AERC 2

Procedures for Determining Heating and Cooling Annual Energy Performance Ratings of Fenestration Attachments

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Foreword

The Attachments Energy Rating Council (AERC) is an independent, public interest, non-profit organization whose mission is to develop and maintain a program to allow participants to rate, label, and certify the performance of fenestration attachments.

The companion document AERC 1 provides the main technical rating procedures to determine the energy performance properties (U-factor, SHGC, VT, and Air Leakage) of fenestration attachments installed in combination with standardized baseline windows and skylights under standardized conditions. This document, AERC 2, provides the procedures to determine the corresponding annual energy performance ratings for fenestration attachments when used in a model residential house: Energy Performance Index for heating, EP_H, and Energy Performance Index for cooling, EP_C. AERC 1 and AERC 2 are supported by AERC 1.1 which provides the technical procedures for determining material property inputs (optical and thermophysical properties), and AERC 1.2 which provides physical testing procedures. The energy performance ratings determined by these technical procedures are designed to be used in conjunction with AERC's labeling and certification program, as detailed in *AERC 100 National Standard for Rating the Energy Performance of Fenestration Attachments*.

The attachment product types currently covered by this standard are listed in Section 2. Other product types such as louvered shutters, roman shades, drapes, and sheer shades may be added in future versions of the standard as technical procedures are developed.

1. Introduction

The purpose of this standard is to provide the standard procedures to determine the annual energy performance ratings for fenestration attachments when used in a model residential house: Energy Performance Index for heating, EP_H, and Energy Performance Index for cooling, EP_C. The impact of the fenestration attachment product upon the energy usage of a model residential house is calculated in a heating-dominated and a cooling-dominated location under changing hourly weather conditions using *AERCalc* (Annual Energy Rating Calculation), a software tool developed by Lawrence Berkeley National Laboratory based on the EnergyPlus annual energy simulation engine. The results are standardized in dimensionless energy performance indices EP_H and EP_C which represent the impact of using the fenestration attachment product on the annual heating and cooling energy performance of the window and house, allowing a standardized comparison of different attachment products. Specifically, EP_H and EP_C are defined as the ratio of annual HVAC heating or cooling energy saving resulting from the addition of a fenestration attachment to the annual energy use caused by the fenestration in the house without the attachment, multiplied by 100. Therefore,

- An EP less than zero means the attachment has a negative impact on the energy performance of the fenestration.
- An EP of zero has neither a negative nor positive impact on the energy performance of the fenestration.

- An EP between 1 and 100 means the attachment has a positive impact on the energy performance of the fenestration, with higher EP indicating higher energy savings.
- An EP greater than 100 means the attachment and fenestration system is a net-energy producer on an annual basis compared to an adiabatic window.

This standard is intended to work in conjunction with *AERC 1 Procedures for Determining Energy Performance Properties of Fenestration Attachments*, which specifies the technical rating procedures to determine the overall heat transfer coefficient (U-factor), solar heat gain coefficient (SHGC), visible transmittance (VT), and air leakage (AL) for fenestration attachments installed in combination with standardized baseline windows and skylights under standardized conditions. AERC 1 provides the methodology to determine and report these properties as single values under static, standardized conditions, but also provides the detailed input data to AERC 2 and AERCalc that allow calculation of annual energy performance under dynamic conditions (changing hourly weather conditions that include varying angles of solar incidence, exterior temperatures, wind speeds, and interior conditions).

2. Scope

This standard shall apply to interior and exterior fenestration attachments, defined as products attached to fenestration, or attached to or near the perimeter of the inner or outer wall surrounding fenestration.

The technical procedures of this standard apply to the following fenestration attachment product types:

- Cellular Shades
- Slat Shades
- Roller Shades
- Residential Secondary Windows including Storm Windows and Window Panels
- Pleated Shades
- Solar Screens
- Surface Applied Films
- Exterior Roller Shutters
- Awnings
- Window Quilts

This standard does not apply to or address:

- Primary fenestration inclusive of windows, doors, and skylights.
- Fenestration attachments over windows or doors in interior walls of buildings and not part of the thermal envelope of the building.
- Changes in performance over time of fenestration attachments or the windows, doors, and skylights over which they are installed.
- Changes in performance using conditions other than the standardized environmental, model house, and baseline window conditions specified in this document.

- Actual energy performance in any specific building or application, which will vary due to differences in location, construction, building and product use, microclimate, year-to-year weather conditions, etc.

3. Referenced Documents and Standards

AERC 1 Revision 7 (2020) – *Procedures for Determining Energy Performance Properties of Fenestration Attachments*, Attachments Energy Rating Council, New York NY, www.aercnet.org.

AERC 1.1 Revision X (2019) – *Procedures for Determining the Optical and Thermal Properties of Window Attachment Materials*, Attachments Energy Rating Council, New York NY, www.aercnet.org.

AERC 1.2 Revision 2 (2019), *Physical Test Methods for Measuring Energy Performance Properties of Fenestration Attachments*, Attachments Energy Rating Council, New York NY, www.aercnet.org.

AERC 400, *Policy and Procedures*, Attachments Energy Rating Council, New York NY, 2019, www.aercnet.org.

AERCalc, Lawrence Berkeley National Laboratory, Berkeley CA, 2017. https://windows.lbl.gov/software/

AERC 1.3-2020, *AERC Simulation Manual*, Lawrence Berkeley National Laboratory, Berkeley CA, 2020.

Complex Glazing Database (CGDB), Lawrence Berkeley National Laboratory, Berkeley CA, 2019. https://windows.lbl.gov/software/

Certified Product Database (CPD), Attachments Energy Rating Council, New York NY, 2019, www.aercnet.org.

"Energy Performance Indices EP_C and EP_H - Calculation Methodology and Implementation in Software Tool", Lawrence Berkeley National Laboratory, Berkeley CA, 2020.

"Modeling Procedure for Window Awnings", Lawrence Berkeley National Laboratory, Berkeley CA, 2020.

IEEE/ASTM SI 10-2010, *American National Standard for Metric Practice*, ASTM International, West Conshohocken PA, 2010, www.astm.org.

International Glazing Database (IGDB), Lawrence Berkeley National Laboratory, Berkeley CA, 2019. https://windows.lbl.gov/software/

THERM 7, Lawrence Berkeley National Laboratory, Berkeley CA, 2019. https://windows.lbl.gov/software/

WINDOW 7, Lawrence Berkeley National Laboratory, Berkeley CA, 2019. https://windows.lbl.gov/software/

4. Terminology

4.1. Definitions

See AERC 400 Appendix A. Where there is a difference in definition between AERC 400 Appendix A and other reference documents, the definition from AERC 400 shall take precedence.

4.2. Acronyms

AERC	Attachments Energy Rating Council
AL	Air leakage
CPD	Certified product database
CGDB	Complex glazing database
EP_H	Energy Performance Index for heating
EP_C	Energy Performance Index for cooling
IGDB	International glazing database
SHGC	Solar heat gain coefficient
VT	Visible transmittance

5. Technical Procedures

This section provides the standard procedures to determine the annual energy performance ratings for fenestration attachments when used in a model residential house: Energy Performance Index for heating, EP_H, and Energy Performance Index for cooling, EP_C.

5.1. Definition of Energy Performance Indices

The Energy Performance Index is defined as the ratio of annual HVAC heating or cooling energy saving resulting from the use of the fenestration attachment product to the annual energy use caused by the baseline fenestration in the standardized model house without the attachment, multiplied by 100:

$$EP = \frac{E_{B-S}}{E_{B-A}} \times 100$$

where

EP = energy performance index for either heating (EP_H) or cooling (EP_C).
EP_H is calculated in a heating-dominated climate (Minneapolis, MN).
EP_c is calculated in a cooling-dominated climate (Houston, TX).

$E_{B-A} = E_B - E_A$, annual heating or cooling energy use caused by the baseline window, compared to an adiabatic window

$E_{S-A} = E_S - E_A$, annual heating or cooling energy use caused by the baseline window with the fenestration product attachment, compared to an adiabatic window

$E_{B-S} = E_B - E_S$, annual heating or cooling energy savings from using the fenestration attachment product over the baseline window

and

E_A = annual HVAC cooling or heating energy use of the model house with adiabatic windows (windows replaced with adiabatic surfaces with zero heat flux)

E_B = annual HVAC cooling or heating energy use of the model house with baseline windows only

E_S = annual HVAC cooling or heating energy use of the model house with baseline windows with the fenestration product attachment.

The A, B, and S conditions for the model house are shown schematically in Figure 1.

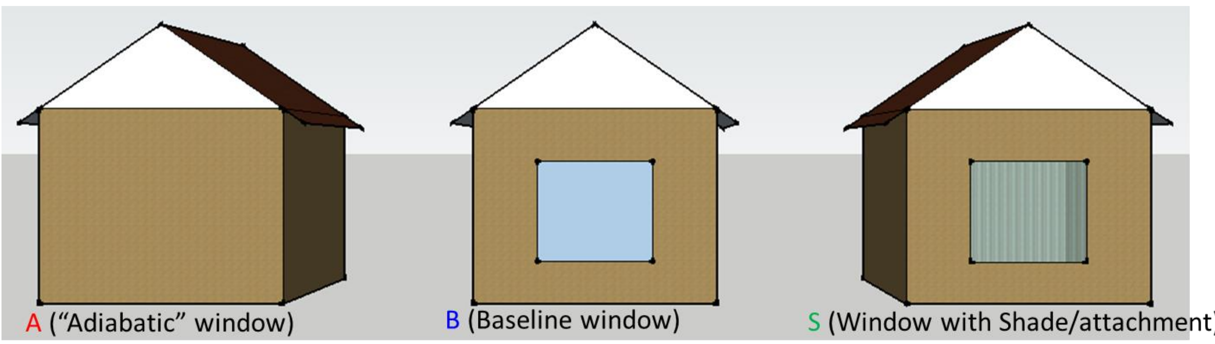

Figure 1. Schematic of three different model house cases

In general,

- An EP less than zero means the attachment has a negative impact on the energy performance of the baseline fenestration.
- An EP between 0 and 100 means the attachment has a positive impact on the energy performance of the baseline fenestration, with higher EP indicating higher energy savings.
- An EP greater than 100 means the attachment and fenestration system is a net-energy producer on an annual basis compared to an adiabatic window.

5.2. Energy Performance Calculation

EP_H and EP_C shall be calculated for each fenestration attachment product using the currently approved Lawrence Berkeley National Laboratory AERCalc software tool and the AERC 1.3 Simulation Manual.

Full details on the AERCalc calculation methodology and Energy Plus runs are provided in *"Energy Performance Indices EP_C and EP_H - Calculation Methodology and Implementation in Software Tool",* Lawrence Berkeley National Laboratory, 2020, reproduced in Appendix A, and "*Modeling Procedure for Window Awnings*", Lawrence Berkeley National Laboratory, Berkeley CA, 2020, reproduced in Appendix H.

5.2.1. Standardized Conditions

Standardized assumptions for the model home and baseline windows are provided in *"Energy Performance Indices EP_C and EP_H - Calculation Methodology and Implementation in Software Tool",* Lawrence Berkeley National Laboratory, 2020, reproduced in Appendix A, and "*Modeling Procedure for Window Awnings*", Lawrence Berkeley National Laboratory, Berkeley CA, 2020, reproduced in Appendix H.

The Energy Performance Index for heating, EP_H, is calculated for the model house in a heating-dominated climate, using TMY3 weather data for Minneapolis-St Paul International Airport (WMO# 726580).

The Energy Performance Index for cooling, EP_C, is calculated for the model house in a cooling-dominated climate, using TMY3 weather data for Houston-Bush Intercontinental Airport (WMO# 722430).

5.2.2. Product Input Data

Prior to calculation of EP_H and EP_C for a fenestration attachment product, the energy performance properties of the fenestration attachment product shall be determined in accordance with AERC 1.

5.2.2.1. Thermal and Solar-Optical Input Properties

Thermal and solar-optical input properties that impact the annual energy calculation are imported from the currently approved Lawrence Berkeley National Laboratory WINDOW / THERM software tools in accordance with AERC 1, the AERC 1.3 Simulation Manual, and the AERCalc user manual. For products with only tested properties for U-factor or SHGC, see Section 5.2.2.3.

Different fenestration attachment product types have a different number of degrees of freedom for operation (e.g. retraction, slat angle). As detailed in Appendix A, AERCalc conducts a different number of EnergyPlus runs for each product type based upon the degrees of freedom and deployment schedule, and requires a different number of input files from WINDOW simulations. Table 1 gives a summary of the combined number of WINDOW simulations required for AERC 1 and AERC 2 for each fenestration attachment product type, and operation schedules are defined in Appendix A and Appendix H. Product types and the meaning of "fully open" or "fully retracted" and "fully closed" or "fully deployed" for each product type are defined in Section 5.2 of AERC 1.

Table 1. WINDOW simulations required by AERC 1 and AERC 2 for different fenestration attachment product types.

Product Type	AERCalc naming code	Degrees of freedom	WINDOW simulations

Cellular shades	CS	1	2: fully open, fully closed
Slat shades*	VB and VL*	2	5: fully open, fully closed, deployed with horizontal 0° slat angle, deployed with -45° slat angle, deployed with +45° slat angle
Roller shades	RS	1	2: fully open, fully closed
Storm Windows & Window Panels	WP	0	1: fully closed
Pleated Shades	PS	1	2: fully open, fully closed
Solar Screens	SS	0	1: fully closed
Applied Films	AF	0	1
Awnings - fixed	AY1A, AY1B, AY2A, AY2B, AS1A, AS1B, AS2A, AS2B	0	1: fully deployed or midpoint deployed geometry as specified in AERC 1 (The seasonally installed fixed awnings schedule also uses uninstalled position with properties of baseline window.)
Awnings - operable	AO1A, AO1B, AO2A, AO2B	1	2: fully deployed, midpoint deployed (fully retracted / unshaded position uses properties of baseline window).

* For the naming convention used in AERCalc for importing input files from WINDOW, slat shades with horizontal slats/vanes shall be named as Venetian Blinds, and slat shades with vertical slats/vanes shall be named as Vertical Louvers.
See AERC 1.3 Simulation Manual.

5.2.2.2. Air Leakage

Air infiltration of the attachment product and baseline window must also be provided as an input parameter for EnergyPlus runs in the AERCalc annual energy performance calculation.

- Where air leakage (AL) is determined for a fenestration attachment product in accordance with Section 5.1.5 of AERC 1, the reported AL value in L/s/m^2 (cfm/ft^2) shall be used in AERCalc.
- Where AL is not required and not determined in accordance with AERC 1 for a fenestration attachment product, a default value the same as the baseline window air infiltration shall be used.

5.2.2.3. Test-Only Products

Currently, EP_H and EP_C cannot be calculated using AERCalc for fenestration attachment products that do not have WINDOW / THERM input files and use the test option for U-factor or SHGC in Sections 5.1.2.2 and 5.1.3.2 of AERC 1.

