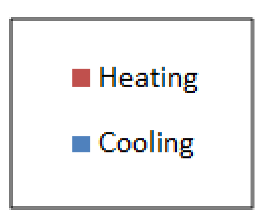


Figure 43. Baseline Window: Double Pane Low-e Vinyl. Central Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



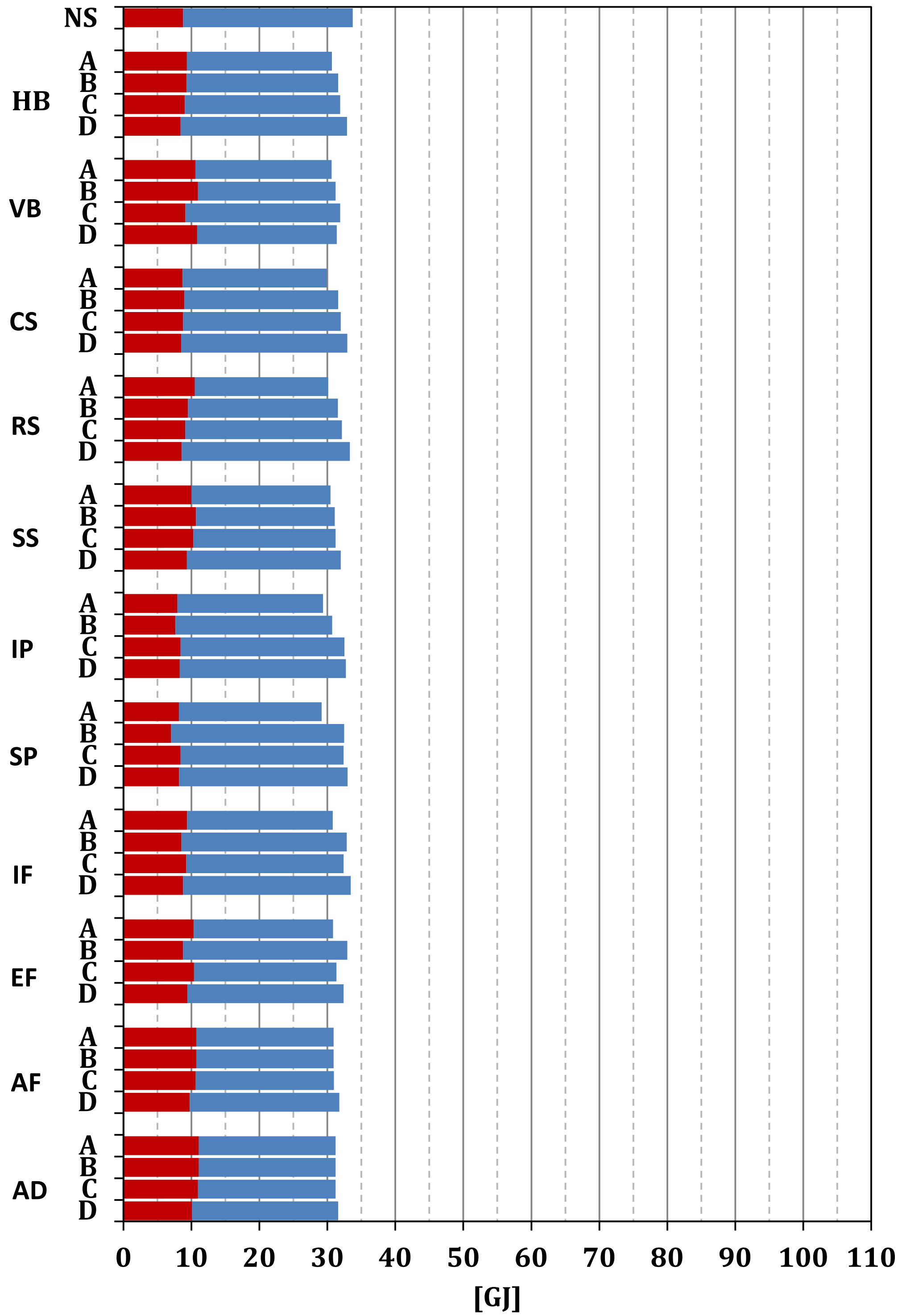
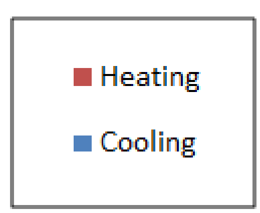


Figure 44. Baseline Window: Double Pane Low-e Vinyl. South Zone Weighted Deployment Schedule Grouped by Shade Category

HB	Horizontal Louvered Blind	IP	Interior Window Panel
VB	Vertical Louvered Blind	SP	Storm Panel
CS	Cellular Shade	IF	Interior Applied Film
RS	Roller Shade	EF	Exterior Applied Film
SS	Solar Screen	AF	Fixed Awning
		AD	Drop-arm Awning



APPENDIX B: Tables with Results

Table 24. Single Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Atlanta	HB	13.2	7.4	7.9	8.3
Atlanta	Vertical Blind	11.7	5.0	7.8	5.0
Atlanta	Cellular Shade	17.6	10.4	9.8	6.5
Atlanta	Roller Shade	13.9	6.4	4.7	4.8
Atlanta	Solar Screen	13.4	7.5	7.6	8.7
Atlanta	Interior Window Panel	28.0	25.6	16.5	16.1
Atlanta	Storm Window	27.8	25.9	16.6	16.5
Atlanta	Interior Applied Film	13.1	11.5	-2.1	-0.5
Atlanta	Exterior Applied Film	1.1	3.2	-1.7	0.1
Atlanta	Fixed Awning	-1.5	-1.5	-1.2	0.3
Atlanta	Droparm Awning	-2.7	-2.7	-2.4	-0.6
Boston	HB	17.4	6.9	8.5	12.1
Boston	Vertical Blind	15.1	2.9	8.4	3.6
Boston	Cellular Shade	25.8	12.7	12.7	8.9
Boston	Roller Shade	18.0	5.0	2.8	7.2
Boston	Solar Screen	17.3	6.8	7.1	11.4
Boston	Interior Window Panel	46.4	49.6	29.4	31.6
Boston	Storm Window	44.6	49.1	28.0	30.9
Boston	Interior Applied Film	13.7	18.7	-14.4	-7.1
Boston	Exterior Applied Film	-10.9	1.0	-13.9	-5.8
Boston	Fixed Awning	-13.5	-13.5	-12.9	-7.9
Boston	Droparm Awning	-12.8	-12.8	-12.3	-8.4
Chicago	HB	20.2	9.0	10.3	13.3
Chicago	Vertical Blind	18.3	5.5	10.3	6.2
Chicago	Cellular Shade	29.4	14.8	14.5	9.6
Chicago	Roller Shade	21.8	7.1	4.0	7.7
Chicago	Solar Screen	20.7	9.5	9.2	12.7
Chicago	Interior Window Panel	52.1	54.3	32.2	34.3
Chicago	Storm Window	50.6	53.8	31.1	33.7
Chicago	Interior Applied Film	17.3	20.3	-12.3	-6.2
Chicago	Exterior Applied Film	-7.1	2.4	-11.6	-4.9
Chicago	Fixed Awning	-11.1	-11.1	-10.6	-6.7
Chicago	Droparm Awning	-10.5	-10.5	-10.1	-7.0

Table 25. Single Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Denver	HB	18.7	8.8	10.3	12.7
Denver	Vertical Blind	15.8	4.0	10.1	4.2
Denver	Cellular Shade	27.2	14.8	14.5	10.1
Denver	Roller Shade	19.4	7.1	5.2	7.7
Denver	Solar Screen	18.8	8.2	8.8	12.6
Denver	Interior Window Panel	44.8	44.3	27.1	27.7
Denver	Storm Window	43.6	44.3	26.6	27.7
Denver	Interior Applied Film	17.2	18.9	-9.1	-3.7
Denver	Exterior Applied Film	-4.6	3.9	-8.7	-2.5
Denver	Fixed Awning	-8.3	-8.3	-7.7	-3.4
Denver	Droparm Awning	-10.3	-10.3	-9.6	-5.1
Fort.Worth	HB	14.2	8.3	8.8	9.0
Fort.Worth	Vertical Blind	12.7	6.0	8.7	5.9
Fort.Worth	Cellular Shade	19.6	11.7	11.1	7.1
Fort.Worth	Roller Shade	15.5	7.5	5.6	5.3
Fort.Worth	Solar Screen	15.0	8.7	8.7	9.7
Fort.Worth	Interior Window Panel	28.6	26.0	16.5	16.0
Fort.Worth	Storm Window	28.4	26.3	16.7	16.4
Fort.Worth	Interior Applied Film	13.3	11.5	-1.2	0.0
Fort.Worth	Exterior Applied Film	2.4	3.9	-0.9	0.6
Fort.Worth	Fixed Awning	-0.7	-0.7	-0.5	0.8
Fort.Worth	Droparm Awning	-1.7	-1.7	-1.4	0.3
Minn	HB	22.8	9.8	11.5	15.4
Minn	Vertical Blind	20.5	5.5	11.4	6.4
Minn	Cellular Shade	34.3	16.9	16.7	10.9
Minn	Roller Shade	25.0	7.7	4.0	8.9
Minn	Solar Screen	23.8	10.4	10.1	14.6
Minn	Interior Window Panel	61.7	65.0	38.6	41.3
Minn	Storm Window	59.8	64.4	37.1	40.5
Minn	Interior Applied Film	19.3	23.6	-15.4	-7.9
Minn	Exterior Applied Film	-9.7	2.2	-14.6	-6.3
Minn	Fixed Awning	-14.1	-14.1	-13.4	-8.2
Minn	Droparm Awning	-13.6	-13.6	-13.1	-8.5