AERC 100 provides for these products to be certified and listed for U-factor, SHGC, VT, and AL, and the ability to determine EP_H and EP_C may be added in future versions of the standard as technical procedures are developed.

6. Reporting

The following information shall be reported:

- Product manufacturer
- Product type, identification, drawings, and materials
- Simulation laboratory
- Date of report
- EP_H and EP_C rounded and reported to integer values. Rounding shall be in accordance with IEEE/ASTM SI 10-2010.
- Products grouped in accordance with AERC 1, if applicable.
- All other information required for inclusion in the certified product database in accordance with AERC 100 and AERC 400 Appendix G (Approved Software and Manuals).

Appendix A - AERCalc Calculation Methodology

(Reproduced from *"Energy Performance Indices EP_C and EP_H - Calculation Methodology and Implementation in Software Tool",* Lawrence Berkeley National Laboratory, Berkeley CA, 2020.)

Energy Technologies Area

Energy Performance Indices EP_C and EP_H Calculation Methodology and Implementation in Software tool

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1. INTRODUCTION & BACKGROUND

Energy performance indices, EP_C and EP_H of window attachments are developed on the basis of ISO 18292 standard (ISO 2011), which gives methodology for calculating heating and cooling energy performance of windows. This methodology is based on the results of energy simulation of a typical residential building (house) in a typical cooling and heating climate.

2. Derivation of Energy Performance Index

For the purpose of calculating energy performance indices of window attachments, Houston climate was selected for cooling performance index, EP_C and Minneapolis was selected for heating energy performance index, EP_H. Energy simulation is done using sub-hourly energy analysis program EnergyPlus (DOE 2016). Three different cases are simulated:

A. Typical house with windows replaced by adiabatic surfaces (i.e., zero heat flux through window surfaces)
B. Typical house with baseline windows
S. Typical house with baseline windows and window shade/attachment over them

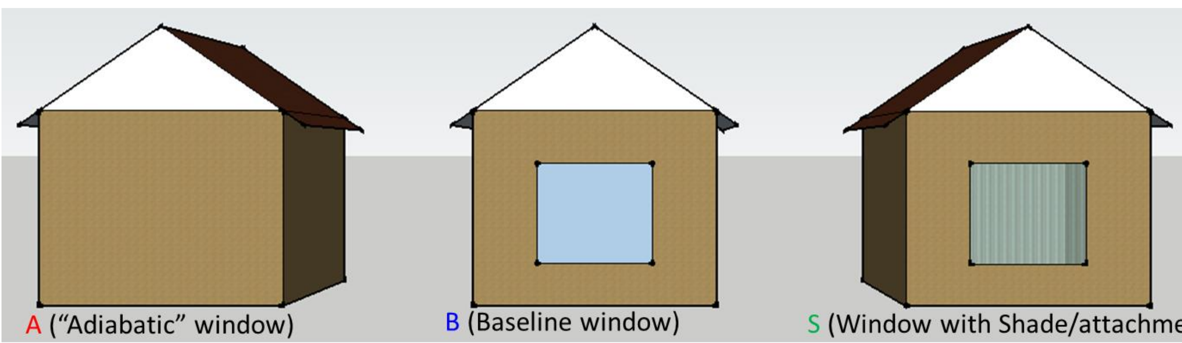


Figure 1. Schematic of three different house models

Energy simulation is done over the typical TMY3 year for each location and results of energy for each case are expressed as:

E_A: annual HVAC cooling or heating energy use of the house with "adiabatic" window

E_B: annual HVAC cooling or heating energy use of the house with baseline window only

E_S: annual HVAC cooling or heating energy use of the house with window attachment.

Based on the results of energy simulation, the following quantities are calculated:

$E_{B-A} = E_B - E_A$, annual energy use caused by the baseline window

$E_{B-S} = E_B - E_S$, window attachment energy savings vs. the baseline window

Energy performance indices of window attachments, EP_C, and EP_H are defined as the ratio of annual cooling/heating energy saving resulting from the addition of window attachment to the annual energy use caused by the baseline window without attachment.

$$EP_C = \frac{(E_{B-S})_{Houston}}{(E_{B-A})_{Houston}} \quad (1)$$

$$EP_H = \frac{(E_{B-S})_{Minneapolis}}{(E_{B-A})_{Minneapolis}} \quad (2)$$

Typical house is defined from the DOE standard residential building model, combining several building vintages into a single typical house. The listing of assumptions is detailed in Appendix A.

Energy plus runs for both *Baseline* and *Adiabatic* runs are performed once for each climate, making for four sets of results (two for heating and two for cooling EP) and saved as fixed information.

EnergyPlus model for the house with baseline windows, E_B is run using Autosize option for HVAC. This is done once for cooling and once for heating climates. Such calculated HVAC size is then fixed for all subsequent runs, including adiabatic and attachment cases. Baseline windows run is detailed in section 1.1.

EnergyPlus model of a house with window attachment is run at least once per product for fixed attachments (i.e., window panels, solar screens, surface-attached films), two times for 1-D operation shades (e.g., roller shades, cellular shades, pleated shades, roman shades, etc.), where one run is for shade fully closed and second run is for shade half closed (fully retracted option is identical to baseline window); and 7 runs for 2-D operation shades (venetian blinds, vertical blinds, etc.). More details are provided in section 1.3.

3. EnergyPlus Runs

Energy analysis is done using EnergyPlus simulation tool and IDF input file for EnergyPlus simulation is created from the collection of include files (*.inc). The reason for splitting IDF files in several include files is that for different runs, only individual include file would be replaced. The list of include files in following sections are marked in green, yellow, and red, signifying how these files are set. Green colored include files are fixed and are used in each case, E_A, E_B, and E_S. Yellow colored include files are fixed, but are inserted based on the case being run. Red colored include files are specific to each window attachment and are prepared on the fly. More details about include files are provided in Appendix C.

Besides IDF files for each run, energy simulation also requires weather data file (TMY3 file). The weather data file names for these two climates are listed below:

- Houston: USA_TX_Houston-Bush.Intercontinental.AP.722430_TMY3.epw
- Minneapolis: USA_MN_Minneapolis-St.Paul.Intl.AP.726580_TMY3.epw

3.1 Adiabatic Windows Run

Houston:

- AERC_Base_Building_Houston.inc
- Air_infiltration_adiabatic_Houston.inc
- System_sizing_Houston.inc

Minneapolis:

- AERC_Base_Building_Minneapolis.inc
- Air_infiltration_adiabatic_Minneapolis.inc
- System_sizing_Minneapolis.inc

Both climate zones:

- Window_configuration.inc
- Window_construction_adiabatic.inc

3.2 Baseline Windows Run

For the baseline window run, the following include files are provided.

Houston:

- AERC_Base_Building_Houston.inc
- Air_infiltration_baseline_Houston.inc
- System_autosize_Houston.inc

Minneapolis:

- AERC_Base_Building_Minneapolis.inc
- Air_infiltration_baseline_Minneapolis.inc
- System_autosize_Minneapolis.inc

Both climate zones:

- Window_configuration.inc
- Window_construction_baseline.inc

3.3 Windows with Attachments

Window construction include files for windows with attachments are first defined for each window attachment in WINDOW software tool and exported as IDF file. While most of window attachments have single degree of freedom in operation (retraction operation only) or 0 degree of freedom (fixed window attachments) and therefore have single construction description for its deployed position, some attachments have 2 degrees of freedom (e.g., louvered shades), resulting in 4 window construction records:

1) horizontal slats, or 0 deg
2) closed slats, or 90 deg
3) -45 deg
4) 45 deg

Depending on the degree of freedom for window attachments, different number of EnergyPlus runs will be required. Table 1 gives summary for each window attachment class/type.

Table 1. Simulation runs for different deployment situation of each shade

Shade Type	Degrees of freedom	Fully Deployed (top & bottom window w/ shade)	Half Deployed (only top window w/ shade)	Total runs
Roller shades	1	1 run	1 run	2
Cellular shades	1	1 run	1 run	2
Solar Screens	0	1 run	--	1
Applied Films	0	1 run	--	1
Venetian Blinds	2	4 runs	3 runs	7
Vertical Blinds	2	4 runs	3 runs	7
Window panels	0	1 run	--	1
Pleated Shades	1	1 run	1 run	2

3.3.1 Fully Deployed Window Attachments Runs

The include files needed for fully deployed window attachments run are listed below.

Houston:

- AERC_Base_Building_Houston.inc
- Air_infiltration_user_input_Houston.inc
- System_sizing_Houston.inc

Minneapolis:

- AERC_Base_Building_Minneapolis.inc
- Air_infiltration_user_input_Minneapolis.inc
- System_sizing_Minneapolis.inc

Both climate zones:

- Window_configuration.inc
- 1D window attachments: Window_construction_user_input.inc
- 2D window attachments – louvered blinds:
  - Window_ construction_user_input0.inc
  - Window_ construction_user_input90.inc
  - Window_ construction_user_input-45.inc
  - Window_ construction_user_input+45.inc

3.3.2 Half-Deployed Window Attachments Runs

The include files needed for half-deployed window attachments run are listed below.

Houston:

- AERC_Base_Building_Houston.inc
- Air_infiltration_baseline_Houston.inc
- System_sizing_Houston.inc

Minneapolis:

- AERC_Base_Building_Minneapolis.inc
- Air_infiltration_baseline_Minneapolis.inc
- System_sizing_Minneapolis.inc

Both climate zones:

- Window_configuration.inc
- Window_construction_baseline.inc
- 1D window attachments: Window_construction_user_input.inc
- 2D window attachments – louvered blinds:
    - Window_ construction_user_input0.inc
    - Window_ construction_user_input90.inc
    - Window_ construction_user_input-45.inc
    - Window_ construction_user_input+45.inc

4. Calculation of Energy Use

Energy use for each case is calculated from HVAC system results of EnergyPlus simulation. Instructions for generating correct output results are provided in include file EP_Output_Fields.inc, shown in Appendix B. Results are stored in IDF_input_file_name.csv file. The following output fields are used in calculation of energy use:

Houston:

- "CENTRAL SYSTEM_UNIT1: Air System DX Cooling Coil Electric Energy [J](Hourly)"
- "CENTRAL SYSTEM_UNIT1:Air System Fan Electric Energy [J](Hourly)".

Minneapolis:

- "CENTRAL SYSTEM_UNIT1: Air System Gas Energy [J](Hourly)"
- "CENTRAL SYSTEM_UNIT1:Air System Fan Electric Energy [J](Hourly)".

For brevity and subsequent use in equations, the following nomenclature will be used:

$E_{DX\,Coil}(\tau_h)$ = CENTRAL SYSTEM_UNIT1: Air System DX Cooling Coil Electric Energy [J](Hourly)

$E_{Fan}(\tau_h)$ = CENTRAL SYSTEM_UNIT1:Air System Fan Electric Energy [J](Hourly)

$E_{Gas}(\tau_h)$ = CENTRAL SYSTEM_UNIT1: Air System Gas Energy [J](Hourly)

Total energy, required for the calculation of E_A, E_B, and E_S is calculated by summing up all hours when cooling system is on (CS=ON) in Houston and when heating system is on (HS=ON) in Minneapolis. "CS=ON" when "CENTRAL SYSTEM_UNIT1: Air System DX Cooling Coil Electric Energy [J](Hourly)", is larger than 0. Correspondingly, "HS=ON" when "CENTRAL SYSTEM_UNIT1: Air System Gas Energy [J](Hourly)", is larger than 0. The energy totals are also corrected to source energy using following conversion factors:

SF_E = conversion factor from electricity to source energy in GJ, $3.167 \cdot 10^{-9}$

SF_G = conversion factor from natural gas to source energy in GJ, $1.084 \cdot 10^{-9}$

4.1 Adiabatic Windows Runs

The energy use for adiabatic window runs are calculated from output of EnergyPlus simulation for adiabatic window case and normalized using source energy correction, which is applied to selected energy contributions.

Houston:

$$E_A = \left(\sum_{CS=ON} E_{DXCoil}\left(\tau_h\right)_A + \sum_{CS=ON} E_{Fan}\left(\tau_h\right)_A \right) \cdot SF_E \tag{3}$$

Minneapolis:

$$E_A = \left(\sum_{HS=ON} E_{Gas}\left(\tau_h\right)_A \right) \cdot SF_G + \left(\sum_{HS=ON} E_{Fan}\left(\tau_h\right)_A \right) \cdot SF_E \tag{4}$$

The resulting energy use E_A is expressed in GJ of source energy. E_A for both locations is calculated once and saved for the calculation of EP.

4.2 Baseline Windows Runs

The energy use for baseline window runs are calculated from output of EnergyPlus simulation for baseline window case and normalized using source energy correction, which is applied to selected energy contributions.

Houston:

$$E_B = \left(\sum_{CS=ON} E_{DXCoil}\left(\tau_h\right)_B + \sum_{CS=ON} E_{Fan}\left(\tau_h\right)_B \right) \cdot SF_E \tag{5}$$

Minneapolis:

$$E_B = \left(\sum_{HS=ON} E_{Gas}\left(\tau_h\right)_B \right) \cdot SF_G + \left(\sum_{HS=ON} E_{Fan}\left(\tau_h\right)_B \right) \cdot SF_E \tag{6}$$

The resulting energy use E_B is expressed in GJ of source energy. E_B for both locations is calculated once and saved for the calculation of EP.

4.3 Windows with Attachments Runs

Energy uses for windows with attachments are done on demand for each attachment for which EP is calculated. Depending on the attachment type, different level of calculation is done. Details of these calculations for different attachment types are provided below.

4.3.1 Fixed Attachments

For fixed attachments (i.e., non-operable), single and non-weighted calculation is done, similar to cases of adiabatic and baseline window energy use calculations:

Houston:

$$E_S = \left(\sum_{CS=ON} E_{DXCoil}\left(\tau_h\right)_S + \sum_{CS=ON} E_{Fan}\left(\tau_h\right)_S \right) \cdot SF_E \tag{7}$$

Minneapolis:

$$E_S = \left(\sum_{HS=ON} E_{Gas}\left(\tau_h\right)_S \right) \cdot SF_G + \left(\sum_{HS=ON} E_{Fan}\left(\tau_h\right)_S \right) \cdot SF_E \tag{8}$$

The resulting energy use E_S is expressed in GJ of source energy.

4.3.2 Operable Window Attachments with 1-D operation

For these window attachment types, the operation consists of attachment retraction to various degrees. The deployment schedule for operable window attachments, was developed from the results of a behavioral study (DRI 2013). Based on the results of the survey of 2,467 households in 12 markets, a deployment schedule was developed for 3 periods during the day, two periods during the week, and for two seasons. 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, week and season.