Table 26. Single Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
New.Orleans	HB	11.0	7.2	7.2	6.2
New.Orleans	Vertical Blind	10.5	6.5	7.1	6.4
New.Orleans	Cellular Shade	13.4	8.9	8.1	5.2
New.Orleans	Roller Shade	11.9	6.7	5.2	3.7
New.Orleans	Solar Screen	11.3	7.9	7.7	7.2
New.Orleans	Interior Window Panel	18.9	15.8	10.5	9.7
New.Orleans	Storm Window	19.2	16.2	11.0	10.2
New.Orleans	Interior Applied Film	11.2	7.9	1.9	1.3
New.Orleans	Exterior Applied Film	4.2	2.9	2.2	1.6
New.Orleans	Fixed Awning	2.5	2.5	2.5	2.4
New.Orleans	Droparm Awning	1.9	1.9	2.0	2.3
Phoenix	HB	16.4	12.0	11.2	8.0
Phoenix	Vertical Blind	16.3	12.3	11.1	11.8
Phoenix	Cellular Shade	18.5	13.1	11.5	6.5
Phoenix	Roller Shade	18.0	11.7	8.8	4.4
Phoenix	Solar Screen	17.0	13.6	12.8	10.1
Phoenix	Interior Window Panel	24.6	17.8	12.6	10.5
Phoenix	Storm Window	25.7	18.5	13.9	11.6
Phoenix	Interior Applied Film	18.2	9.9	7.9	4.2
Phoenix	Exterior Applied Film	12.2	5.1	8.5	4.5
Phoenix	Fixed Awning	9.5	9.5	9.2	6.4
Phoenix	Droparm Awning	8.2	8.2	8.1	6.7
San.Antonio	HB	13.6	9.2	9.0	7.5
San.Antonio	Vertical Blind	13.1	8.7	8.9	8.4
San.Antonio	Cellular Shade	16.5	11.0	9.9	6.1
San.Antonio	Roller Shade	14.9	8.7	6.5	4.3
San.Antonio	Solar Screen	14.2	10.2	9.8	8.7
San.Antonio	Interior Window Panel	22.9	18.8	12.5	11.4
San.Antonio	Storm Window	23.4	19.3	13.2	12.0
San.Antonio	Interior Applied Film	14.1	9.2	3.5	2.1
San.Antonio	Exterior Applied Film	7.0	4.0	4.0	2.4
San.Antonio	Fixed Awning	4.4	4.4	4.4	3.4
San.Antonio	Droparm Awning	3.7	3.7	3.7	3.5

Table 27. Single Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
San.Francisco	HB	12.7	7.0	8.0	8.5
San.Francisco	Vertical Blind	9.2	1.2	7.8	1.1
San.Francisco	Cellular Shade	17.1	10.6	10.1	7.1
San.Francisco	Roller Shade	11.4	5.8	5.2	5.2
San.Francisco	Solar Screen	12.2	5.4	6.7	9.1
San.Francisco	Interior Window Panel	27.1	23.9	15.9	15.4
San.Francisco	Storm Window	26.9	24.3	16.2	15.8
San.Francisco	Interior Applied Film	13.3	12.1	-2.8	-0.2
San.Francisco	Exterior Applied Film	0.4	4.6	-2.7	0.4
San.Francisco	Fixed Awning	-1.9	-1.9	-1.5	0.3
San.Francisco	Droparm Awning	-5.7	-5.7	-5.2	-2.2
Tampa	HB	11.7	8.9	8.2	5.5
Tampa	Vertical Blind	12.0	9.7	8.1	9.3
Tampa	Cellular Shade	12.6	9.3	8.0	4.5
Tampa	Roller Shade	13.0	8.7	6.5	3.0
Tampa	Solar Screen	12.2	10.3	9.6	7.2
Tampa	Interior Window Panel	16.5	11.1	8.4	6.7
Tampa	Storm Window	17.5	11.7	9.5	7.6
Tampa	Interior Applied Film	13.3	6.7	6.7	3.6
Tampa	Exterior Applied Film	9.6	3.8	7.1	3.7
Tampa	Fixed Awning	7.7	7.7	7.5	5.5
Tampa	Droparm Awning	7.2	7.2	7.1	6.0
Washington.DC	HB	14.8	6.3	7.5	10.1
Washington.DC	Vertical Blind	12.7	2.6	7.4	3.0
Washington.DC	Cellular Shade	22.9	11.4	11.3	7.6
Washington.DC	Roller Shade	16.1	4.9	2.9	5.9
Washington.DC	Solar Screen	15.6	6.2	6.3	9.6
Washington.DC	Interior Window Panel	38.6	39.6	23.6	24.8
Washington.DC	Storm Window	37.4	39.4	22.8	24.4
Washington.DC	Interior Applied Film	12.7	15.1	-9.1	-4.2
Washington.DC	Exterior Applied Film	-4.2	3.2	-8.8	-3.3
Washington.DC	Fixed Awning	-8.3	-8.3	-7.9	-4.5
Washington.DC	Droparm Awning	-9.6	-9.6	-9.2	-6.0

Table 28. Double Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Atlanta	HB	5.2	3.0	3.2	2.8
Atlanta	Vertical Blind	2.6	-0.2	2.2	-0.4
Atlanta	Cellular Shade	8.0	4.3	3.9	2.4
Atlanta	Roller Shade	5.1	2.7	2.2	1.6
Atlanta	Solar Screen	5.1	2.1	2.5	3.3
Atlanta	Interior Window Panel	13.0	11.4	6.0	5.6
Atlanta	Storm Window	12.7	11.4	6.3	6.0
Atlanta	Interior Applied Film	5.3	4.1	0.9	0.6
Atlanta	Exterior Applied Film	0.5	1.7	-0.1	0.9
Atlanta	Fixed Awning	0.0	0.0	0.2	1.2
Atlanta	Droparm Awning	-1.3	-1.3	-1.0	0.5
Boston	HB	2.7	-0.5	0.6	3.1
Boston	Vertical Blind	-2.3	-7.2	-1.4	-6.7
Boston	Cellular Shade	8.1	2.3	2.7	2.4
Boston	Roller Shade	1.6	-1.3	-0.7	2.0
Boston	Solar Screen	1.9	-3.5	-2.6	0.9
Boston	Interior Window Panel	16.3	19.1	8.0	9.4
Boston	Storm Window	14.0	18.8	6.4	8.5
Boston	Interior Applied Film	-0.4	4.8	-6.0	-1.9
Boston	Exterior Applied Film	-11.2	-1.8	-10.9	-4.8
Boston	Fixed Awning	-10.5	-10.5	-10.0	-5.8
Boston	Droparm Awning	-10.4	-10.4	-10.0	-6.6
Chicago	HB	4.4	0.6	1.5	3.6
Chicago	Vertical Blind	-0.3	-5.5	-0.6	-5.0
Chicago	Cellular Shade	10.2	3.4	3.6	2.8
Chicago	Roller Shade	4.0	-0.2	0.0	2.2
Chicago	Solar Screen	4.0	-1.8	-1.2	1.8
Chicago	Interior Window Panel	19.6	21.5	9.3	10.6
Chicago	Storm Window	17.6	21.1	7.9	9.7
Chicago	Interior Applied Film	1.6	5.4	-5.2	-1.7
Chicago	Exterior Applied Film	-8.9	-1.2	-9.4	-4.2
Chicago	Fixed Awning	-8.9	-8.9	-8.4	-5.1
Chicago	Droparm Awning	-8.7	-8.7	-8.4	-5.7

Table 29. Double Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Denver	HB	5.4	2.0	2.9	4.0
Denver	Vertical Blind	0.1	-5.0	1.1	-4.9
Denver	Cellular Shade	10.7	4.8	4.7	3.4
Denver	Roller Shade	4.2	1.3	1.6	2.4
Denver	Solar Screen	4.5	-1.0	0.1	3.2
Denver	Interior Window Panel	18.9	18.9	9.0	9.2
Denver	Storm Window	17.2	18.7	8.5	9.2
Denver	Interior Applied Film	4.4	6.1	-2.1	-0.4
Denver	Exterior Applied Film	-5.3	1.1	-5.5	-1.3
Denver	Fixed Awning	-5.3	-5.3	-4.8	-1.5
Denver	Droparm Awning	-7.6	-7.6	-7.0	-3.2
Fort.Worth	HB	6.1	3.7	3.9	3.2
Fort.Worth	Vertical Blind	3.3	0.4	2.9	0.2
Fort.Worth	Cellular Shade	9.4	5.1	4.7	2.8
Fort.Worth	Roller Shade	6.1	3.4	2.8	1.9
Fort.Worth	Solar Screen	6.2	2.9	3.2	4.0
Fort.Worth	Interior Window Panel	13.9	12.1	6.3	5.9
Fort.Worth	Storm Window	13.4	12.1	6.7	6.3
Fort.Worth	Interior Applied Film	5.7	4.2	1.3	0.7
Fort.Worth	Exterior Applied Film	1.2	2.1	0.4	1.3
Fort.Worth	Fixed Awning	0.5	0.5	0.6	1.5
Fort.Worth	Droparm Awning	-0.7	-0.7	-0.4	1.1
Minn	HB	4.3	0.1	1.3	4.1
Minn	Vertical Blind	-1.2	-7.3	-1.2	-6.7
Minn	Cellular Shade	11.4	3.4	3.8	3.2
Minn	Roller Shade	3.8	-0.9	-0.5	2.6
Minn	Solar Screen	3.7	-3.0	-2.3	1.6
Minn	Interior Window Panel	22.6	25.5	10.9	12.6
Minn	Storm Window	20.0	24.9	9.0	11.4
Minn	Interior Applied Film	0.9	6.1	-6.9	-2.3
Minn	Exterior Applied Film	-11.7	-1.9	-12.0	-5.5
Minn	Fixed Awning	-11.4	-11.4	-10.8	-6.3
Minn	Droparm Awning	-11.5	-11.5	-11.0	-7.0

Table 30. Double Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
New.Orleans	HB	5.6	3.8	3.5	2.3
New.Orleans	Vertical Blind	4.6	2.8	3.1	2.6
New.Orleans	Cellular Shade	7.3	4.4	3.8	2.1
New.Orleans	Roller Shade	6.2	3.7	2.8	1.3
New.Orleans	Solar Screen	6.0	4.2	4.1	3.7
New.Orleans	Interior Window Panel	10.0	7.8	4.4	3.8
New.Orleans	Storm Window	10.3	7.8	5.1	4.3
New.Orleans	Interior Applied Film	5.8	3.2	2.2	0.9
New.Orleans	Exterior Applied Film	3.5	2.0	2.6	2.0
New.Orleans	Fixed Awning	2.8	2.8	2.8	2.5
New.Orleans	Droparm Awning	2.3	2.3	2.3	2.5
Phoenix	HB	10.2	7.4	6.5	3.4
Phoenix	Vertical Blind	10.0	8.0	6.2	7.5
Phoenix	Cellular Shade	11.8	7.6	6.3	2.9
Phoenix	Roller Shade	11.8	7.5	5.4	1.8
Phoenix	Solar Screen	11.2	9.4	8.9	6.6
Phoenix	Interior Window Panel	15.1	10.0	6.3	4.8
Phoenix	Storm Window	16.4	10.2	8.1	6.0
Phoenix	Interior Applied Film	11.3	4.6	5.7	2.0
Phoenix	Exterior Applied Film	10.0	4.0	8.0	4.8
Phoenix	Fixed Awning	8.7	8.7	8.5	5.8
Phoenix	Droparm Awning	7.8	7.8	7.8	6.4
San.Antonio	HB	7.3	5.0	4.6	2.9
San.Antonio	Vertical Blind	6.2	4.2	4.0	3.9
San.Antonio	Cellular Shade	9.3	5.6	4.8	2.5
San.Antonio	Roller Shade	8.2	4.9	3.6	1.6
San.Antonio	Solar Screen	7.9	5.8	5.6	4.7
San.Antonio	Interior Window Panel	12.5	9.5	5.4	4.6
San.Antonio	Storm Window	13.0	9.6	6.3	5.3
San.Antonio	Interior Applied Film	7.5	3.8	3.1	1.2
San.Antonio	Exterior Applied Film	5.3	2.7	3.9	2.7
San.Antonio	Fixed Awning	4.2	4.2	4.2	3.2
San.Antonio	Droparm Awning	3.7	3.7	3.7	3.5

Table 31. Double Clear Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
San.Francisco	HB	5.4	3.4	3.6	2.8
San.Francisco	Vertical Blind	0.3	-3.2	2.4	-3.4
San.Francisco	Cellular Shade	7.9	4.7	4.2	2.6
San.Francisco	Roller Shade	3.4	3.0	2.7	1.7
San.Francisco	Solar Screen	4.5	1.0	2.3	3.9
San.Francisco	Interior Window Panel	12.8	10.5	5.9	5.3
San.Francisco	Storm Window	12.6	10.6	6.5	5.8
San.Francisco	Interior Applied Film	6.0	4.3	1.5	0.8
San.Francisco	Exterior Applied Film	0.8	2.6	0.3	1.5
San.Francisco	Fixed Awning	0.8	0.8	1.0	1.6
San.Francisco	Droparm Awning	-2.7	-2.7	-2.3	-0.2
Tampa	HB	7.6	5.7	4.9	2.3
Tampa	Vertical Blind	8.1	7.0	4.8	6.6
Tampa	Cellular Shade	8.4	5.6	4.6	2.0
Tampa	Roller Shade	9.2	5.8	4.1	1.2
Tampa	Solar Screen	8.6	7.6	7.1	5.0
Tampa	Interior Window Panel	10.7	6.5	4.4	3.1
Tampa	Storm Window	11.8	6.7	5.9	4.2
Tampa	Interior Applied Film	8.6	3.2	4.7	1.6
Tampa	Exterior Applied Film	8.3	3.2	6.8	4.0
Tampa	Fixed Awning	7.2	7.2	7.0	5.1
Tampa	Droparm Awning	6.9	6.9	6.8	5.8
Washington.DC	HB	3.3	0.4	1.3	2.9
Washington.DC	Vertical Blind	-1.1	-5.4	-0.4	-5.1
Washington.DC	Cellular Shade	8.3	2.9	3.0	2.3
Washington.DC	Roller Shade	2.6	-0.2	0.1	1.7
Washington.DC	Solar Screen	2.9	-2.0	-1.3	1.5
Washington.DC	Interior Window Panel	15.3	16.4	7.3	8.0
Washington.DC	Storm Window	13.8	16.2	6.4	7.6
Washington.DC	Interior Applied Film	1.7	4.4	-3.2	-0.9
Washington.DC	Exterior Applied Film	-5.9	0.1	-6.5	-2.5
Washington.DC	Fixed Awning	-6.3	-6.3	-5.9	-3.0
Washington.DC	Droparm Awning	-7.6	-7.6	-7.3	-4.4

Table 32. Double Low-e Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Atlanta	HB	0.5	0.0	0.2	0.6
Atlanta	Vertical Blind	-0.5	-1.4	0.1	-1.3
Atlanta	Cellular Shade	1.8	0.4	0.5	0.4
Atlanta	Roller Shade	-0.1	-0.2	0.0	0.3
Atlanta	Solar Screen	0.0	-1.2	-0.9	-0.1
Atlanta	Interior Window Panel	3.6	3.5	1.2	1.3
Atlanta	Storm Window	3.5	3.5	1.3	1.4
Atlanta	Interior Applied Film	0.3	0.7	-0.3	-0.1
Atlanta	Exterior Applied Film	-1.2	0.1	-1.2	-0.5
Atlanta	Fixed Awning	-1.7	-1.7	-1.5	-0.6
Atlanta	Droparm Awning	-1.9	-1.9	-1.8	-0.9
Boston	HB	-1.2	-1.8	-1.1	0.6
Boston	Vertical Blind	-3.0	-4.5	-1.4	-4.1
Boston	Cellular Shade	1.3	-0.8	-0.4	0.3
Boston	Roller Shade	-2.5	-2.3	-1.5	0.3
Boston	Solar Screen	-2.3	-4.4	-3.8	-1.7
Boston	Interior Window Panel	5.1	6.2	2.0	2.5
Boston	Storm Window	4.6	8.6	2.2	3.1
Boston	Interior Applied Film	-2.4	0.9	-2.5	-0.5
Boston	Exterior Applied Film	-6.0	-0.9	-5.6	-2.7
Boston	Fixed Awning	-6.6	-6.6	-6.3	-4.1
Boston	Droparm Awning	-6.1	-6.1	-5.9	-4.2
Chicago	HB	-0.2	-1.1	-0.6	0.9
Chicago	Vertical Blind	-1.8	-3.5	-0.8	-3.1
Chicago	Cellular Shade	2.5	-0.2	0.1	0.5
Chicago	Roller Shade	-1.1	-1.6	-1.0	0.4
Chicago	Solar Screen	-1.1	-3.3	-2.8	-1.1
Chicago	Interior Window Panel	6.7	7.4	2.5	2.9
Chicago	Storm Window	6.3	9.4	2.8	3.6
Chicago	Interior Applied Film	-1.3	1.2	-2.1	-0.5
Chicago	Exterior Applied Film	-4.7	-0.5	-4.6	-2.2
Chicago	Fixed Awning	-5.5	-5.5	-5.2	-3.4
Chicago	Droparm Awning	-5.1	-5.1	-4.9	-3.5