The deployment positions of window attachments considered were:

1. **O:** Open (Baseline window runs)
2. **H:** Half-Open (Half-Deployed window attachment runs)
3. **C:** Closed (Fully-Deployed window attachment runs)

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. of next day)

The periods of week considered were:

1. **D:** Weekday
2. **E:** Weekend and holidays

Note: Each weather data file contains standard US holidays, which are assigned the weekend schedule in the EnergyPlus input.

Time-weighting of energy use is done in addition to the consideration when cooling or heating system is on, to calculate E_S. 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 source energy use from operable window shades with 1 degree of freedom:

$$E_S = E_O + E_H + E_C \tag{9}$$

Where:

$$E_O = \sum_{\tau_w=S_1}^{S_N} \left(E_{SDO}(\tau_w) + E_{SEO}(\tau_w)\right) + \sum_{\tau_w=W_1}^{W_N} \left(E_{WDO}(\tau_w) + E_{WEO}(\tau_w)\right) \tag{10}$$

$$E_H = \sum_{\tau_w=S_1}^{S_N} \left(E_{SDH}(\tau_w) + E_{SEH}(\tau_w)\right) + \sum_{\tau_w=W_1}^{W_N} \left(E_{WDH}(\tau_w) + E_{WEH}(\tau_w)\right) \tag{11}$$

$$E_C = \sum_{\tau_w=S_1}^{S_N} \left(E_{SDC}(\tau_w) + E_{SEC}(\tau_w)\right) + \sum_{\tau_w=W_1}^{W_N} \left(E_{WDC}(\tau_w) + E_{WEC}(\tau_w)\right) \tag{12}$$

Where (Equations 5-16):

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

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

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

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

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

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

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

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

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

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

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

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

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 Appendix D.

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

Table 2. Energy Use Variables

	Cooling Weekday	Cooling Weekend	Heating Weekday	Heating Weekend
Open	E_{SDO}	E_{SEO}	E_{WDO}	E_{WEO}
Half-open	E_{SDH}	E_{SEH}	E_{WDH}	E_{WEH}
Closed	E_{SDC}	E_{SEC}	E_{WDC}	E_{WEC}

Table 3. Deployment Fraction Variables

	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_{WDNO}	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_{WDNH}	F_{WEMH}	F_{WEAH}	F_{WENH}
Closed	F_{SDMC}	F_{SDAC}	F_{SDNC}	F_{SEMC}	F_{SEAC}	F_{SENC}	F_{WDMC}	F_{WDAC}	F_{WDNC}	F_{WEMC}	F_{WEAC}	F_{WENC}

Deployment fraction data for North (heating) and South (cooling) climates are presented in Table 4 and Table 5.

Table 4. Deployment Schedule for North (Heating) Climate Zone

Cooling Weekday				Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Open	0.26	0.24	0.23	0.26	0.25	0.23	0.29	0.30	0.23	0.28	0.29	0.22
Half-open	0.35	0.34	0.32	0.36	0.36	0.33	0.32	0.33	0.28	0.32	0.33	0.29
Closed	0.39	0.41	0.45	0.38	0.39	0.44	0.39	0.38	0.49	0.40	0.38	0.49

Table 5. Deployment Schedule for South (Cooling) Climate Zone

Cooling Weekday				Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Open	0.17	0.15	0.13	0.18	0.17	0.14	0.23	0.23	0.17	0.23	0.23	0.17
Half-open	0.26	0.25	0.23	0.26	0.25	0.24	0.25	0.26	0.22	0.27	0.27	0.23
Closed	0.57	0.60	0.65	0.56	0.58	0.62	0.52	0.51	0.61	0.51	0.50	0.59

Cooling and heating periods are defined for each city in Appendix D.

$E(\tau_w, \tau_d, \tau_h)$ is calculated as follows for each city:

Houston:

$$E_O(\tau_w, \tau_d, \tau_h) = \left(E_{DXCoil}(\tau_h)_B + E_{Fan}(\tau_h)_B\right)_{CS=ON} \cdot SF_E \tag{13}$$

$$E_H(\tau_w, \tau_d, \tau_h) = \left(E_{DXCoil}(\tau_h)_H + E_{Fan}(\tau_h)_H\right)_{CS=ON} \cdot SF_E \tag{14}$$

$$E_C(\tau_w, \tau_d, \tau_h) = \left(E_{DXCoil}(\tau_h)_C + E_{Fan}(\tau_h)_C\right)_{CS=ON} \cdot SF_E \tag{15}$$

Minneapolis:

$$E_O(\tau_w, \tau_d, \tau_h) = \left(E_{Gas}(\tau_h)_B\right) \cdot SF_G + \left(E_{Fan}(\tau_h)_B\right)_{HS=ON} \cdot SF_E \tag{16}$$

$$E_H(\tau_w, \tau_d, \tau_h) = \left(E_{Gas}(\tau_h)_H\right) \cdot SF_G + \left(E_{Fan}(\tau_h)_H\right)_{HS=ON} \cdot SF_E \tag{17}$$

$$E_C(\tau_w, \tau_d, \tau_h) = \left(E_{Gas}(\tau_h)_C\right) \cdot SF_G + \left(E_{Fan}(\tau_h)_C\right)_{HS=ON} \cdot SF_E \tag{18}$$

4.3.3 Operable Window Attachments with 2-D operation

Similar to window attachments with 1 degree freedom in operation, energy use for window attachment with 2-D operation is calculated by summing-up weighting Open, Half-Open and Closed states. Because of the increased complexity of the definition of Open, and Half-Open states for attachments with 2 degrees of freedom (retraction levels and slat angle), multiple deployment states are attached to Open and Half-Open states. Currently, louvered blinds (both horizontal louvered blinds, or Venetian blinds, and vertical louvered blinds) have simulation models available for them. Assignment of different EnergyPlus runs and deployment states for louvered blinds are shown in Table 6.

Table 6. Deployment Information for Louvered blinds

		Run No.	Top Window	Bottom Window
Open (O)	Fully-deployed	1	0º slat angle	0º slat angle
	Fully-retracted	2	No shade	No shade
Half-Open (H)	Fully-deployed	3	45º slat angle	45º slat angle
	Fully-deployed	4	-45º slat angle	-45º slat angle
	Half-deployed	5	90º slat angle	No shade
	Half-deployed	6	45º slat angle	No shade
	Half-deployed	7	-45º slat angle	No shade
Closed (C)	Fully-deployed	8	90º slat angle	90º slat angle

The energy use for louvered blinds is the result of averaging hourly results for two open deployments, five half-open and one closed deployment schedules. Averaging procedure is detailed in Equations (19) to (21). Numbers in the third column in Table 6 are used in subsequent equations as an index number (1-2 for open, 3-7 for half-open, and 8 for closed).

$$E_O = \frac{\sum_{i=1}^{2}\left(\sum_{\tau_w=S_1}^{S_N}\left(E_{SDO,i}\left(\tau_w\right)+E_{SEO,i}\left(\tau_w\right)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDO,i}\left(\tau_w\right)+E_{WEO,i}\left(\tau_w\right)\right)\right)}{2} \tag{19}$$

$$E_H = \frac{\sum_{i=3}^{7}\left(\sum_{\tau_w=S_1}^{S_N}\left(E_{SDH,i}\left(\tau_w\right)+E_{SEH,i}\left(\tau_w\right)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDH,i}\left(\tau_w\right)+E_{WEH,i}\left(\tau_w\right)\right)\right)}{5} \tag{20}$$

$$E_C = \sum_{\tau_w=S_1}^{S_N}\left(E_{SDC,8}\left(\tau_w\right)+E_{SEC,8}\left(\tau_w\right)\right)+\sum_{\tau_w=W_1}^{W_N}\left(E_{WDC,8}\left(\tau_w\right)+E_{WEC,8}\left(\tau_w\right)\right) \tag{21}$$

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.

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

$E\,(\tau_w, \tau_d, \tau_h)$ is calculated as follows for each city:

Houston:

$$E_{O,i}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{DXCoil}\left(\tau_h\right)_{O,i}+E_{Fan}\left(\tau_h\right)_{O,i}\right)_{CS=ON}\cdot SF_E \quad (i=1,2) \tag{22}$$

$$E_{H,i}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{DXCoil}\left(\tau_h\right)_{H,i}+E_{Fan}\left(\tau_h\right)_{H,i}\right)_{CS=ON}\cdot SF_E \quad (i=3,4,5,6,7) \tag{23}$$

$$E_{C,8}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{DXCoil}\left(\tau_h\right)_{C,8}+E_{Fan}\left(\tau_h\right)_{C,8}\right)_{CS=ON}\cdot SF_E \tag{24}$$

Minneapolis:

$$E_{O,i}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{Gas}\left(\tau_h\right)_{O,i}\right)_{HS=ON}\cdot SF_G+\left(E_{Fan}\left(\tau_h\right)_{O,i}\right)_{HS=ON}\cdot SF_E \quad (i=1,2) \tag{25}$$

$$E_{H,i}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{Gas}\left(\tau_h\right)_{H,i}\right)_{HS=ON}\cdot SF_G+\left(E_{Fan}\left(\tau_h\right)_{H,i}\right)_{HS=ON}\cdot SF_E \quad (i=3,4,5,6,7) \tag{26}$$

$$E_{C,8}\left(\tau_w,\tau_d,\tau_h\right)=\left(E_{Gas}\left(\tau_h\right)_{C,8}\right)_{HS=ON}\cdot SF_G+\left(E_{Fan}\left(\tau_h\right)_{C,8}\right)_{HS=ON}\cdot SF_E \tag{27}$$

5. Calculation of Final Results

Energy simulation by EnergyPlus is output into csv files, from which E_A, E_B, and E_S is calculated, using formulas detailed above, and depending on the specific window attachment. The following is process outline:

- Selection which calculation is to be performed, E_A, E_B, E_S/EP
- City; Houston or Minneapolis (alternatively could be choice between Cooling and Heating)
- Window attachment type (for E_A and E_B only, no attachment is supplied)
- Number of csv files
- Each csv file name
  - Deployment state (Open, half-open or closed)
  - Slat angle for louvered blinds

Output from software tool:

- E_A, E_B, and/or E_S, as requested
- EP (applicable when E_S is requested)

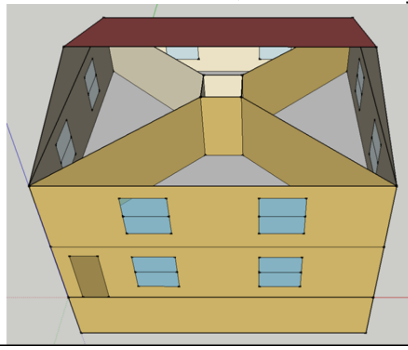
This interface is accomplished through XML file. XML Schema and example files are included in Appendix E

6. References

ISO. 2011. "ISO 18292: Energy Performance of Fenestration Systems for Residential Buildings – Calculation Procedure". International Standards Organization. Geneva, Switzerland.

DOE. 2016. "EnergyPlus 8.6: Software Tool for Calculating Energy Performance of Buildings"

Appendix A: Typical US Residential Buildings Assumptions

<table>
<tr><th>PARAMETERS</th><th>Proposed Residential Model Values</th><th>Value inputs in E+</th></tr>
<tr><td>Floor Area
(ft² & dim)</td><td>2400 ft² , 34.64ft (W) x 34.64ft (L) x8.5ft (H) x2 stories</td><td>10.55858m(X)*10.55858m(Y)*2.59m(H)*2 stories</td></tr>
<tr><td>House Type</td><td>2-story – One small core zone and four big perimeter zones for each floor, but it has only one HVAC zone.
</td><td>Core zone Area=1.41458m*1.41458m

Refer to Residential model for AERC MEETING (0415).xlsx</td></tr>
<tr><td>Bathrooms</td><td>3</td><td></td></tr>
<tr><td>Bedrooms</td><td>3</td><td></td></tr>
<tr><td>Typical Cities</td><td>Heating: Minneapolis, MN (Climate Zone 6A)
Cooling: Houston, TX (Climate Zone 2A)</td><td>Refer to Residential model for AERC MEETING (0415).xlsx</td></tr>
<tr><td>Foundation</td><td>Unheated Basement for the north heating dominated city, viz. Minneapolis, MN;

Slab-on-grade without insulation for the south cooling dominated city, viz. Houston, TX.</td><td>Basement: 10.55858m(X)*10.55858m(Y)*(-2.13)m(H)</td></tr>
<tr><td>Insulation [a]</td><td>Envelope insulation levels vary with the locations. The following insulation requirements are referred to IECC 1998.
<table>
<tr><th>Location:</th><th>Ceiling R-value</th><th>Wall R-value</th><th>Floor R-value</th><th>Slab/Basement R-value</th></tr>
<tr><td>Houston:</td><td>R-30</td><td>R-13</td><td>R-11</td><td>Slab, R-0</td></tr>
<tr><td>Minneapolis:</td><td>R-49</td><td>R-21</td><td>R-21</td><td>Bsmt, R-11</td></tr>
</table></td><td>Minneapolis:
Exterior Floor: R21
Interior Floor: R21
Exterior Wall: R21
Ceiling: R49
Exterior Roof: R49
Basement wall: R11

Houston:
Exterior Floor: R11
Interior Floor: R11
Exterior Wall: R13
Ceiling: R30
Exterior Roof: R30</td></tr>
<tr><td>Infiltration</td><td>Minneapolis: ACH50=7

Houston: ACH50=10</td><td>Minneapolis baseline window case: ELA=873;

Minneapolis super insulated window case: ELA=669, air infiltration of super insulated window was 0;

Houston baseline window case: ELA=1248;

Houston super insulated window case: ELA=1044, air infiltration of super insulated window was 0;

The converting method from ACH to ELA is described in ELACalculation.xlsx</td></tr>
<tr><td>Internal Mass
Furniture (lb/ft²)</td><td>8.0 lb/ft² of floor area</td><td></td></tr>
</table>