Table 33. Double Low-e Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
Denver	HB	-0.8	-1.4	-0.8	0.7
Denver	Vertical Blind	-3.1	-4.6	-1.0	-4.4
Denver	Cellular Shade	1.6	-0.4	-0.1	0.5
Denver	Roller Shade	-2.5	-1.9	-1.1	0.3
Denver	Solar Screen	-2.2	-4.3	-3.6	-1.4
Denver	Interior Window Panel	5.2	5.8	1.9	2.2
Denver	Storm Window	4.7	7.2	2.1	2.6
Denver	Interior Applied Film	-1.3	1.1	-1.7	-0.4
Denver	Exterior Applied Film	-4.7	-0.3	-4.5	-1.9
Denver	Fixed Awning	-5.6	-5.6	-5.2	-2.9
Denver	Droparm Awning	-6.0	-6.0	-5.7	-3.5
Fort.Worth	HB	0.6	0.1	0.3	0.7
Fort.Worth	Vertical Blind	-0.6	-1.4	0.2	-1.4
Fort.Worth	Cellular Shade	2.1	0.6	0.6	0.5
Fort.Worth	Roller Shade	0.0	-0.2	0.0	0.4
Fort.Worth	Solar Screen	0.1	-1.2	-0.9	-0.1
Fort.Worth	Interior Window Panel	3.8	3.7	1.3	1.4
Fort.Worth	Storm Window	3.6	3.7	1.4	1.5
Fort.Worth	Interior Applied Film	0.2	0.7	-0.3	0.0
Fort.Worth	Exterior Applied Film	-1.2	0.1	-1.3	-0.4
Fort.Worth	Fixed Awning	-1.8	-1.8	-1.7	-0.7
Fort.Worth	Droparm Awning	-2.0	-2.0	-1.9	-0.9
Minn	HB	-0.3	-1.3	-0.6	1.2
Minn	Vertical Blind	-2.3	-4.3	-1.0	-3.8
Minn	Cellular Shade	2.9	-0.2	0.1	0.7
Minn	Roller Shade	-1.5	-2.0	-1.2	0.6
Minn	Solar Screen	-1.4	-4.1	-3.5	-1.3
Minn	Interior Window Panel	8.1	9.0	3.1	3.7
Minn	Storm Window	7.5	11.7	3.6	4.5
Minn	Interior Applied Film	-1.7	1.5	-2.6	-0.6
Minn	Exterior Applied Film	-6.0	-0.7	-5.8	-2.8
Minn	Fixed Awning	-6.8	-6.8	-6.5	-4.1
Minn	Droparm Awning	-6.4	-6.4	-6.2	-4.2

Table 34. Double Low-e Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
New.Orleans	HB	1.3	0.8	0.7	0.5
New.Orleans	Vertical Blind	1.0	0.4	0.7	0.4
New.Orleans	Cellular Shade	2.0	0.9	0.8	0.4
New.Orleans	Roller Shade	1.3	0.7	0.5	0.2
New.Orleans	Solar Screen	1.2	0.6	0.6	0.6
New.Orleans	Interior Window Panel	2.9	2.3	0.9	0.8
New.Orleans	Storm Window	2.9	1.8	0.9	0.8
New.Orleans	Interior Applied Film	1.1	0.5	0.3	0.1
New.Orleans	Exterior Applied Film	0.6	0.3	0.4	0.3
New.Orleans	Fixed Awning	0.3	0.3	0.4	0.5
New.Orleans	Droparm Awning	0.3	0.3	0.3	0.5
Phoenix	HB	3.0	2.1	1.8	0.8
Phoenix	Vertical Blind	3.1	2.5	1.8	2.3
Phoenix	Cellular Shade	3.8	2.1	1.7	0.8
Phoenix	Roller Shade	3.6	2.1	1.6	0.4
Phoenix	Solar Screen	3.3	2.6	2.5	1.7
Phoenix	Interior Window Panel	4.3	3.0	1.2	1.0
Phoenix	Storm Window	4.6	1.2	1.3	0.7
Phoenix	Interior Applied Film	2.9	0.9	1.3	0.3
Phoenix	Exterior Applied Film	2.9	0.8	2.4	1.3
Phoenix	Fixed Awning	2.8	2.8	2.7	2.0
Phoenix	Droparm Awning	2.5	2.5	2.5	2.1
San.Antonio	HB	1.8	1.2	1.1	0.7
San.Antonio	Vertical Blind	1.5	0.9	1.0	0.9
San.Antonio	Cellular Shade	2.7	1.3	1.1	0.6
San.Antonio	Roller Shade	2.0	1.1	0.9	0.4
San.Antonio	Solar Screen	1.8	1.1	1.1	0.9
San.Antonio	Interior Window Panel	3.7	2.9	1.1	1.0
San.Antonio	Storm Window	3.7	2.1	1.2	0.9
San.Antonio	Interior Applied Film	1.6	0.7	0.6	0.1
San.Antonio	Exterior Applied Film	1.1	0.5	0.8	0.6
San.Antonio	Fixed Awning	0.8	0.8	0.8	0.8
San.Antonio	Droparm Awning	0.7	0.7	0.7	0.9

Table 35. Double Low-e Glazing -Total Energy Savings [GJ] Compared to an Un-Shaded Baseline for All Attachment Types in a House With Slab, Gas Heating, and Electric A/C, for Four Attachment Qualities (A, B, C, D).

Location	Attachment Type	A	B	C	D
San.Francisco	HB	0.2	-0.1	0.2	0.6
San.Francisco	Vertical Blind	-2.1	-3.1	0.1	-3.1
San.Francisco	Cellular Shade	1.3	0.4	0.5	0.5
San.Francisco	Roller Shade	-1.7	-0.4	0.0	0.3
San.Francisco	Solar Screen	-1.0	-2.4	-1.7	-0.1
San.Francisco	Interior Window Panel	3.2	3.0	1.1	1.1
San.Francisco	Storm Window	3.0	2.6	1.2	1.1
San.Francisco	Interior Applied Film	0.2	0.7	-0.2	0.0
San.Francisco	Exterior Applied Film	-1.6	0.4	-1.5	-0.3
San.Francisco	Fixed Awning	-2.2	-2.2	-2.0	-0.8
San.Francisco	Droparm Awning	-3.4	-3.4	-3.1	-1.8
Tampa	HB	2.5	1.8	1.5	0.5
Tampa	Vertical Blind	2.9	2.5	1.5	2.4
Tampa	Cellular Shade	2.8	1.7	1.3	0.5
Tampa	Roller Shade	3.2	1.9	1.3	0.3
Tampa	Solar Screen	2.9	2.6	2.3	1.5
Tampa	Interior Window Panel	3.1	2.0	0.8	0.6
Tampa	Storm Window	3.3	0.4	0.9	0.4
Tampa	Interior Applied Film	2.4	0.6	1.2	0.2
Tampa	Exterior Applied Film	2.7	0.7	2.3	1.2
Tampa	Fixed Awning	2.7	2.7	2.6	1.9
Tampa	Droparm Awning	2.6	2.6	2.6	2.2
Washington.DC	HB	-0.8	-1.3	-0.8	0.5
Washington.DC	Vertical Blind	-2.5	-3.8	-1.1	-3.5
Washington.DC	Cellular Shade	1.4	-0.5	-0.2	0.2
Washington.DC	Roller Shade	-1.9	-1.8	-1.2	0.1
Washington.DC	Solar Screen	-1.7	-3.6	-3.1	-1.4
Washington.DC	Interior Window Panel	4.8	5.3	1.8	2.1
Washington.DC	Storm Window	4.4	6.9	1.9	2.5
Washington.DC	Interior Applied Film	-1.3	0.8	-1.6	-0.3
Washington.DC	Exterior Applied Film	-3.8	-0.3	-3.8	-1.8
Washington.DC	Fixed Awning	-4.6	-4.6	-4.4	-2.7
Washington.DC	Droparm Awning	-5.0	-5.0	-4.8	-3.3

APPENDIX C: Operable Shades Deployment Comparison

The graphs in this appendix are the same graphs as in the main body of the report, in the section on "Operable shades deployment comparison" but for the remainder of attachment qualities, i.e., A, C, and D.

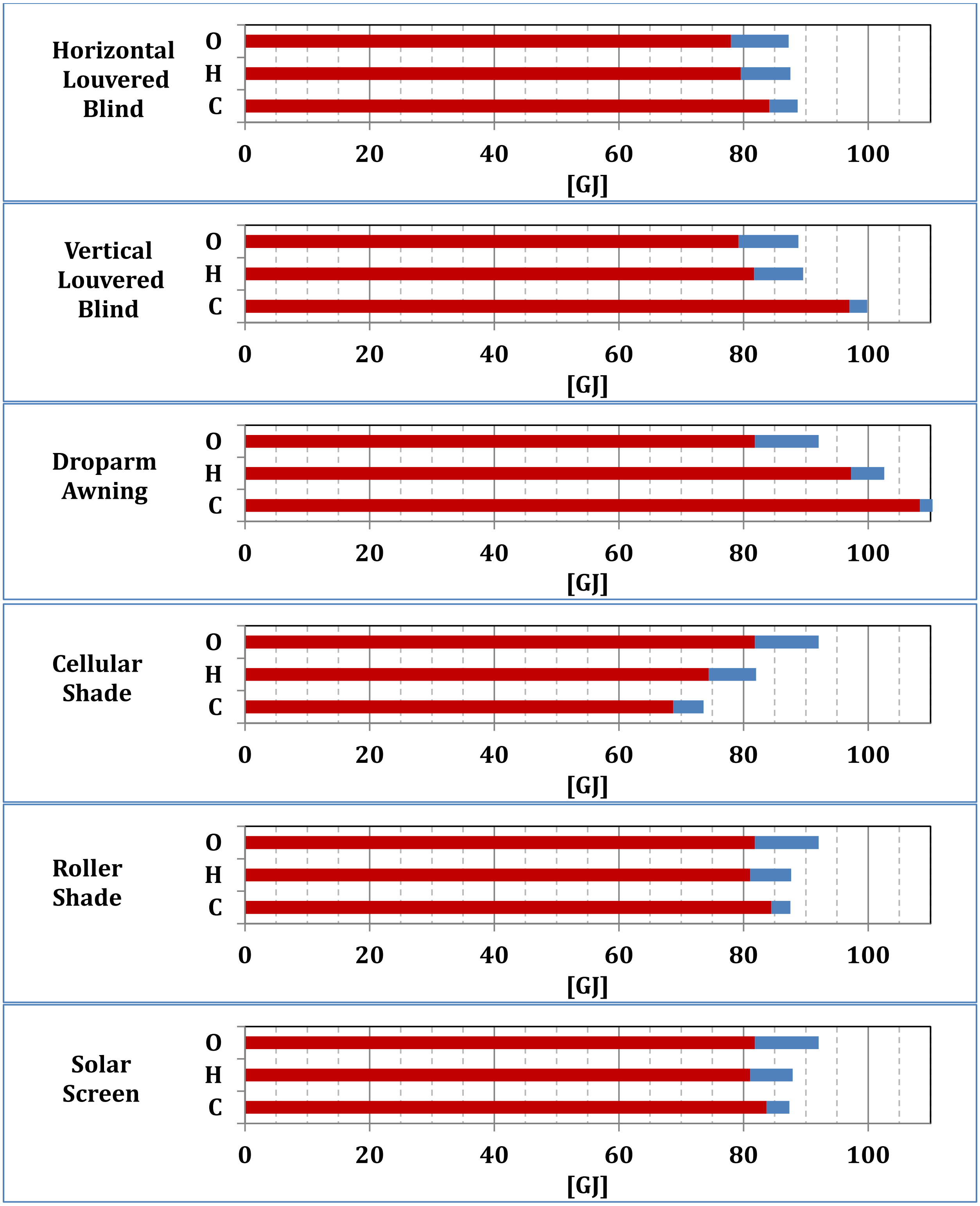


Figure 45. Operable Shade Deployment Comparison for the Quality A Case Over Double Clear Window in North Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

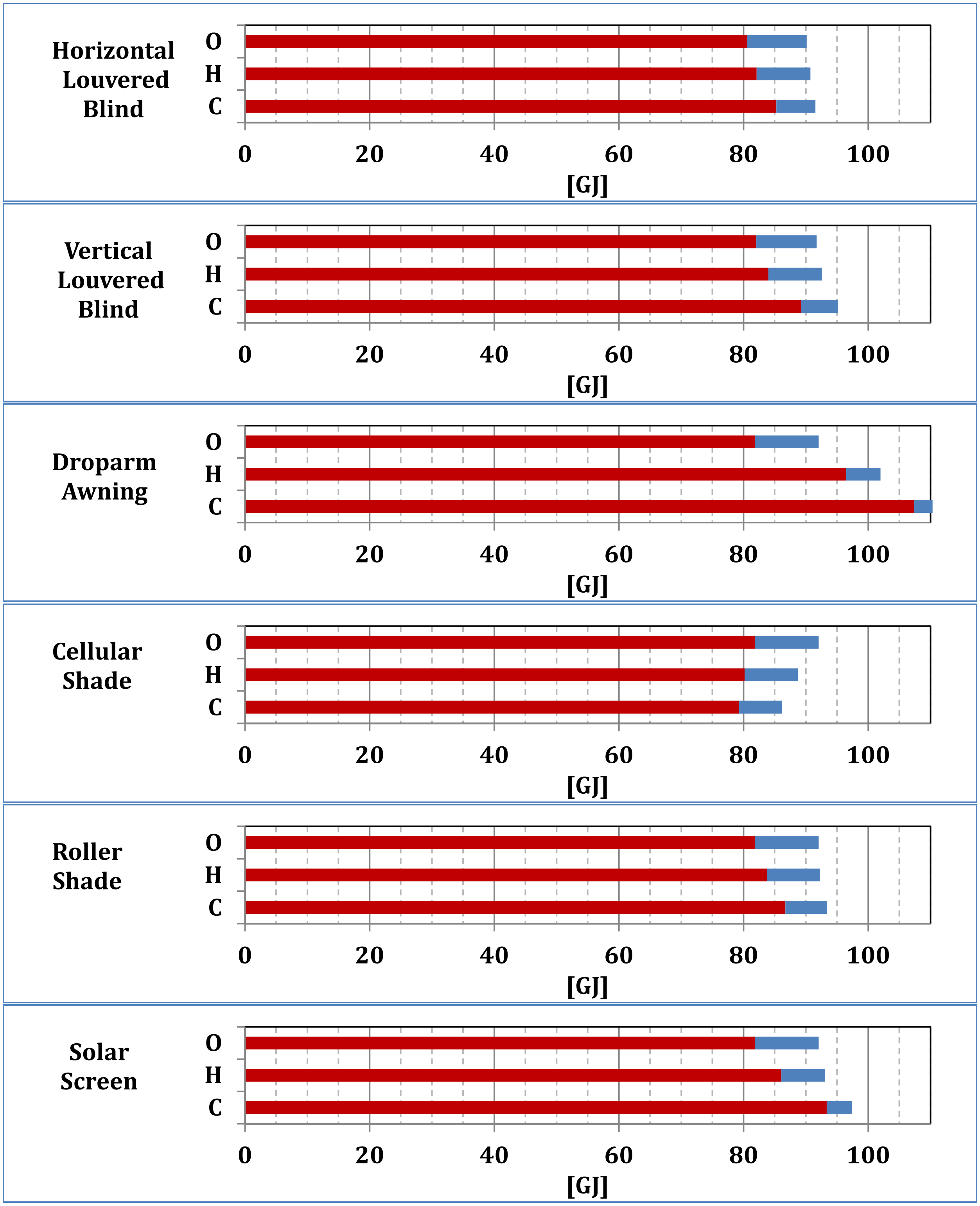


Figure 46. Operable Shade Deployment Comparison for the Quality C Case Over Double Clear Window in North Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

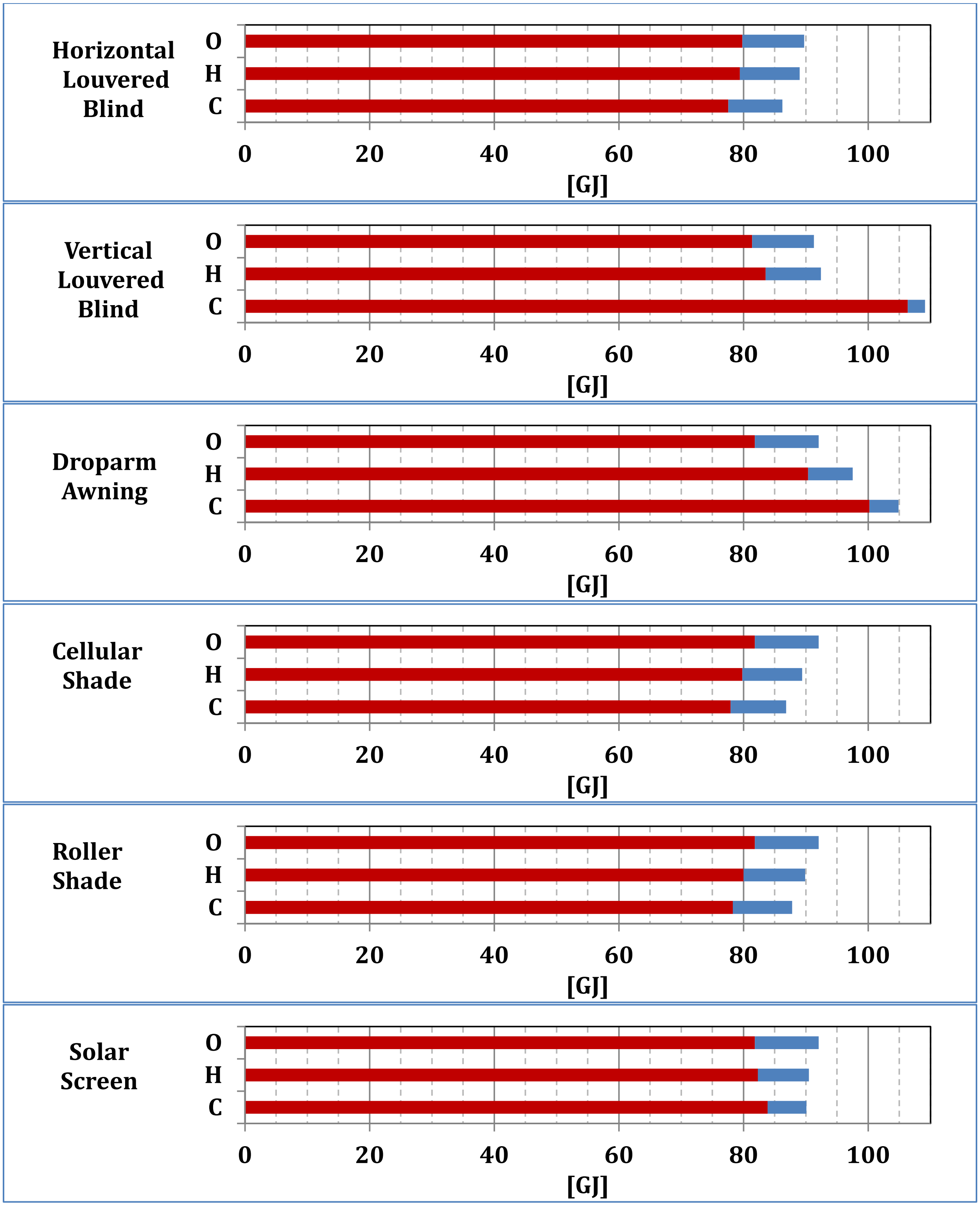


Figure 47. Operable Shade Deployment Comparison for the Quality D Case Over Double Clear Window in North Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