PARAMETERS	Proposed Residential Model Values	Value inputs in E+
Ventilation Air Requirements	0.15 L/s per square meter of floor space	0.0334566392745 82m3/s =0.15*10.55858*10.55858*2
Wall framing system	Wood	
External Doors	U factor: 1.14 W/(m^2.k)	R=0.88
Window Area (% Floor Area)	15.1%. There are two windows (each window with dimension 2*1.4 m*0.75 m) on each orientation each floor.	2*14(w)*0.75(h) Refer to Residential model for AERC MEETING (0415).xlsx
Window Type	Double clear wood frame baseline window for both climates; VT=0.639, SHGC=0.601, U=0.472 Btu/hr.ft^2.F, AL=2 cfm/ft^2 Adiabatic window: VT=0, SHGC=0, U=0, AL=0	Baseline window: double clear using CLEAR_3.DAT, wood fixed frame Adiabatic window: custom created super-insulated opaque window without frame Refer to AERC 1 Baseline window B.docx
Window Distribution	8 windows per floor, distributed evenly and centered on the external walls. Each big window was split into the upper and lower small windows.	Refer to Residential model for AERC MEETING (0415).xlsx
Heating Systems	Gas Furnace for Minneapolis, MN; Heat Pump for Houston, TX.	
Heating System Fuels	Gas for Minneapolis, MN; Electricity for Houston, TX.	
Cooling Systems	A/C for Minneapolis, MN; Heat Pump for Houston, TX.	
HVAC System Sizing	For each climate, the HVAC systems were sized based on the base window option (without window attachments).	Houston (HP): Cooling capacity: 13131.31W Heating capacity: 13131.31W Sensible heat ratio: 0.733253 Air flow rate: 0.652m3/s Minneapolis (GAC): Cooling capacity: 10628.64W Heating capacity: 16720.73W Sensible heat ratio: 0.753625 Air flow rate: 0.563m3/s Refer to Doubleclear_basement_Minneapolis, & Doubleclear_slab_Houston
HVAC Efficiencies	Minneapolis (GAC): AFUE= 0.78 for Gas furnace heating (annual fuel utilization efficiency) Houston (HP): HSPF=6.8 for Air-cooled heat pumps heating mode (the converted COP for heating is ~1.99) Both: SEER=10.0 for Air-cooled air conditioners and heat pumps cooling mode (the converted COP for cooling is ~2.70)	(1) EER = 1.12 * SEER - 0.02 * SEER2 (2) EER = COP * 3.41 (3) Avg COP = Heat transferred / electrical energy supplied = (HSPF * 1055.056 J/BTU) / (3600 J/watt-hour) = 0.29307111 HSPF.
Thermostat Settings	Heating: 70°F, Cooling: 75°F No setback	Heating set point: 21.11 ℃ Cooling set point: 23.89 ℃
Internal Loads	Number of People = 3 Hardwire Lights = 1.22 Watts/m^2 Plug-in Lights = 0.478 Watts/m^2 Refrigerator = 91.09 Watts – Design Level Misc. Electrical Equipment = 2.46 Watts/m^2	

PARAMETERS	Proposed Residential Model Values	Value inputs in E+
	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/m^2 Exterior Lights = 58 Watts – Design Level Garage Lights = 9.5 Watts – Design Level The operation schedules of the all equipment are referred to the PNNL model.	
Weather Data	USA_TX_Houston-Bush.Intercontinental.AP.722430_TMY3.epw USA_MN_Minneapolis-St.Paul.Intl.AP.726580_TMY3_2.epw	All TMY3
Number of Locations	2 typical US cities: Minneapolis, MN for heating; Houston, TX for cooling.	
Calculation Tool	EnergyPlus version 8.5 (LBN's custom version that addresses issue with TIR>0)	
Energy Code	Combination of vintages for each climate zone, but mostly like IECC 1998	
Results extracted from E+	Heating energy use, cooling energy use, fan energy use and total energy use of the house which includes the all energy uses, such as lighting.	
Attachment deployment operations	Refer to (Bickel, 2013)	
Ground temperature	For Minneapolis unheated basement with R11 insulation; For Houston, slab-on-grade with no slab insulation.	
Super insulated window	This window can be regarded as an adiabatic surface without heat transferring.	0.003, !- Thickness {m} 0.000001, !- Solar Transmittance 0.999999, !- Front Reflectance 0.999999, !- Back Reflectance 0.000001, !- Visible Transmittance 0.999999, !- Front Visible Reflectance 0.999999, !- Back Visible Reflectance 0.000000, !- Infrared Transmittance 0.000001, !- Front Infrared Emissivity 0.000001, !- Back Infrared Emissivity 0.00000001; !- Conductivity {W/m-K}

Appendix B: Output Section in IDF File

```
!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:VARIABLE ===========

Output:Variable,*,Site Day Type Index,hourly;

Output:Variable,*,Air System Electric Energy,hourly;

Output:Variable,*,Air System Fan Electric Energy,hourly;

Output:Variable,*,Air System DX Cooling Coil Electric Energy,hourly;

Output:Variable,*,Zone Lights Electric Energy,hourly;

Output:Variable,*,Facility Net Purchased Electric Energy,hourly;

Output:Variable,*,Facility Total Building Electric Demand Power,hourly;

Output:Variable,*,Facility Total HVAC Electric Demand Power,hourly;

Output:Variable,*,Facility Total Electric Demand Power,hourly;

Output:Variable,*,Air System Cooling Coil Total Cooling Energy,hourly;

Output:Variable,*,Air System Heating Coil Total Heating Energy,hourly;

Output:Variable,*,Air System Fan Air Heating Energy,hourly;

Output:Variable,*,Air System Gas Energy,hourly;

Output:Variable,*,Zone Gas Equipment Gas Energy,hourly;

Output:Variable,*,Water Heater Gas Energy,hourly;
```

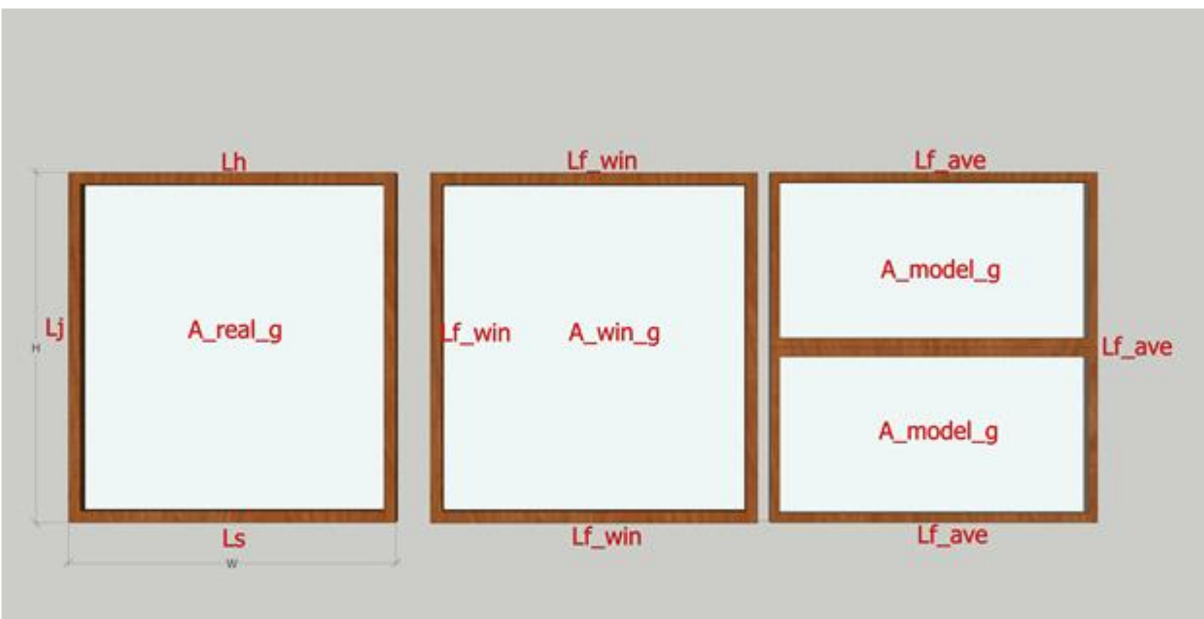
Appendix C: Include Files

C.1 Windows:

Same window configuration file is provided for both climate zones/cities. Also, same window configuration file is used for all windows, however with changes made for construction reference (glazing construction and frame) for different window attachment runs (e.g., For baseline window, construction reference is AERC_Doubleclear_Baseline). For different baseline windows, as their averaged frame width are different, the glazing coordinates should be changed as well. The following sections depict the methodologies of calculating the averaged frame width and changing the fenestration coordinates.

C.1.1 Calculating and exporting the average frame width in WINDOW

As EnergyPlus can't model the half-deployed scenario for a window shade, we used two separate small windows (one at the top and one at the bottom) to replace a single window in simulation. However, this replacement results in a larger frame area for the modelled window because the head and sill are counted twice (as shown in the rightmost drawing of the following picture). So, we will replace the original averaged frame width (L_{f_WIN}) from WINDOW with a new averaged frame width (L_{f_ave}) to make sure the modeled two small windows have the same glazing and frame areas as the original window. The methodology for the averaged frame width calculation is detailed later in this section. The following figure illustrates the original window with original frame dimensions, L_s, L_j, and Lh, then window with the original averaged frame dimension, L_{f_WIN}, as it is exported from WINDOW to IDF file, and resulting 2 windows used in simulation, with the new averaged frame width, L_{f_ave}.



A_{real_g} is the actual window glazing area.

A_{win_g} is the window glazing area normally exported from WINDOW.

A_{model_g} is the window glazing area in E+ simulation.

The first step is to calculate the original averaged frame width (L_{f_WIN}). WINDOW program can calculate L_{f_WIN} according to the below equations.

$$A_{real\_g} = W \cdot H - (L_h \cdot W + L_s \cdot W + 2 \cdot L_j \cdot \left(H - L_h - L_{s)}\right) \tag{C.1}$$

$$A_{WIN\_g} = W \cdot H - \left(2 \cdot W \cdot L_{f\_WIN} + 2 \cdot L_{f\_WIN} \cdot \left(H - 2 \cdot L_{f\_WIN}\right)\right) \tag{C.2}$$

Considering that $A_{real\_g} = A_{win\_g}$, and substituting (1) and (2) into this equality, then:

$$W \cdot H - (L_h \cdot W + L_s \cdot W + 2 \cdot L_j \cdot \left(H - L_h - L_{s)}\right) = W \cdot H - \left(2 \cdot W \cdot L_{f\_WIN} + 2 \cdot L_{f\_WIN} \cdot \left(H - 2 \cdot L_{f\_WIN}\right)\right) \tag{C.3}$$

Or expressed as quadratic equation that can be solved for L_{f_WIN}.

$$4 \cdot L_{f\_WIN}^{2} + 2 \cdot (H + W) \cdot L_{f\_WIN} - \left(W \cdot (L_h + L_s) + 2 \cdot L_j \cdot (H - L_h - L_s)\right) = 0 \tag{C.4}$$

$$L_{f\_WIN} = \frac{-2 \cdot (H + W) \pm \sqrt{4 \cdot (H + W)^2 + 16 \cdot \left(W \cdot (L_h + L_s) + 2 \cdot L_j \cdot (H - L_h - L_s)\right)}}{8} \tag{C.5}$$

WINDOW program can also export the original averaged frame width (L_{f_WIN}) to a normal IDF file (which is different from the specialized IDF file for EPCalc only, called "AERC EnergyPlus IDF"). An example of L_{f_WIN} exportation for AERC Baseline Window B is shown in the following figure.

```
!-----------------------------------------------------
!       Window Frames and Dividers Data
!-----------------------------------------------------
WindowProperty:FrameAndDivider,
AERC_Wood_Frame,                                       ne
0.057150,                 !
,                         !
,                         !- Frame Insider Projection {m}
2.918756,                !- Frame Conductance {W/m2-K}
1.075423,                 !- Ratio of Frame-Edge Glass Conductance
0.300000,                 !- Frame Solar absorptance
0.300000,                 !- Frame Visible absorptance
0.9,                      !- Frame Thermal hemispherical Emissivit
,                         !- Divider Type
,                         !- Divider Width {m}
,                         !- Number of Horizontal Dividers
,                         !- Number of Vertical Dividers
,                         !- Divider Outside Projection {m}
,                         !- Divider Insider Projection {m}
,                         !- Divider Conductance {W/m2-K}
,                         !- Ratio of Divider-Edge Glass Conductar
,                         !- Divider Solar Absorptance
,                         !- Divider Visible Absorptance
,                         !- Divider Thermal Hemispherical Emissiv
,                         !- Outside Reveal Solar Absorptance
,                         !- Inside Sill Depth (m)
,                         !- Inside Sill Solar Absorptance
,                         !- Inside Reveal Depth (m)
;                         !- Inside Reveal Solar Absorptance
```

Lf_win is exported in a normal IDF by WINDOW

The next step is to calculate the new averaged frame width (L_{f_ave}) for the configuration consisting of two windows (top and bottom) with the original averaged frame width (L_{f_WIN}). This calculation was conducted in WINDOW program according to the below equations.

$$A_{Model\_g} = W \cdot H - \left(4 \cdot W \cdot L_{f\_Ave} + 4 \cdot L_{f\_Ave} \cdot \left(\frac{H}{2} - 2 \cdot L_{f\_Ave} \right) \right) \tag{C.6}$$

Considering that $A_{Model\_g} = A_{win\_g}$, and substituting (2) and (6) into this equality, then:

$$W \cdot H - \left(2 \cdot W \cdot L_{f\_WIN} + 2 \cdot L_{f\_WIN} \cdot \left(H - 2 \cdot L_{f\_WIN} \right) \right) = W \cdot H - \left(4 \cdot W \cdot L_{f\_Ave} + 4 \cdot L_{f\_Ave} \cdot \left(\frac{H}{2} - 2 \cdot L_{f\_Ave} \right) \right) \tag{C.7}$$

Or expressed as quadratic equation that can be solved for L_{f_Ave}.

$$-4 \cdot L_{f\_Ave}{}^2 + \left(H + 2 \cdot W \right) \cdot L_{f\_Ave} + 2 \cdot L_{f\_WIN}{}^2 - \left(W + H \right) \cdot L_{f\_WIN} = 0 \tag{C.8}$$

$$L_{f\_Ave} = \frac{-\left(H + 2 \cdot W \right) \pm \sqrt{\left(H + 2 \cdot W \right)^2 + 16 \cdot \left(2 \cdot L_{f\_WIN}{}^2 - \left(W + H \right) \cdot L_{f\_WIN} \right)}}{-8} \tag{C.9}$$

There are two roots to the quadratic equation (9), $L_{f\_Ave\_1}$ and $L_{f\_Ave\_2}$, of which one is solution that we are seeking.

$$L_{f\_Ave} = \min\left(L_{f\_Ave\_1}, L_{f\_Ave\_2} \right) \tag{C10}$$

Take the current AERC baseline window B as an example:

W = 1.4 m

H = 1.5 m

Lf_win = 0.057150 m

So Equations (8) and (9) can be written as:

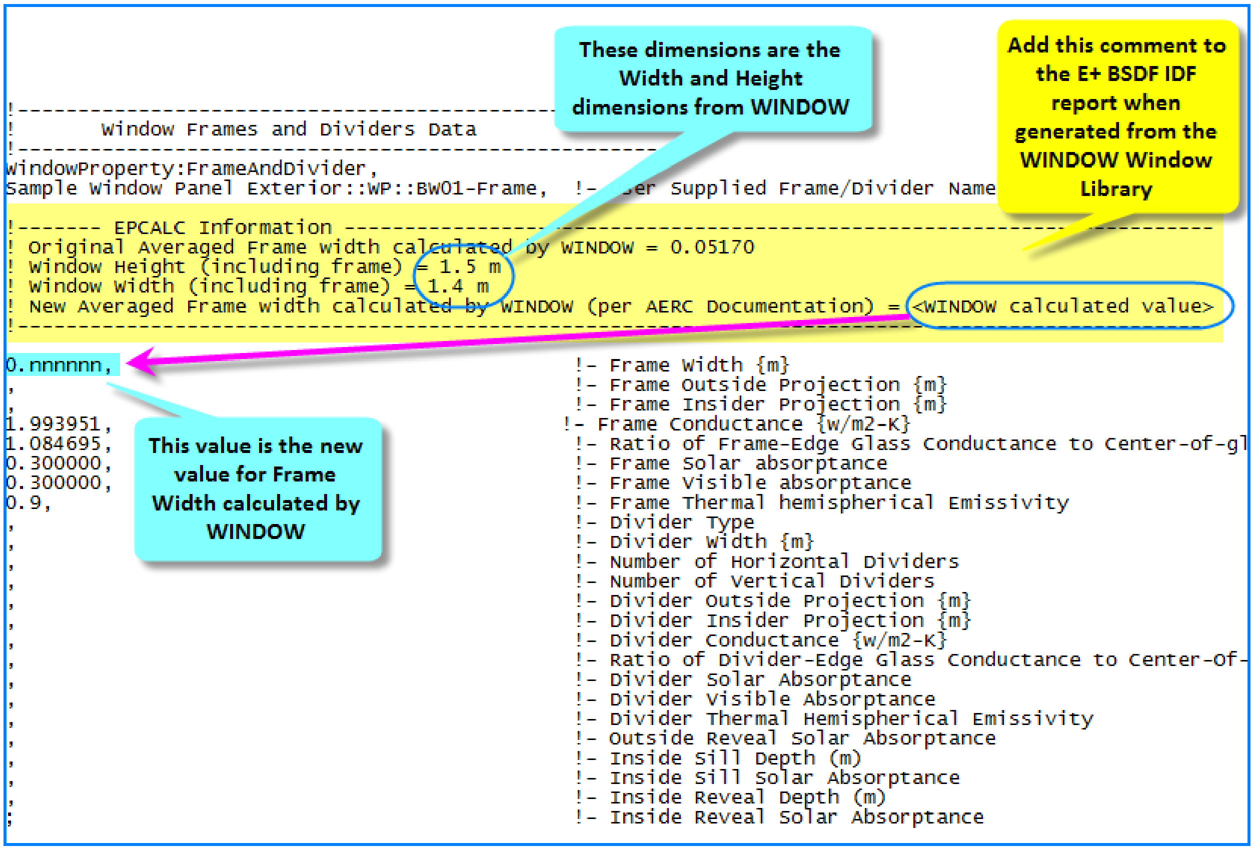
$$-4 \cdot L_{f\_Ave}{}^2 + 4.3 \cdot L_{f\_Ave} - 0.1592027 = 0$$

$$L_{f\_Ave} = \frac{-4.3 \pm \sqrt{18.49 - 2.54724}}{-8}$$

$$L_{f\_Ave} = \min\left(0.038395, 1.036605 \right)$$

L_{f_Ave} = 0.038395

This calculation is built into Berkeley Lab WINDOW software tool, which is exported to AERCalc in a new specialized IDF file, called "AERC Energy Plus IDF", where the original frame width, L_{f_WIN}, new averaged frame width L_{f_ave}, and window width and height (W and H, include the frame width), are included in the commented section. New averaged frame width is also inserted in the appropriate IDF field where it is used by EnergyPlus. The following figure illustrates this new AERC EnergyPlus IDF .



```
!-------------------------------------------------------
!       Window Frames and Dividers Data
!-------------------------------------------------------
WindowProperty:FrameAndDivider,
Sample Window Panel Exterior::WP::BW01-Frame,  !- User Supplied Frame/Divider Name

!------- EPCALC Information ----------------------------------------------------------------
! Original Averaged Frame width calculated by WINDOW = 0.05170
! Window Height (including frame) = 1.5 m
! Window Width (including frame) = 1.4 m
! New Averaged Frame width calculated by WINDOW (per AERC Documentation) = <WINDOW calculated value>
!-------------------------------------------------------------------------------------------

0.nnnnnn,                               !- Frame Width {m}
,                                       !- Frame Outside Projection {m}
,                                       !- Frame Insider Projection {m}
1.993951,                              !- Frame Conductance {W/m2-K}
1.084695,                               !- Ratio of Frame-Edge Glass Conductance to Center-of-Gl
0.300000,                               !- Frame Solar absorptance
0.300000,                               !- Frame Visible absorptance
0.9,                                    !- Frame Thermal hemispherical Emissivity
,                                       !- Divider Type
,                                       !- Divider Width {m}
,                                       !- Number of Horizontal Dividers
,                                       !- Number of Vertical Dividers
,                                       !- Divider Outside Projection {m}
,                                       !- Divider Insider Projection {m}
,                                       !- Divider Conductance {W/m2-K}
,                                       !- Ratio of Divider-Edge Glass Conductance to Center-Of-
,                                       !- Divider Solar Absorptance
,                                       !- Divider Visible Absorptance
,                                       !- Divider Thermal Hemispherical Emissivity
,                                       !- Outside Reveal Solar Absorptance
,                                       !- Inside Sill Depth (m)
,                                       !- Inside Sill Solar Absorptance
,                                       !- Inside Reveal Depth (m)
;                                       !- Inside Reveal Solar Absorptance
```


For other baseline windows which may have different frame widths, WINDOW program will calculate L_{f_Ave} using equations (9) and (10) and export L_{f_Ave} as shown in the above figure.

C.1.2 Changing the fenestration coordinates in window configuration file

The whole window area, consisting of the glass area and the frame area, is given by specifying the window width (W, includes the frame width) and the height (H, includes the frame width). However, in Energyplus, window coordinates describe vision portion of glazing system only, so full window area is obtained by adding frame width to glazing area. The fenestration coordinates can be calculated by using the window width (W), the window height (H) and the new averaged frame width **(**L_{f_Ave}**)**. The methodology is detailed in this section.

For each window in a typical building, the coordinates of the vertices for the vision area of glazing are calculated starting with lower left corner. The remaining three vertices are then calculated based on the fixed coordinates of the lower-left corner point, the window width (W), height (H) and the new averaged frame width (L_{f_Ave}). However, it is worth noting that the coordinate calculation method is different for different oriented windows. The calculation methods for different orientations are illustrated in sections below.

C.1.2.1 Template for IDF snippet for windows

An IDF snippet for the definition of each window is required. There are 8 windows on each orientation. Template for the IDF snippet is illustrated as follows:

```
 FenestrationSurface:Detailed,
  Window_OriF_N_Pos.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_OriW_F.unit1,      !- Building Surface Name
  ,                  !- Outside Boundary Condition Object
  ,                  !- View Factor to Ground
  ,                  !- Shading Control Name
  AERC_Wood_Frame,       !- Frame and Divider Name
  1,                  !- Multiplier
  4,                  !- Number of Vertices
  X1,     Y1,     Z1,            !- X,Y,Z ==> Vertex 1 {m}
  X2,     Y2,     Z2,            !- X,Y,Z ==> Vertex 2 {m}
  X3,     Y3,     Z3,            !- X,Y,Z ==> Vertex 3 {m}
  X4,     Y4,     Z4;            !- X,Y,Z ==> Vertex 4 {m}
```

Where OriF_N_Pos stand for:

- Ori = Orientation (ldf– front side (South), ldb – back side (North), sdr – right side (East), sdl – left side (West))
- F = Floor number (1 – first floor, 2 – second floor)
- N = Window number on each floor and orientation (1 – left side window, 2 – right side window)
- Pos = Window position(Bot – bottom window, Top – top window)
- W = Wall number of each perimeter zone on each floor (1 – external wall on which the windows were installed)

For example, Window_ldf1_2_Bot.unit1 means the right bottom window on the first floor on the south orientation; Wall_sdr1_2.unit1 means the external wall on the second floor of east orientation

C.1.2.2 South facing windows:

There are eight south facing windows (named as Window_ldfF_N_Pos.unit1).

where, the coordinates of the lower-left corner vertice (X1, Y1, Z1) are fixed as follows:

X1= values for each of south facing windows are listed in table below

Y1=Y2=Y3=Y4=0.00,

Z1 values for each of south facing windows are listed in table below

The coordinates of the remaining three vertices are calculated based on the window width (W), the window height (H) and the new averaged frame width (L_{f_Ave}) using the below formulas:

X2=X1+(W-2* L_{f_Ave})
Z2=Z1
X3=X+(W-2* L_{f_Ave})
Z3=Z+(H/2-2* L_{f_Ave})
X4=X1
Z4=Z+(H/2-2* L_{f_Ave})

For baseline window B, the coordinates of the lower-left corner vertices of the eight south facing windows are listed as follows:

Fenestration Name	Building Surface Name	X1	Y1	Z1
Window_ldf1_1_Bot.unit1	Wall_ldf1_1.unit1	2.50	0.00	0.60
Window_ldf1_1_Top.unit1	Wall_ldf1_1.unit1	2.50		1.35
Window_ldf1_2_Bot.unit1	Wall_ldf1_1.unit1	6.60		0.60
Window_ldf1_2_Top.unit1	Wall_ldf1_1.unit1	6.60		1.35
Window_ldf2_1_Bot.unit1	Wall_ldf1_2.unit1	2.50		3.20
Window_ldf2_1_Top.unit1	Wall_ldf1_2.unit1	2.50		3.95
Window_ldf2_2_Bot.unit1	Wall_ldf1_2.unit1	6.60		3.20
Window_ldf2_2_Top.unit1	Wall_ldf1_2.unit1	6.60		3.95

The coordinates of the lower-left corner vertices of the eight south facing windows are fixed in the E+ model and will be used for different baseline windows. With the coordinates of the lower-left corner vertices, the coordinates of the remaining vertices of each south facing window can be calculated using Equations above.

Take the current AERC baseline window B as an example:

W = 1.4 m

H = 1.5 m

L_{f_Ave} = 0.038395 m

the coordinates of the eight south facing windows are calculated and the values are listed in the below table.

Fenestration Name	Building Surface	Vertices	X	Y	Z
Window_ldf1_1_Bot.unit1	Wall_ldf1_1.unit1	1	2.50000	0.00000	0.60000
		2	3.82321	0.00000	0.60000
		3	3.82321	0.00000	1.27321
		4	2.50000	0.00000	1.27321
Window_ldf1_1_Top.unit1	Wall_ldf1_1.unit1	1	2.50000	0.00000	1.35000
		2	3.82321	0.00000	1.35000
		3	3.82321	0.00000	2.02321
		4	2.50000	0.00000	2.02321
Window_ldf1_2_Bot.unit1	Wall_ldf1_1.unit1	1	6.60000	0.00000	0.60000
		2	7.92321	0.00000	0.60000
		3	7.92321	0.00000	1.27321
		4	6.60000	0.00000	1.27321
Window_ldf1_2_Top.unit1	Wall_ldf1_1.unit1	1	6.60000	0.00000	1.35000
		2	7.92321	0.00000	1.35000
		3	7.92321	0.00000	2.02321
		4	6.60000	0.00000	2.02321
Window_ldf2_1_Bot.unit1	Wall_ldf1_2.unit1	1	2.50000	0.00000	3.20000
		2	3.82321	0.00000	3.20000
		3	3.82321	0.00000	3.87321
		4	2.50000	0.00000	3.87321
Window_ldf2_1_Top.unit1	Wall_ldf1_2.unit1	1	2.50000	0.00000	3.95000
		2	3.82321	0.00000	3.95000
		3	3.82321	0.00000	4.62321
		4	2.50000	0.00000	4.62321
Window_ldf2_2_Bot.unit1	Wall_ldf1_2.unit1	1	6.60000	0.00000	3.20000
		2	7.92321	0.00000	3.20000
		3	7.92321	0.00000	3.87321
		4	6.60000	0.00000	3.87321
Window_ldf2_2_Top.unit1	Wall_ldf1_2.unit1	1	6.60000	0.00000	3.95000
		2	7.92321	0.00000	3.95000
		3	7.92321	0.00000	4.62321
		4	6.60000	0.00000	4.62321

C.1.2.3 North facing windows:

There are also eight north facing windows (named as Window_ldbF_N_Pos.unit1). Coordinates of the lower-left corner vertice (X1, Y1, Z1) are fixed as follows:

X1= values for each of north facing windows are listed in table below

Y1=Y2=Y3=Y4=10.55858,

Z1= values for each of north facing windows are listed in table below

The coordinates of the remaining three vertices can be calculated based on the window width (W), the window height (H) and the new averaged frame width (L_{f_Ave}) using the formulas below:

$X2=X1-(W-2*L_{f\_Ave})$
$Z2=Z1$
$X3=X1-(W-2*L_{f\_Ave})$
$Z3=Z1+(H/2-2*L_{f\_Ave})$
$X4=X1$
$Z4=Z1+(H/2-2*L_{f\_Ave})$

The coordinates of the lower-left corner vertices of the eight north facing windows are listed as follows:

<table>
<tr><th>Fenestration Name</th><th>Building Surface Name</th><th>X1</th><th>Y1</th><th>Z1</th></tr>
<tr><td>Window_ldb1_1_Bot.unit1</td><td>Wall_ldb1_1.unit1</td><td>8.00</td><td rowspan="8">10.55858</td><td>0.60</td></tr>
<tr><td>Window_ldb1_1_Top.unit1</td><td>Wall_ldb1_1.unit1</td><td>8.00</td><td>1.35</td></tr>
<tr><td>Window_ldb1_2_Bot.unit1</td><td>Wall_ldb1_1.unit1</td><td>3.90</td><td>0.60</td></tr>
<tr><td>Window_ldb1_2_Top.unit1</td><td>Wall_ldb1_1.unit1</td><td>3.90</td><td>1.35</td></tr>
<tr><td>Window_ldb2_1_Bot.unit1</td><td>Wall_ldb1_2.unit1</td><td>8.00</td><td>3.20</td></tr>
<tr><td>Window_ldb2_1_Top.unit1</td><td>Wall_ldb1_2.unit1</td><td>8.00</td><td>3.95</td></tr>
<tr><td>Window_ldb2_2_Bot.unit1</td><td>Wall_ldb1_2.unit1</td><td>3.90</td><td>3.20</td></tr>
<tr><td>Window_ldb2_2_Top.unit1</td><td>Wall_ldb1_2.unit1</td><td>3.90</td><td>3.95</td></tr>
</table>

The coordinates of the remaining vertices of each north facing window are calculated using above equation.