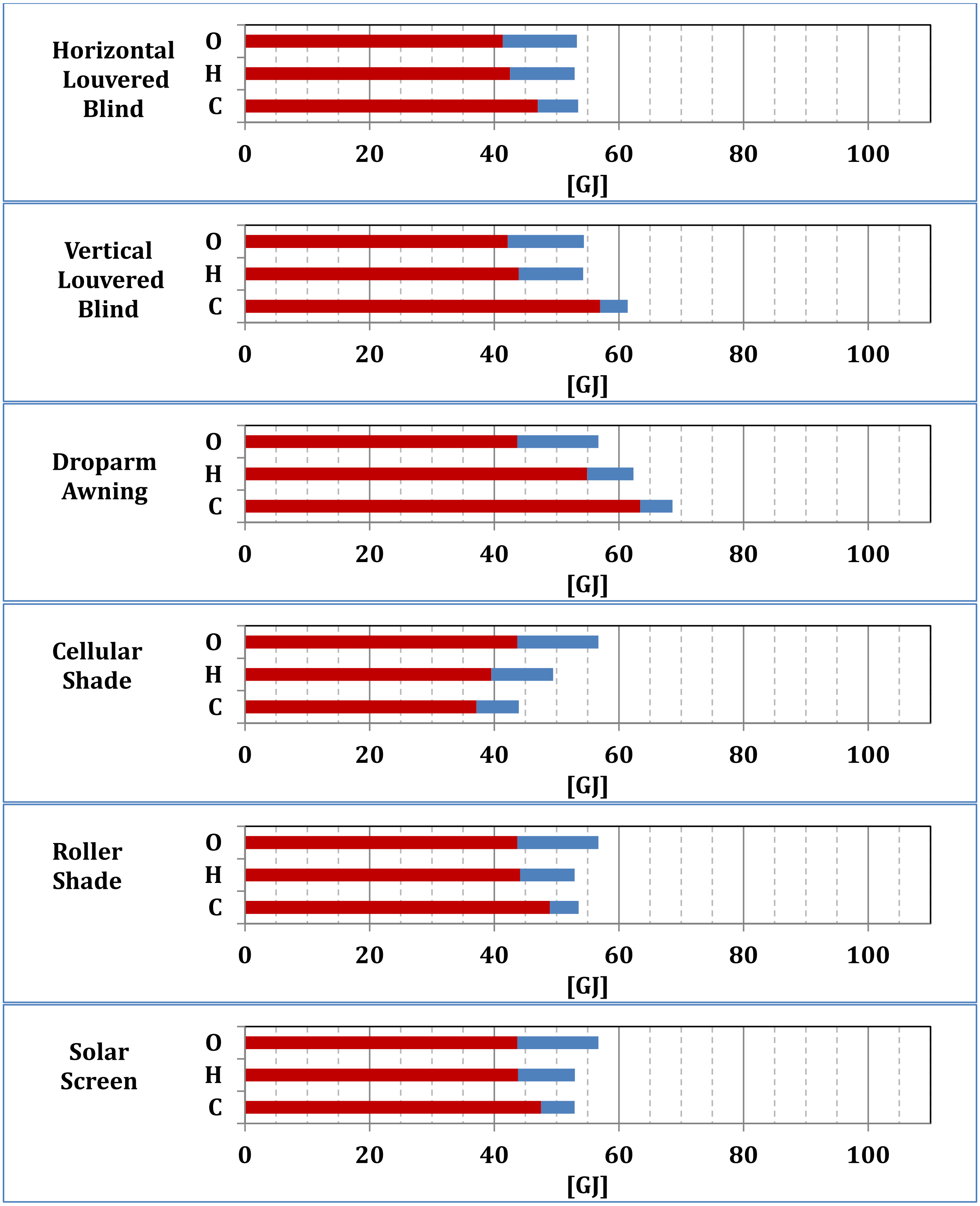


Figure 48. Operable Shade Deployment Comparison for the Quality A Case Over Double Clear Window in Central Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

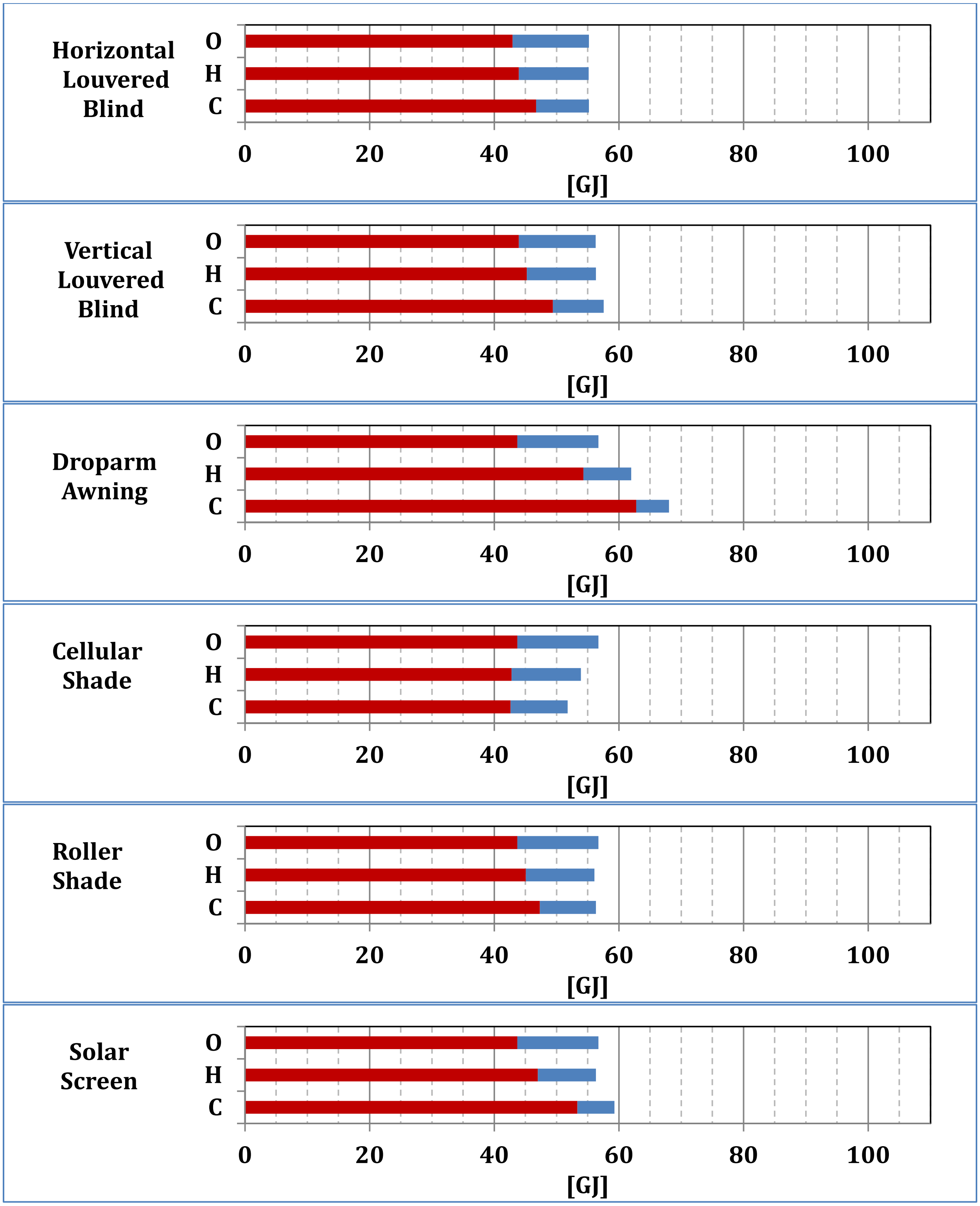
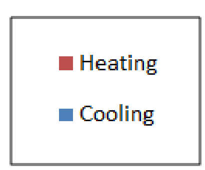