For AERC baseline window B, the coordinates of the eight north facing windows are as follows

Fenestration Name	Building Surface	Vertices	X	Y	Z
Window_ldb1_1_Bot.unit1	Wall_ldb1_1.unit1	1	8.00000	10.55858	0.60000
		2	6.67679	10.55858	0.60000
		3	6.67679	10.55858	1.27321
		4	8.00000	10.55858	1.27321
Window_ldb1_1_Top.unit1	Wall_ldb1_1.unit1	1	8.00000	10.55858	1.35000
		2	6.67679	10.55858	1.35000
		3	6.67679	10.55858	2.02321
		4	8.00000	10.55858	2.02321
Window_ldb1_2_Bot.unit1	Wall_ldb1_1.unit1	1	3.90000	10.55858	0.60000
		2	2.57679	10.55858	0.60000
		3	2.57679	10.55858	1.27321
		4	3.90000	10.55858	1.27321
Window_ldb1_2_Top.unit1	Wall_ldb1_1.unit1	1	3.90000	10.55858	1.35000
		2	2.57679	10.55858	1.35000
		3	2.57679	10.55858	2.02321
		4	3.90000	10.55858	2.02321
Window_ldb2_1_Bot.unit1	Wall_ldb1_2.unit1	1	8.00000	10.55858	3.20000
		2	6.67679	10.55858	3.20000
		3	6.67679	10.55858	3.87321
		4	8.00000	10.55858	3.87321
Window_ldb2_1_Top.unit1	Wall_ldb1_2.unit1	1	8.00000	10.55858	3.95000
		2	6.67679	10.55858	3.95000
		3	6.67679	10.55858	4.62321
		4	8.00000	10.55858	4.62321
Window_ldb2_2_Bot.unit1	Wall_ldb1_2.unit1	1	3.90000	10.55858	3.20000
		2	2.57679	10.55858	3.20000
		3	2.57679	10.55858	3.87321
		4	3.90000	10.55858	3.87321
Window_ldb2_2_Top.unit1	Wall_ldb1_2.unit1	1	3.90000	10.55858	3.95000
		2	2.57679	10.55858	3.95000
		3	2.57679	10.55858	4.62321
		4	3.90000	10.55858	4.62321

C.1.2.4 East facing windows:

There are also eight east facing windows (named as Window_sdrF_N_Pos.unit1).

Coordinates of the lower-left corner vertice (X1, Y1, Z1) are fixed as follows:

X1= X2=X3=X4= 10.55858,

Y1= values for each of east facing windows are listed in table below

Z1= values for each of east facing windows are listed in table below

The coordinates of the remaining three vertices are calculated based on the window width (W), the window height (H) and the new averaged frame width (L_{f_Ave}) using the below formulas:

Y2= Y1+(W-2* L_{f_Ave})

Z2=Z1

Y3= Y1+(W-2* L_{f_Ave})

Z3= Z1+(H/2-2* L_{f_Ave})

Y4=Y1

Z4= Z1+(H/2-2* L_{f_Ave})

The coordinates of the lower-left corner vertices of the eight east facing windows are listed as follows:

Fenestration Name	Building Surface Name	X1	Y1	Z1
Window_sdr1_1_Bot.unit1	Wall_sdr1_1.unit1	10.55858	2.50	0.60
Window_sdr1_1_Top.unit1	Wall_sdr1_1.unit1		2.50	1.35
Window_sdr1_2_Bot.unit1	Wall_sdr1_1.unit1		6.60	0.60
Window_sdr1_2_Top.unit1	Wall_sdr1_1.unit1		6.60	1.35
Window_sdr2_1_Bot.unit1	Wall_sdr1_2.unit1		2.50	3.20
Window_sdr2_1_Top.unit1	Wall_sdr1_2.unit1		2.50	3.95
Window_sdr2_2_Bot.unit1	Wall_sdr1_2.unit1		6.60	3.20
Window_sdr2_2_Top.unit1	Wall_sdr1_2.unit1		6.60	3.95

The coordinates of the remaining vertices of each east facing window are calculated using above equations.

For AERC baseline window B, the full set of coordinates for the eight east facing windows are listed in the table below.

Fenestration Name	Building Surface	Vertices	X	Y	Z
Window_sdr1_1_Bot.unit1	Wall_sdr1_1.unit1	1	10.55858	2.50000	0.60000
		2	10.55858	3.82321	0.60000
		3	10.55858	3.82321	1.27321
		4	10.55858	2.50000	1.27321
Window_sdr1_1_Top.unit1	Wall_sdr1_1.unit1	1	10.55858	2.50000	1.35000
		2	10.55858	3.82321	1.35000
		3	10.55858	3.82321	2.02321
		4	10.55858	2.50000	2.02321
Window_sdr1_2_Bot.unit1	Wall_sdr1_1.unit1	1	10.55858	6.60000	0.60000
		2	10.55858	7.92321	0.60000
		3	10.55858	7.92321	1.27321
		4	10.55858	6.60000	1.27321
Window_sdr1_2_Top.unit1	Wall_sdr1_1.unit1	1	10.55858	6.60000	1.35000
		2	10.55858	7.92321	1.35000
		3	10.55858	7.92321	2.02321
		4	10.55858	6.60000	2.02321
Window_sdr2_1_Bot.unit1	Wall_sdr1_2.unit1	1	10.55858	2.50000	3.20000
		2	10.55858	3.82321	3.20000
		3	10.55858	3.82321	3.87321
		4	10.55858	2.50000	3.87321
Window_sdr2_1_Top.unit1	Wall_sdr1_2.unit1	1	10.55858	2.50000	3.95000
		2	10.55858	3.82321	3.95000
		3	10.55858	3.82321	4.62321
		4	10.55858	2.50000	4.62321
Window_sdr2_2_Bot.unit1	Wall_sdr1_2.unit1	1	10.55858	6.60000	3.20000
		2	10.55858	7.92321	3.20000
		3	10.55858	7.92321	3.87321
		4	10.55858	6.60000	3.87321
Window_sdr2_2_Top.unit1	Wall_sdr1_2.unit1	1	10.55858	6.60000	3.95000
		2	10.55858	7.92321	3.95000
		3	10.55858	7.92321	4.62321
		4	10.55858	6.60000	4.62321

C.1.2.5 West facing windows:

There are also eight west facing windows (named as Window_sdlF_N_Pos.unit1). where, the coordinates of the lower-left corner vertice (X1, Y1, Z1) are fixed as follows:

X1=X2=X3=X4=0.00,

Y1=values for each of west facing windows are listed in table below

Z1=values for each of west facing windows are listed in table below

The coordinates of the remaining three vertices are calculated based on the window width (W), the window height (H) and the new averaged frame width (L_{f_Ave}) using the below formulas:

Y2= Y1-(W-2* L_{f_Ave})

Z2=Z1

Y3= Y1-(W-2* L_{f_Ave})

Z3= Z1+(H/2-2* L_{f_Ave})

Y4=Y1

Z4= Z1+(H/2-2* L_{f_Ave})

The coordinates of the lower-left corner vertices of the eight west facing windows are listed as follows:

Fenestration Name	Building Surface Name	X	Y	Z
Window_sdl1_1_Bot.unit1	Wall_sdl1_1.unit1	0.00	8.00	0.60
Window_sdl1_1_Top.unit1	Wall_sdl1_1.unit1		8.00	1.35
Window_sdl1_2_Bot.unit1	Wall_sdl1_1.unit1		3.90	0.60
Window_sdl1_2_Top.unit1	Wall_sdl1_1.unit1		3.90	1.35
Window_sdl2_1_Bot.unit1	Wall_sdl1_2.unit1		8.00	3.20
Window_sdl2_1_Top.unit1	Wall_sdl1_2.unit1		8.00	3.95
Window_sdl2_2_Bot.unit1	Wall_sdl1_2.unit1		3.90	3.20
Window_sdl2_2_Top.unit1	Wall_sdl1_2.unit1		3.90	3.95

The coordinates of the remaining vertices of each west facing window are calculated using above equations.

For AERC baseline window B, the coordinates of the eight west facing windows are listed in the table below.

Fenestration Name	Building Surface	Vertices	X	Y	Z
Window_sdl1_1_Bot.unit1	Wall_sdl1_1.unit1	1	0.00000	8.00000	0.60000
		2	0.00000	6.67679	0.60000
		3	0.00000	6.67679	1.27321
		4	0.00000	8.00000	1.27321
Window_sdl1_1_Top.unit1	Wall_sdl1_1.unit1	1	0.00000	8.00000	1.35000
		2	0.00000	6.67679	1.35000
		3	0.00000	6.67679	2.02321
		4	0.00000	8.00000	2.02321
Window_sdl1_2_Bot.unit1	Wall_sdl1_1.unit1	1	0.00000	3.90000	0.60000
		2	0.00000	2.57679	0.60000
		3	0.00000	2.57679	1.27321
		4	0.00000	3.90000	1.27321
Window_sdl1_2_Top.unit1	Wall_sdl1_1.unit1	1	0.00000	3.90000	1.35000
		2	0.00000	2.57679	1.35000
		3	0.00000	2.57679	2.02321
		4	0.00000	3.90000	2.02321
Window_sdl2_1_Bot.unit1	Wall_sdl1_2.unit1	1	0.00000	8.00000	3.20000
		2	0.00000	6.67679	3.20000
		3	0.00000	6.67679	3.87321
		4	0.00000	8.00000	3.87321
Window_sdl2_1_Top.unit1	Wall_sdl1_2.unit1	1	0.00000	8.00000	3.95000
		2	0.00000	6.67679	3.95000
		3	0.00000	6.67679	4.62321
		4	0.00000	8.00000	4.62321
Window_sdl2_2_Bot.unit1	Wall_sdl1_2.unit1	1	0.00000	3.90000	3.20000
		2	0.00000	2.57679	3.20000
		3	0.00000	2.57679	3.87321
		4	0.00000	3.90000	3.87321
Window_sdl2_2_Top.unit1	Wall_sdl1_2.unit1	1	0.00000	3.90000	3.95000
		2	0.00000	2.57679	3.95000
		3	0.00000	2.57679	4.62321
		4	0.00000	3.90000	4.62321

A complete EnergyPlus window configuration inc file for the current AERC baseline window B was attached at the end of this document as Appendix F.

Baseline Window Configuration Include File:

```
FenestrationSurface:Detailed,
  Window_Idf1_1_Bot.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,   !- Construction Name
  Wall_Idf1_1.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  2.500000000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  Window_Idf1_1_Top.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,   !- Construction Name
  Wall_Idf1_1.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  2.500000000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

B: Baseline window run:
Glazing construction name is AERC_Doubleclear_Baseline. Frame construction name is AERC_Wood_Frame for both top and bottom "half" of the baseline window.

```
!      Window Material/Construction file with spectral data in IDF format
Construction:ComplexFenestrationState,
AERC_Doubleclear_Baseline,                    !- name
LBNLWindow,                                   !- basis type
None,                                         !- basis symmetry type
ThermParam_Glz_10001,                         !- window thermal model
CFS_Glz_10001_Basis,                          !- basis matrix name
CFS_Glz_10001_TfSol,                          !- Tfsol
CFS_Glz_10001_RbSol,                          !- Rbsol
CFS_Glz_10001_Tfvis,                          !- Tfvis
CFS_Glz_10001_Rbvis,                          !- Rbvis
Glass_102_Layer,                              !- layer 1 name
CFS_Glz_10001_Layer_1_fAbs,                   !- fAbs
CFS_Glz_10001_Layer_1_bAbs,                   !- bAbs
Gap_1_Glz_10001_Layer_1,                      !- gap 1 name
,
,
Glass_102_Layer,                              !- layer 2 name
CFS_Glz_10001_Layer_2_fAbs,                   !- fAbs
CFS_Glz_10001_Layer_2_bAbs;                   !- bAbs
...
```

Adiabatic Window Configuration Include File:

```
FenestrationSurface:Detailed,
  Window_Idf1_1_Bot.unit1, !- Name
  Window,                  !- Surface Type
  Adiabatic_Window,          !- Construction Name
  Wall_Idf1_1.unit1,       !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  ,                        !- View Factor to Ground
  ,                        !- Shading Control Name
  ,                        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  2.500000000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  Window_Idf1_1_Top.unit1, !- Name
  Window,                  !- Surface Type
  Adiabatic_Window,          !- Construction Name
  Wall_Idf1_1.unit1,       !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  ,                        !- View Factor to Ground
  ,                        !- Shading Control Name
  ,                        !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  2.500000000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

A: Adiabatic window run:
Glazing construction name is Adiabatic_window. Frame and divider construction name is blank (keep a comma) for both top and bottom "half" of the baseline window.

Adiabatic Window Construction Include File (Window_construction_adiabatic.inc):

```
!-------------------------------------------------------
!      Window Glass Layers
!-------------------------------------------------------

 WindowMaterial:Glazing,
  Super_Insulated_Glass,   !- Name
  SpectralAverage,         !- Optical Data Type
  ,                        !- Window Glass Spectral Data Set Name
  0.003,                   !- Thickness {m}
  0.000001,                !- Solar Transmittance at Normal Incidence
  0.999999,                !- Front Side Solar Reflectance at Normal Incidence
  0.999999,                !- Back Side Solar Reflectance at Normal Incidence
  0.000001,                !- Visible Transmittance at Normal Incidence
  0.999999,                !- Front Side Visible Reflectance at Normal Incidence
  0.999999,                !- Back Side Visible Reflectance at Normal Incidence
  0.000000,                !- Infrared Transmittance at Normal Incidence
  0.000001,                !- Front Side Infrared Hemispherical Emissivity
  0.000001,                !- Back Side Infrared Hemispherical Emissivity
  0.00000001;              !- Conductivity {W/m-K}

!-------------------------------------------------------
!      Window Construction
!-------------------------------------------------------
 Construction,
  Adiabatic_window,        !- Name
  Super_Insulated_Glass;   !- Outside Layer
```

Half-Deployed Window Configuration Include File:

```
FenestrationSurface:Detailed,
  Window_Idf1_1_Bot_unit1, !- Name
  Window,                !- Surface Type
  AERC_Doubleclear_Baseline,   !- Construction Name
  Wall_Idf1_1.unit1,     !- Building Surface Name
  ,                      !- Outside Boundary Condition Object
  ,                      !- View Factor to Ground
  ,                      !- Shading Control Name
  AERC_Wood_Frame,       !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  2.500000000000, 0.000000000000, 0.600000000000,  !-
  3.823210000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  Window_Idf1_1_Top_unit1, !- Name
  Window,                !- Surface Type
  AERC_Doubleclear_Attachment,   !- Construction Name
  Wall_Idf1_1.unit1,     !- Building Surface Name
  ,                      !- Outside Boundary Condition Object
  ,                      !- View Factor to Ground
  ,                      !- Shading Control Name
  AERC_Wood_Frame,       !- Frame and Divider Name
  1,                     !- Multiplier
  4,                     !- Number of Vertices
  2.500000000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

H: Attachments half deployed: Glazing Construction for "Bot" window unit AERC_Doubleclear_Baseline. Glazing Construction for "Top" window unit is AERC_Doubleclear_Attachment, which is user-specified. Frame construction name is AERC_Wood_Frame for both top and bottom "half" of the baseline window.

Fully-Deployed Window Configuration Include File :

```
FenestrationSurface:Detailed,
  Window_Idf1_1_Bot.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Attachment,  !- Construction Name
  Wall_Idf1_1.unit1,      !- Building Surface Name
  ,                   !- Outside Boundary Condition Object
  ,                   !- View Factor to Ground
  ,                   !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  2.500000000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
  Window_Idf1_1_Top.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Attachment,  !- Construction Name
  Wall_Idf1_1.unit1,      !- Building Surface Name
  ,                   !- Outside Boundary Condition Object
  ,                   !- View Factor to Ground
  ,                   !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  2.500000000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000, 0.000000000000, 1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000, 0.000000000000, 2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000, 0.000000000000, 2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

S: Attachments fully deployed: Glazing Construction is AERC_Doubleclear_Attachment, which is user-specified. Frame construction name is AERC_Wood_Frame for both top and bottom "half" of the baseline window.