Figure 49. Operable Shade Deployment Comparison for the Quality C Case Over Double Clear Window in Central Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade



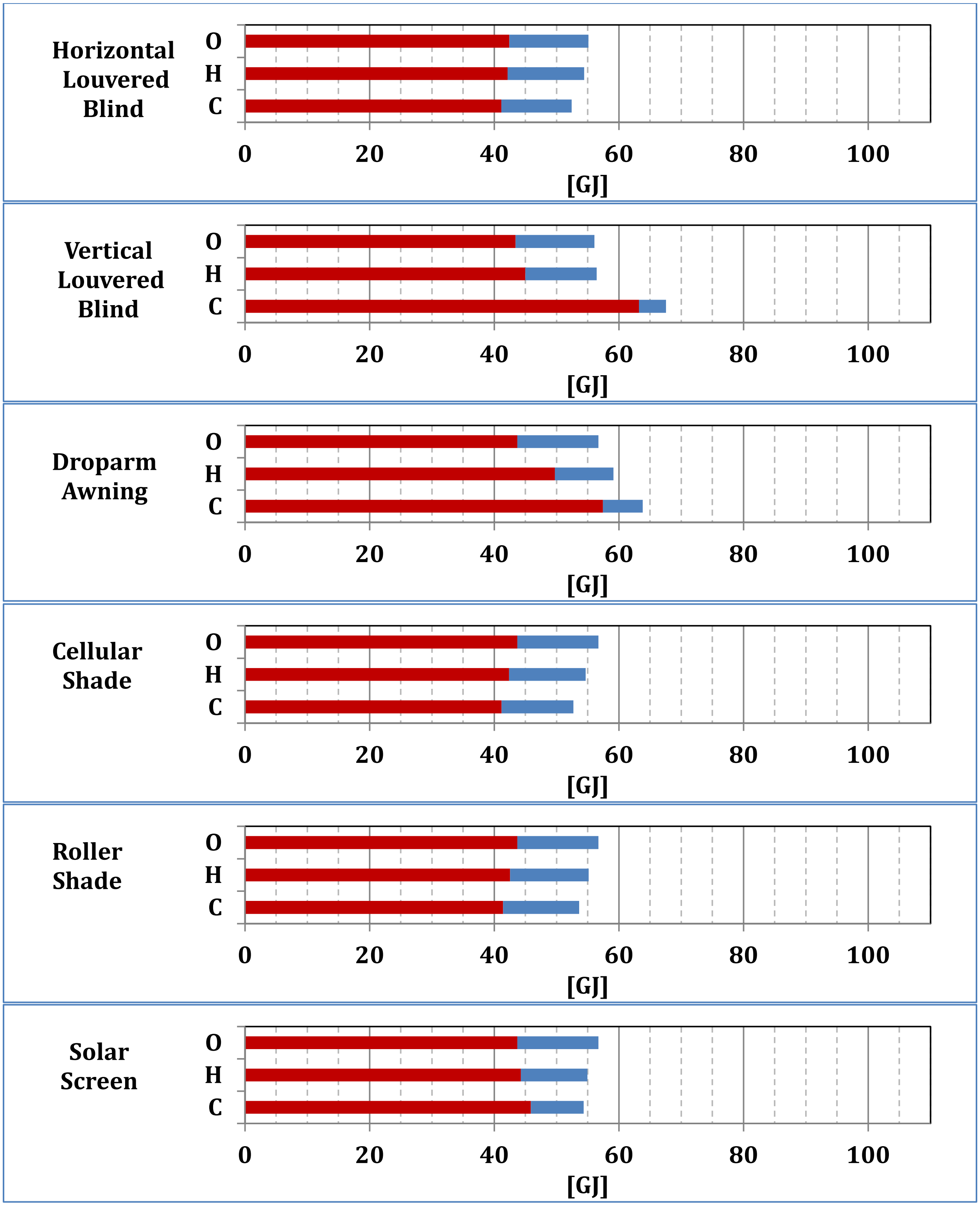
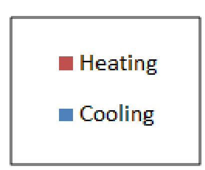


Figure 50. Operable Shade Deployment Comparison for the Quality D Case Over Double Clear Window in Central Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade



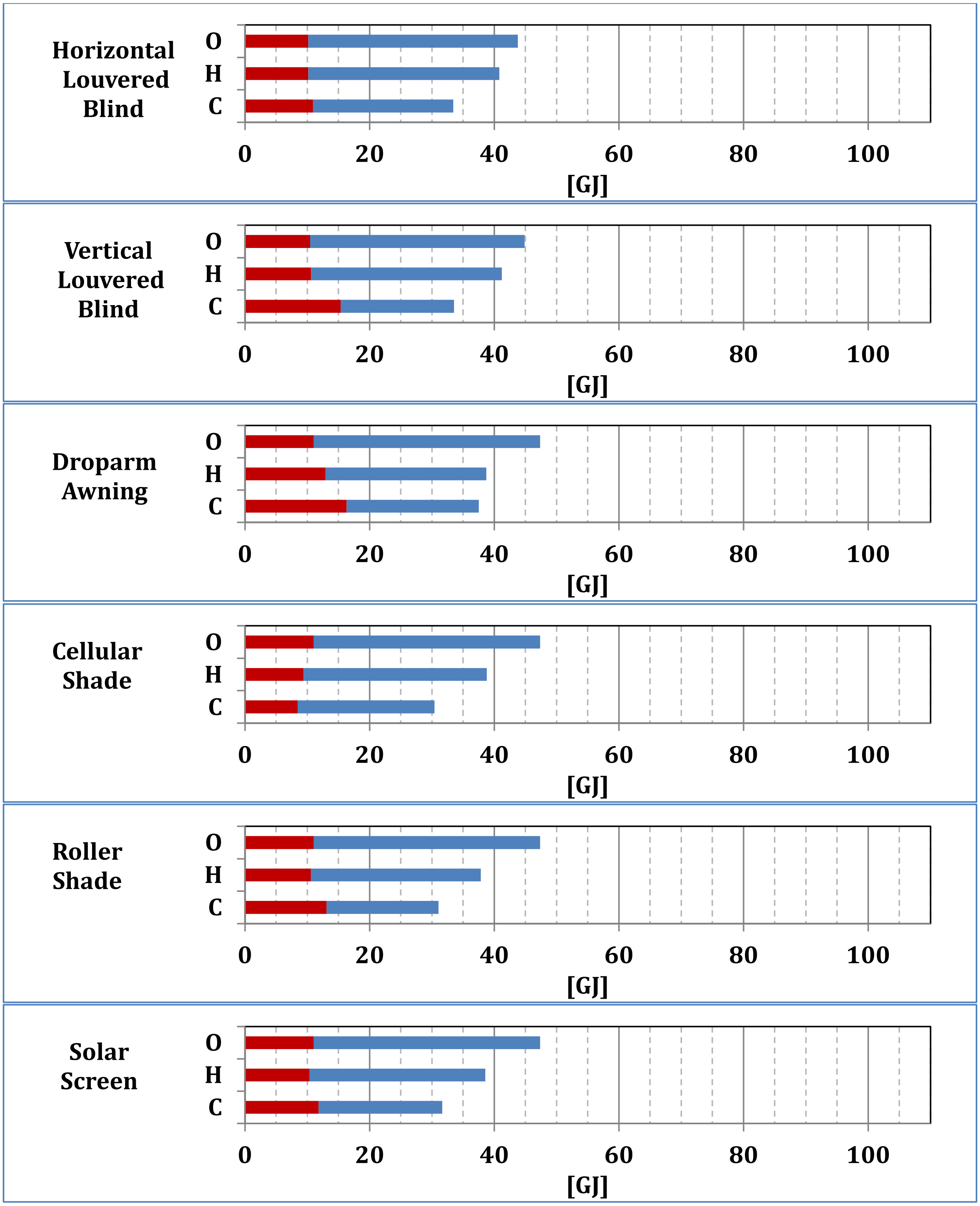
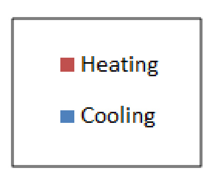


Figure 51. Operable Shade Deployment Comparison for the Quality A Case Over Double Clear Window in Southern Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade



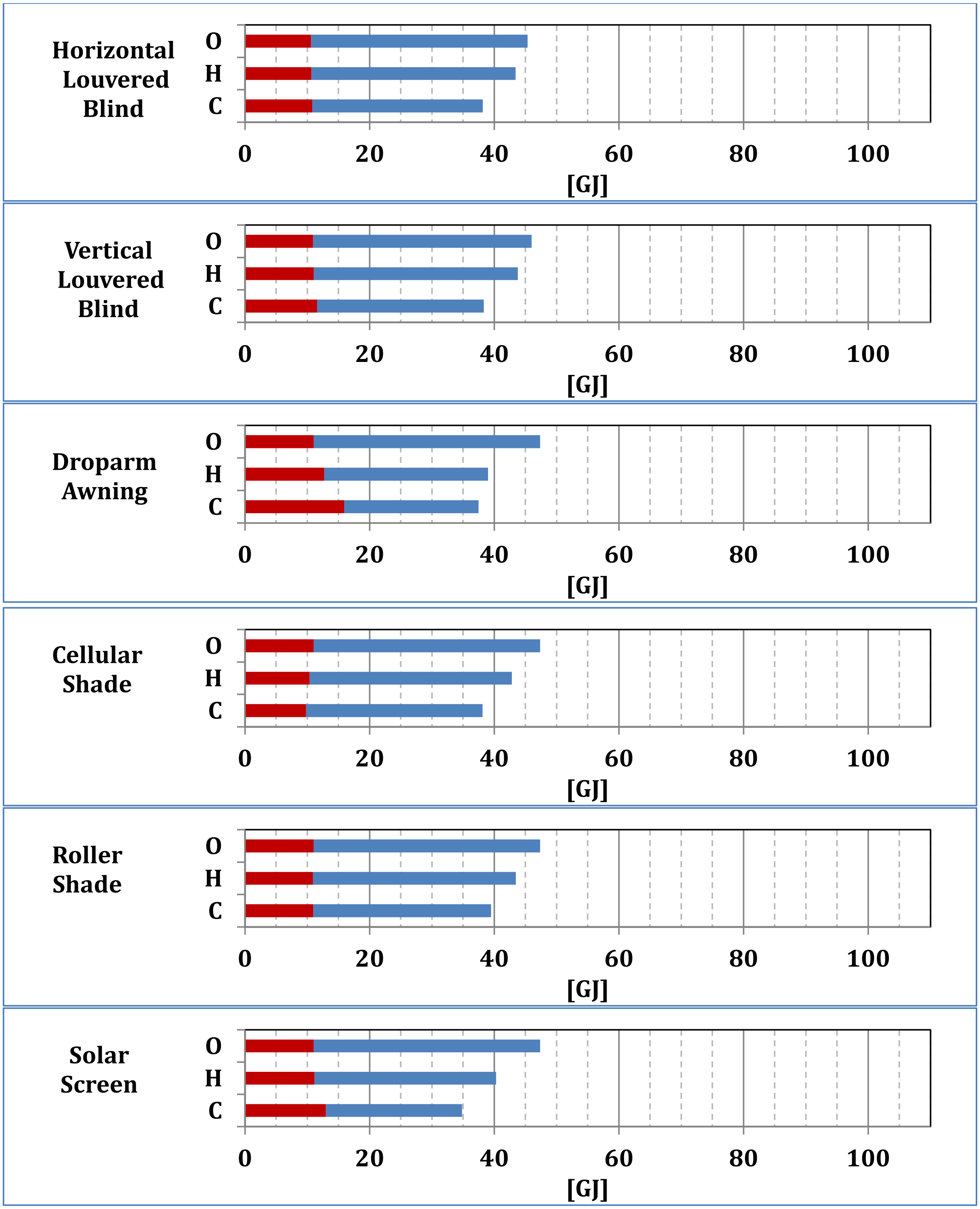


Figure 52. Operable Shade Deployment Comparison for the Quality C Case Over Double Clear Window in Southern Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade

Heating
Cooling

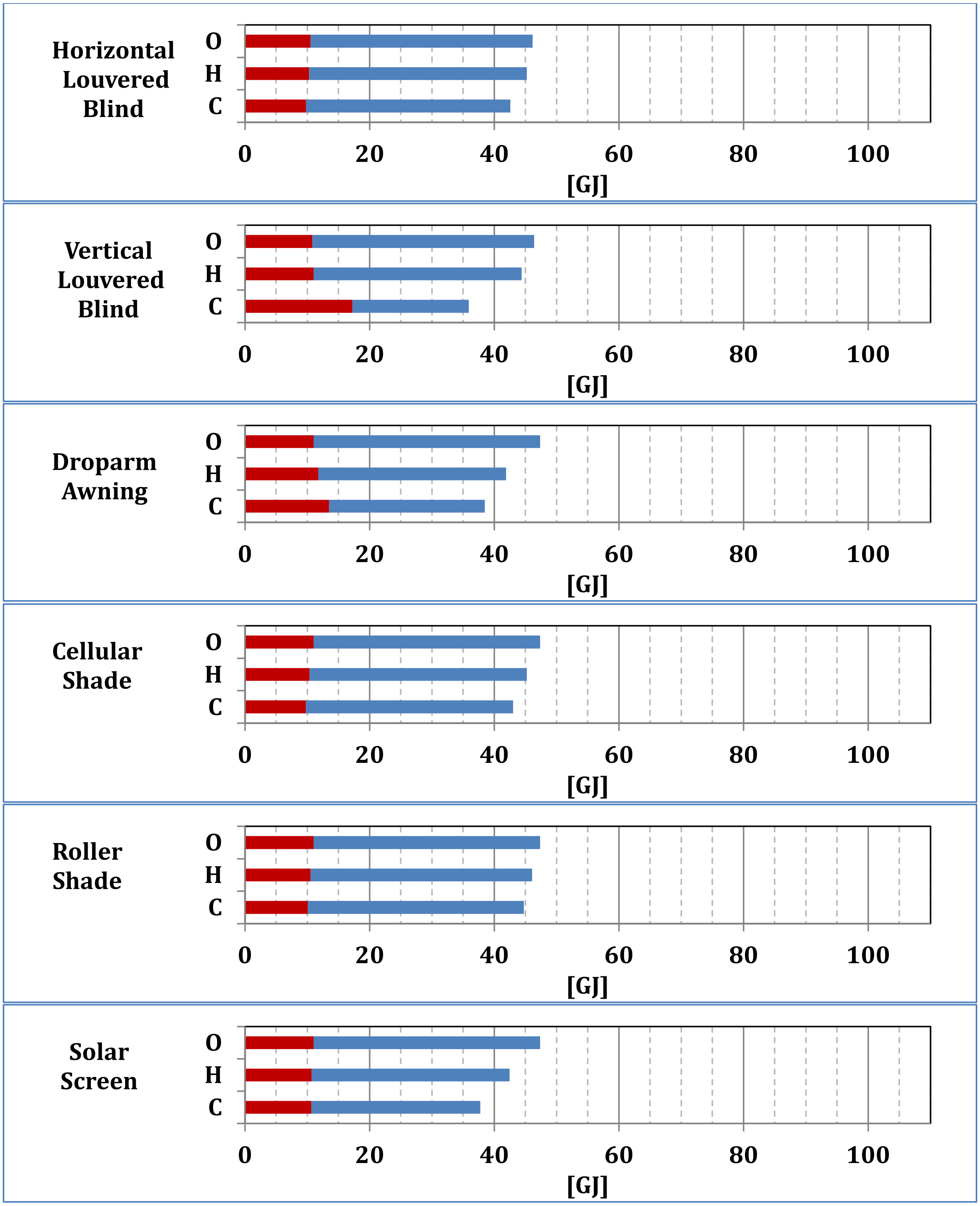
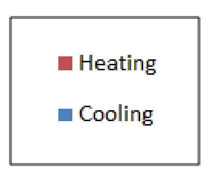


Figure 53. Operable Shade Deployment Comparison for the Quality D Case Over Double Clear Window in Southern Climate Zone

O	Open Shade
H	Half Open Shade
C	Closed Shade



APPENDIX D: Detailed List of Assumptions for Typical House

PARAMETER	Prototype Residential Model
Floor Area (ft^2 & dimensions)	2400 ft^2 (34.64ft x 34.64ft)
House Type	2-story – One core and four perimeter zones
Foundation	Basement Slab-on-Grade
Insulation	Envelope insulation levels are based on location.
Infiltration	ach50 =0 5 for Climate Zone 1 & 2 ach50 =0 3 for all other climates
Window Area (% Floor Area)	%15
Window Size	9.1 ft x 4.9 ft
Window Distribution	4 windows per floor, distributed evenly and centered on the wall
HVAC System	Furnace & A/C, Heat Pump
HVAC System Sizing	For each climate, system was sized for the base window option.)
HVAC Efficiency	AFUE=, 0.78 for Gas Furnace AFUE=, 1 for Heat Pump A/C SEER=13.0
Part-Load Performance	New part-load curves for DOE2 (Henderson 1998)
Thermostat Settings	Heating: 72°F, Cooling: 75°F No setback
Cooling Setup	N/A
Internal Loads	Number of People = 3 Hardwire Lights = 1.22 Watts/m2 Plug-in Lights = 0.478 Watts/m2 Refrigerator = 91.01 Watts – Design Level Misc. Electrical Equipment = 2.46 Watts/m2 Clothes Washer = 29.6 Watts – Design Level Clothes Dryer = 222.1 Watts – Design Level Dish Washer = 68.3 Watts – Design Level Misc. Electrical Load = 182.5 Watts – Design Level Gas Cooking range =248.5 Watts – Design Level Misc. Gas Load = 0.297 Watts/m2 Exterior Lights = 58 Watts – Design Level Garage Lights = 9.5 Watts – Design Level
Weather Data	All TMY3[(f)]
Number of Locations	12 US cities: Atlanta, Boston, Denver, Phoenix, Minneapolis, Fort Worth, Tampa, San Antonio, San Francisco, Chicago, New Orleans, Washington DC
Calculation Tool	EnergyPlus version 8.1
Energy Code	IEEC 2012

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