C.2 Zone Infiltration:

The method of calculating air infiltration for the house with baseline windows, adiabatic windows and baseline windows with attachments consists of the following steps:

(1) Calculate the ELA of the whole house with baseline windows, ELA_H

(2) Calculate the ELA of all baseline windows, ELA_W

(3) Calculate the ELA of the whole house with adiabatic windows (no window infiltration), ELA_{HO}

(4) Calculate the ELA of all windows with attachment, ELA_{WA}

(5) Calculate the ELA of the whole house with windows and attachments, ELA_{HWA}

C.2.1 Calculating the ELA of the whole house with baseline windows, ELA$_H$

$$ELA_H = \frac{Q_{50}\left[\frac{\Delta P_4}{\Delta P_{50}}\right]^n}{\left[\frac{2\Delta P_4}{\rho}\right]^{0.5}} \times 10000 \tag{I.1}$$

$$Q_{50} = \frac{V_H \cdot ACH_{50}}{3600} \tag{I.2}$$

Where:

ELA_H = Effective leakage area of the whole house with baseline windows, (cm^2)

Q_{50} = Total house infiltration at 50 Pa, (m^3/s)

ΔP_{50} = 50 Pa test pressure for windows, (Pa)

ΔP_4 = 4 Pa used as baseline for comparison, (Pa)

n = 0.65; Flow exponent [-]

ρ = 1.29; Air density at standard temp. & press., (kg/m^3)

V_H = The volume of the house, (m^3)

ACH_{50} = Air changes per hour at 50 Pa

C.2.2 Calculating the ELA of all baseline windows, ELAW

$$ELA_W = \frac{Q_{W75}\left[\dfrac{\Delta P_4}{\Delta P_{75}}\right]^n}{\left[\dfrac{2\Delta P_4}{\rho}\right]^{0.5}} \times 10000 \tag{I.3}$$

$$Q_{W75} = q_{W75} \cdot A_W \tag{I.4}$$

Where:

ELA_W = Effective leakage area of all baseline windows, (cm^2)

Q_{W75} = Total baseline window infiltration at 75 Pa, (m^3/s)

ΔP_{75} = 75 Pa test pressure for windows, (Pa)

q_{W75} = 0.01016 $m^3/(s \cdot m^2)$ (2.0 cfm/ft^2); The infiltration per unit area of baseline window at 75 Pa, ($m^3/s \cdot m^2$)

A_w = Total window area, (m^2)

C.2.3 Calculating the ELA of the whole house without windows, ELAHO

$$ELA_{HO} = ELA_H - ELA_W \tag{I.5}$$

C.2.4 Calculating the ELA of windows with attachments, ELAWA

$$ELA_{WA} = \frac{Q_{WA75}\left[\dfrac{\Delta P_4}{\Delta P_{75}}\right]^n}{\left[\dfrac{2\Delta P_4}{\rho}\right]^{0.5}} \cdot 10000 \tag{I.6}$$

$$Q_{WA75} = q_{WA75} \cdot A_W \tag{I.7}$$

Where:

ELA_{WA} = Effective leakage area of all windows with attachment, (cm^2)

Q_{75WA} = Total infiltration of the windows with attachment at 75 Pa, (m^3/s)

q_{WA75} = The measured air infiltration per unit area of the window with attachment at 75 Pa, also known as air leakage measurement; [$m^3/(s \cdot m^2)$]

Conversion of measured air leakage from IP units (cfm/sf^2) to SI units ($m^3/(s \cdot m^2)$) is given by. This quantity is specified as input data in AERCalc for infiltration of window attachment product (baseline window plus window attachment):

$$q_{WA75}(SI) = 0.00508 \cdot q_{WA75}(IP)$$

Where the conversion factor 0.00508 is the result of the following conversion action: (ft to m)/(min to sec), or 0.3048/60.

C.2.5 Calculating the ELA of the whole house with window and attachment, ELA_{HWA}

$$ELA_{HWA} = ELA_{HO} + ELA_{WA} \tag{I.8}$$

Numerical values for the typical house and baseline window in AERCalc air:

$$V_H = 577.6288 \text{ m}^3 \tag{I.9}$$

$$ACH_{50}\_cooling=10 \text{ 1/hr} \tag{I.10}$$

$$ACH_{50}\_heating=7 \text{ 1/hr} \tag{I.11}$$

$$q_{W75} = 0.01016 \text{ m}^3/(\text{s}\cdot\text{m}^2) \tag{I.12}$$

$$A_W = 33.6 \text{ m}^2 \tag{I.13}$$

<u>For cooling climate:</u>

$$ELA_{HO} = 1{,}044 \text{ cm}^2$$

$$ELA_{HWA} = 1{,}044 + ELA_{WA} \text{ cm}^2 \tag{I.14}$$

For example, if the measured air infiltration of the window with attachment is 1 cfm/sf^2, then:

ELA_{HWA} equals to 1146 cm^2, this value should be inputted in the ELA filed of EnergyPlus IDF files for cooling simulation.

$$ELA_{WA} = \frac{1 \cdot 0.00508 \cdot 33.6 \cdot \left[\frac{4}{75}\right]^{0.65}}{\left[\frac{8}{1.29}\right]^{0.5}} \cdot 10000 = 101.977 cm^2$$

Therefore,

$$ELA_{HWA} = 1{,}044 + 101.977 = 1{,}145.997 cm^2$$

<u>For heating climate calculation:</u>

$$ELA_{H0} = 669 \text{ cm}^2$$

$$ELA_{HWA} = 669 + ELA_{WA} \ (\text{cm}^2) \tag{I.15}$$

For the same example the infiltration for the house with window attachments will be:

$$ELA_{HWA} = 669 + 101.977 = 770.997cm^2$$

<u>Baseline window and half-deployed window infiltration include file for Houston (Air_infiltration_baseline_Houston.inc):</u>

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,       !- Zone Name
  always_avail,       !- Schedule Name
  1248,               !- Effective Air Leakage Are
  0.00029,            !- Stack Coefficient
  0.000231;           !- Wind Coefficient
```

B and H: Baseline window run and half-deployed window run: the effective air leakage area (ELA) is 1044+ELAw in Houston. ELAw is 204.

<u>Baseline window and half-deployed window infiltration include file for Minneapolis (Air_infiltration_baseline_Minneapolis.inc):</u>

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,       !- Zone Name
  always_avail,       !- Schedule Name
  873,               !- Effective Air Leakage Area
  0.00029,            !- Stack Coefficient
  0.000231;           !- Wind Coefficient
```

B and H: Baseline window run and half-deployed window run: the effective air leakage area (ELA) is 669+ELAw in Minneapolis. ELAw is 204.

<u>Adiabatic window infiltration include file for Houston (Air_infiltration_adiabatic_Houston.inc):</u>

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,       !- Zone Name
  always_avail,       !- Schedule Name
  1044,               !- Effective Air Leakage Area {cm2}
  0.00029,            !- Stack Coefficient
  0.000231;           !- Wind Coefficient
```

A: Adiabatic window run: the effective air leakage area (ELA) is 1044 in Houston.

Adiabatic window infiltration include file for Minneapolis (Air_infiltration_adiabatic_Minneapolis.inc):

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,      !- Zone Name
  always_avail,      !- Schedule Name
  669,               !- Effective Air Leakage Area {cm2}
  0.00029,           !- Stack Coefficient
  0.000231;          !- Wind Coefficient
```

A: Adiabatic window run: the effective air leakage area (ELA) is 669 in Minneapolis.

Fully-deployed window infiltration include file for Houston (Air_infiltration_user_input_Houston.inc):

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,      !- Zone Name
  always_avail,      !- Schedule Name
  1044+ELAS,               !- Effective Air Leakag
  0.00029,           !- Stack Coefficient
  0.000231;          !- Wind Coefficient
```

F: Attachments fully deployed: the effective air leakage area (ELA) is $1044+ELA_S$ in Houston. ELA_S is attachment dependent and is specified as input data.

Fully-deployed window infiltration include file for Minneapolis (Air_infiltration_user_input_Minneapolis.inc):

```
ZoneInfiltration:EffectiveLeakageArea,
  Living_ShermanGrimsrud_unit1,  !- Name
  living_unit1,      !- Zone Name
  always_avail,      !- Schedule Name
  669+ELAS,               !- Effective Air Leakage
  0.00029,           !- Stack Coefficient
  0.000231;          !- Wind Coefficient
```

F: Attachments fully deployed: the effective air leakage area (ELA) is $669+ELA_S$ in Houston. ELA_S is attachment dependent and is specified as input data.

Note 1: ELA_S in annotations above was replaced with ELA_{WA} notation in equations preeding these annotations.

Note 2: In AERCalc, users are required to input the measured air leakage (AL) of the window with attachment, but in EnergyPlus the infiltration is calculated based on the effective leakage area of the whole house including the windows with attachments. Thus, it is *necessary to convert the user-input air leakage to the effective leakage area of the whole house (ELA_{HWA})at the back-end before starting simulation. In addition to this conversion, unit conversion will often be required, since most common way of reporting AL is in IP units of cfm/sf^2. The methodology of converting AL into ELA_{HWA} was illustrated in above.*

C.3 HVAC:

<u>HVAC System for Houston</u>

- Red highlight: System_autosize_Houston.inc
- Yellow highlight: System_sizing_Houston.inc

```
Sizing:System,
  Central System_unit1,      !- AirLoop Name
  Sensible,                  !- Type of Load to Size On
  autosize,                  !- Design Outdoor Air Flow Rate {m3/s}
  0.652,                     !- Design Outdoor Air Flow Rate {m3/s}
  1,                         !- Central Heating Maximum System Air Flow Ratio
  7,                         !- Preheat Design Temperature {C}
  0.008,                     !- Preheat Design Humidity Ratio {kgWater/kgDryAi
  11,                        !- Precool Design Temperature {C}
  0.008,                     !- Precool Design Humidity Ratio {kgWater/kgDryAi
  12,                        !- Central Cooling Design Supply Air Temperature
  50,                        !- Central Heating Design Supply Air Temperature
  NonCoincident,             !- Type of Zone Sum to Use
  No,                        !- 100% Outdoor Air in Cooling
  No,                        !- 100% Outdoor Air in Heating
  0.008,                     !- Central Cooling Design Supply Air Humidity Rat
  0.008,                     !- Central Heating Design Supply Air Humidity Rat
  designday,                 !- Cooling Supply Air Flow Rate Method
  ,                          !- Cooling Supply Air Flow Rate {m3/s}
  ,                          !- Cooling Supply Air Flow Rate Per Floor Area {m
  ,                          !- Cooling Fraction of Autosized Cooling Supply A
  ,                          !- Cooling Supply Air Flow Rate Per Unit Cooling
  designday,                 !- Heating Supply Air Flow Rate Method
  ,                          !- Heating Supply Air Flow Rate {m3/s}
  ,                          !- Heating Supply Air Flow Rate Per Floor Area {m
  ,                          !- Heating Fraction of Autosized Heating Supply A
  ,                          !- Heating Fraction of Autosized Cooling Supply A
  ,                          !- Heating Supply Air Flow Rate Per Unit Heating
  ZoneSum,                   !- System Outdoor Air Method
  0.5,                       !- Zone Maximum Outdoor Air Fraction {dimensionle
  CoolingDesignCapacity,     !- Cooling Design Capacity Method
  autosize,                  !- Cooling Design Capacity {W}
  9485.25,                   !- Cooling Design Capacity {W}
  ,                          !- Cooling Design Capacity Per Floor Area {W/m2}
  ,                          !- Fraction of Autosized Cooling Design Capacity
  HeatingDesignCapacity,     !- Heating Design Capacity Method
  autosize,                  !- Heating Design Capacity {W}
  7126.4,                    !- Heating Design Capacity {W}
  ,                          !- Heating Design Capacity Per Floor Area {W/m2}
  ,                          !- Fraction of Autosized Heating Design Capacity
  ;                          !- Central Cooling Capacity Control Method
```

1, for baseline window run, this field keeps autosize, for other runs, viz. adiabatic window run, shade fully deployed run and shade half deployed run, this field replaces with 0.652

2, for baseline window run, this field keeps autosize, for other runs, this field replaces with 9485.25

3, for baseline window run, this field keeps autosize, for other runs, this field replaces with 7126.4

```
AirTerminal:SingleDuct:Uncontrolled,
  ZoneDirectAir_unit1,       !- Name
  always_avail,              !- Availability Schedule Name
  Zone Inlet Node_unit1,     !- Zone Supply Air Node Name
  autosize;                  !- Maximum Air Flow Rate {m3/s}
  0.652;                     !- Maximum Air Flow Rate {m3/s}
```

4, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
Coil:Cooling:DX:SingleSpeed,
  DX Cooling Coil_unit1,    !- Name
  always_avail,             !- Availability Schedule Name
  autosize,                 !- Gross Rated Total Cooling Capacity
  13131.31,                 !- Gross Rated Total Cooling Capacity
  autosize,                 !- Gross Rated Sensible Heat Ratio
  0.733253,                 !- Gross Rated Sensible Heat Ratio
  2.70,                     !- Gross Rated Cooling COP {W/W}
  autosize,                     !- Rated Air Flow Rate {m3/s}
  0.652,                      !- Rated Air Flow Rate {m3/s}
  ,                         !- Rated Evaporator Fan Power Per Volu
  Cooling Coil Air Inlet Node_unit1,  !- Air Inlet Node Name
  Heating Coil Air Inlet Node_unit1,  !- Air Outlet Node Name
  HPACCoolCapFT,            !- Total Cooling Capacity Function of
  HPACCoolCapFFF,           !- Total Cooling Capacity Function of
  HPACCOOLEIRFT,            !- Energy Input Ratio Function of Temp
  HPACCOOLEIRFFF,           !- Energy Input Ratio Function of Flow
  HPACCOOLPLFFPLR;          !- Part Load Fraction Correlation Curv
```

5, for baseline window run, this field keeps autosize, for other runs, this field replaces with 13131.31

6, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.733253

7, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
Fan:OnOff,
  Supply Fan_unit1,         !- Name
  always_avail,             !- Availability Schedule Name
  0.7,                      !- Fan Total Efficiency
  400,                      !- Pressure Rise {Pa}
  autosize,                     !- Maximum Flow Rate {m3/s
  0.652,                    !- Maximum Flow Rate {m3/s}
  0.8,                      !- Motor Efficiency
  1,                        !- Motor In Airstream Fraction
  air loop inlet node_unit1,   !- Air Inlet Node Name
  cooling coil air inlet node_unit1,   !- Air Outlet Node
  ,                         !- Fan Power Ratio Function of
  ,                         !- Fan Efficiency Ratio Functi
  General;                  !- End-Use Subcategory
```

8, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
Coil:Heating:DX:SingleSpeed,
  Main DX Heating Coil_unit1,   !- Name
  always_avail,             !- Availability Schedule Name
  autosize,                 !- Rated Total Heating Capacity {W}
  13131.31,                 !- Rated Total Heating Capacity {W}
  1.99,                     !- Rated COP {W/W}
  autosize,                     !- Rated Air Flow Rate {m3/s}
  0.652,                      !- Rated Air Flow Rate {m3/s}
  ,                         !- Rated Evaporator Fan Power Per Vol
  Heating Coil Air Inlet Node_unit1,  !- Air Inlet Node Name
  Supp Heating Coil Air Inlet Node_unit1,  !- Air Outlet Node N
  HPACHeatCapFT,            !- Total Heating Capacity Function o
  HPACHeatCapFFF,           !- Total Heating Capacity Function o
  HPACHeatEIRFT,            !- Energy Input Ratio Function of Te
  HPACHeatEIRFFF,           !- Energy Input Ratio Function of Fl
  HPACCOOLPLFFPLR,          !- Part Load Fraction Correlation Cu
  Defrost_EIR_FT,           !- Defrost Energy Input Ratio Functi
  -17.78,                   !- Minimum Outdoor Dry-Bulb Temperat
  ,                         !- Outdoor Dry-Bulb Temperature to T
  5.0,                      !- Maximum Outdoor Dry-Bulb Temperat
  200.0,                    !- Crankcase Heater Capacity {W}
  10.0,                     !- Maximum Outdoor Dry-Bulb Temperat
  ReverseCycle,             !- Defrost Strategy
  OnDemand,                 !- Defrost Control
  ,                         !- Defrost Time Period Fraction
  ;                         !- Resistive Defrost Heater Capacity
```

9, for baseline window run, this field keeps autosize, for other runs, this field replaces with 13131.31

10, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
Coil:Heating:Electric,
    Supp Heating Coil_unit1, !- Name
    always_avail,            !- Availability Schedule Name
    1,                       !- Efficiency
    autosize,                 !- Nominal Capacity {W}
    7910.07,                 !- Nominal Capacity {W}
    Supp Heating Coil Air Inlet Node_unit1,  !- Air Inlet Node Name
    Air Loop Outlet Node_unit1;  !- Air Outlet Node Name
```

11, for baseline window run, this field keeps autosize, for other runs, this field replaces with 7910.07

```
!-   ===========  ALL OBJECTS IN CLASS: AIRLOOPHVAC ===========

  AirLoopHVAC,
    Central System_unit1,    !- Name
    ,                        !- Controller List Name
    availability list,       !- Availability Manager List Name
    autosize,                    !- Design Supply Air Flow Rate {m3/s}
    0.652,                    !- Design Supply Air Flow Rate {m3/s}
    Air Loop Branches_unit1, !- Branch List Name
    ,                        !- Connector List Name
    Air Loop Inlet Node_unit1,  !- Supply Side Inlet Node Name
    Return Air Mixer Outlet_unit1,  !- Demand Side Outlet Node Name
    Zone Equipment Inlet Node_unit1,  !- Demand Side Inlet Node Names
    Air Loop Outlet Node_unit1;  !- Supply Side Outlet Node Names
```

12, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
AirLoopHVAC:UnitaryHeatPump:AirToAir,
   Heat Pump_unit1,           !- Name
   always_avail,              !- Availability Schedule Name
   Air Loop Inlet node_unit1,  !- Air Inlet Node Name
   Air Loop Outlet Node_unit1,  !- Air Outlet Node Name
   autosize,                    !- Supply Air Flow Rate During Cooling Oper
   0.652,                    !- Supply Air Flow Rate During Cooling Operat:
   autosize,                    !- Supply Air Flow Rate During Heating Oper
   0.652,                    !- Supply Air Flow Rate During Heating Operat:
   0.0,                       !- Supply Air Flow Rate When No Cooling or Heat
   living_unit1,              !- Controlling Zone or Thermostat Location
   Fan:OnOff,                 !- Supply Air Fan Object Type
   Supply Fan_unit1,          !- Supply Air Fan Name
   Coil:Heating:DX:SingleSpeed,  !- Heating Coil Object Type
   Main DX Heating Coil_unit1,  !- Heating Coil Name
   Coil:Cooling:DX:SingleSpeed,  !- Cooling Coil Object Type
   DX Cooling Coil_unit1,     !- Cooling Coil Name
   Coil:Heating:Electric,     !- Supplemental Heating Coil Object Type
   Supp Heating Coil_unit1,  !- Supplemental Heating Coil Name
   50,                        !- Maximum Supply Air Temperature from Suppleme
   10,                        !- Maximum Outdoor Dry-Bulb Temperature for Su
   BlowThrough,               !- Fan Placement
   fan_cycle;                 !- Supply Air Fan Operating Mode Schedule Name
```

13, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

14, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
 Branch,
   Air Loop Main Branch_unit1,  !- Name
   autosize,                    !- Maximum Flow Rate {m3/s}
   0.652,                    !- Maximum Flow Rate {m3/s}
   ,                         !- Pressure Drop Curve Name
   AirLoopHVAC:UnitaryHeatPump:AirtoAir,  !- Component 1 Object Type
   Heat Pump_unit1,             !- Component 1 Name
   Air Loop Inlet Node_unit1,   !- Component 1 Inlet Node Name
   Air Loop Outlet Node_unit1,  !- Component 1 Outlet Node Name
   ACTIVE;                   !- Component 1 Branch Control Type
```

15, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.652

```
Pump:VariableSpeed,
  Mains Pressure_unit1,      !- Name
  Mains Inlet Node_unit1,    !- Inlet Node Name
  Mains Pressure Outlet Node_unit1,  !- Outlet Node Name
  autosize,                  !- Design Maximum Flow Rate {m3/s}
  0.000009,                  !- Design Maximum Flow Rate {m3/s}
  179352,                    !- Design Pump Head {Pa}
  autosize,                  !- Design Power Consumption {W}
  0.9,                       !- Motor Efficiency
  0,                         !- Fraction of Motor Inefficiencies
  0,                         !- Coefficient 1 of the Part Load P
  1,                         !- Coefficient 2 of the Part Load P
  0,                         !- Coefficient 3 of the Part Load P
  0,                         !- Coefficient 4 of the Part Load P
  0,                         !- Design Minimum Flow Rate {m3/s}
  Intermittent;              !- Pump Control Type
```

16, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

```
WaterHeater:Mixed,
  Water Heater_unit1,         !- Name
  0.196841372,                !- Tank Volume {m3}
  dhw_setpt,                  !- Setpoint Temperature Schedule Name
  2,                          !- Deadband Temperature Difference {deltaC}
  50,                         !- Maximum Temperature Limit
  Cycle,                      !- Heater Control Type
  autosize,                   !- Heater Maximum Capacity {W
  5500,                       !- Heater Maximum Capacity {W
  0,                          !- Heater Minimum Capacity {W
  0,                          !- Heater Ignition Minimum Fl
  ,                           !- Heater Ignition Delay {s}
  electricity,                !- Heater Fuel Type
  1,                          !- Heater Thermal Efficiency
  ,                           !- Part Load Factor Curve Name
  ,                           !- Off Cycle Parasitic Fuel Consumption Rate {W}
  ,                           !- Off Cycle Parasitic Fuel Type
  ,                           !- Off Cycle Parasitic Heat Fraction to Tank
  ,                           !- On Cycle Parasitic Fuel Consumption Rate {W}
  ,                           !- On Cycle Parasitic Fuel Type
  ,                           !- On Cycle Parasitic Heat Fraction to Tank
  Zone,                       !- Ambient Temperature Indicator
  ,                           !- Ambient Temperature Schedule Name
  living_unit1,               !- Ambient Temperature Zone Name
  ,                           !- Ambient Temperature Outdoor Air Node Name
  1.3306616,                  !- Off Cycle Loss Coefficient to Ambient Temperature {W/K}
  1,                          !- Off Cycle Loss Fraction to Zone
  1.3306616,                  !- On Cycle Loss Coefficient to Ambient Temperature {W/K}
  1,                          !- On Cycle Loss Fraction to Zone
  0,                          !- Peak Use Flow Rate {m3/s}
  ,                           !- Use Flow Rate Fraction Sch
  ,                           !- Cold Water Supply Temperat
  Water Heater use inlet node_unit1,  !- Use Side Inlet
  Water Heater use outlet node_unit1,  !- Use Side Outle
  1,                          !- Use Side Effectiveness
  ,                           !- Source Side Inlet Node Nam
  ,                           !- Source Side Outlet Node Na
  1,                          !- Source Side Effectiveness
  autosize,                   !- Use Side Design Flow Rate {m3/s}
  0.000009,                   !- Use Side Design Flow Rate {m3/s}
  0,                          !- Source Side Design Flow Rate {m3/s}
  1.5;                        !- Indirect Water Heating Recovery Time {hr}
```

17, for baseline window run, this field keeps autosize, for other runs, this field replaces with 5500

18, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

```
PlantLoop,
  DHW Loop_unit1,             !- Name
  Water,                      !- Fluid Type
  ,                           !- User Defined Fluid Type
  DHW Loop Operation_unit1,!- Plant Equipment Operatio
  DHW Supply Outlet Node_unit1,  !- Loop Temperature S
  100,                        !- Maximum Loop Temperature
  0,                          !- Minimum Loop Temperature
  autosize,                   !- Maximum Loop Flow Rate {
  0.000009,                   !- Maximum Loop Flow Rate {
  0,                          !- Minimum Loop Flow Rate {
  autocalculate,              !- Plant Loop Volume {m3}
  0.006851,                   !- Plant Loop Volume {m3}
  Mains Inlet Node_unit1,     !- Plant Side Inlet Node Name
  DHW Supply Outlet Node_unit1,  !- Plant Side Outlet
  DHW Supply Branches_unit1,  !- Plant Side Branch Lis
  DHW Supply Connectors_unit1,  !- Plant Side Connecto
  DHW Demand Inlet Node_unit1,  !- Demand Side Inlet N
  Mains Makeup Node_unit1, !- Demand Side Outlet Node
  DHW Demand Branches_unit1,  !- Demand Side Branch Li
  DHW Demand Connectors_unit1,  !- Demand Side Connect
  Optimal;                    !- Load Distribution Scheme
```

19, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

20, for baseline window run, this field keeps autocalculate, for other runs, this field replaces with 0.006851

HVAC System for Minneapolis

- Red highlight: System_autosize_Minneapolis.inc
- Yellow highlight: System_sizing_Minneapolis.inc

```
Sizing:System,
  Central System_unit1,       !- AirLoop Name
  Sensible,                   !- Type of Load to Size On
  autosize,                     !- Design Outdoor Air Flow Rate {m3/s}
  0.563,                      !- Design Outdoor Air Flow Rate {m3/s}
  1,                          !- Central Heating Maximum System Air Flow
  7,                          !- Preheat Design Temperature {C}
  0.008,                      !- Preheat Design Humidity Ratio {kgWater/
  11,                         !- Precool Design Temperature {C}
  0.008,                      !- Precool Design Humidity Ratio {kgWater/
  12,                         !- Central Cooling Design Supply Air Tempe
  50,                         !- Central Heating Design Supply Air Tempe
  NonCoincident,              !- Type of Zone Sum to Use
  No,                         !- 100% Outdoor Air in Cooling
  No,                         !- 100% Outdoor Air in Heating
  0.008,                      !- Central Cooling Design Supply Air Humid
  0.008,                      !- Central Heating Design Supply Air Humid
  designday,                  !- Cooling Supply Air Flow Rate Method
  ,                           !- Cooling Supply Air Flow Rate {m3/s}
  ,                           !- Cooling Supply Air Flow Rate Per Floor
  ,                           !- Cooling Fraction of Autosized Cooling S
  ,                           !- Cooling Supply Air Flow Rate Per Unit C
  designday,                  !- Heating Supply Air Flow Rate Method
  ,                           !- Heating Supply Air Flow Rate {m3/s}
  ,                           !- Heating Supply Air Flow Rate Per Floor
  ,                           !- Heating Fraction of Autosized Heating S
  ,                           !- Heating Fraction of Autosized Cooling S
  ,                           !- Heating Supply Air Flow Rate Per Unit H
  ZoneSum,                    !- System Outdoor Air Method
  0.5,                        !- Zone Maximum Outdoor Air Fraction {dime
  CoolingDesignCapacity,      !- Cooling Design Capacity Method
  autosize,                    !- Cooling Design Capacity {W}
  7979.19,                    !- Cooling Design Capacity {W}
  ,                           !- Cooling Design Capacity Per Floor Area
  ,                           !- Fraction of Autosized Cooling Design Ca
  HeatingDesignCapacity,      !- Heating Design Capacity Method
  autosize,                   !- Heating Design Capacity {W}
  15123.09,                   !- Heating Design Capacity {W}
  ,                           !- Heating Design Capacity Per Floor Area
  ,                           !- Fraction of Autosized Heating Design Ca
  ;                           !- Central Cooling Capacity Control Method
```

1, for baseline window run, this field keeps autosize, for other runs, viz. adiabatic window run, shade fully-deployed run and shade half-deployed run, this field replaces with 0.563

2, for baseline window run, this field keeps autosize, for other runs, this field replaces with 7979.19

3, for baseline window run, this field keeps autosize, for other runs, this field replaces with 15123.09

```
AirTerminal:SingleDuct:Uncontrolled,
  ZoneDirectAir_unit1,        !- Name
  always_avail,               !- Availability Schedule Name
  Zone Inlet Node_unit1,      !- Zone Supply Air Node Name
  autosize;                     !- Maximum Air Flow Rate {m3/s}
  0.563;                      !- Maximum Air Flow Rate {m3/s}
```

4, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
Coil:Cooling:DX:SingleSpeed,
  DX Cooling Coil_unit1,    !- Name
  always_avail,             !- Availability Schedule Name
  autosize,                 !- Gross Rated Total Cooling Capacity {W}
  10628.64,                 !- Gross Rated Total Cooling Capacity {W}
  autosize,                 !- Gross Rated Sensible Heat Ratio
  0.753625,                 !- Gross Rated Sensible Heat Ratio
  2.70,                     !- Gross Rated Cooling COP {W/W}          SEER=
  autosize,                    !- Rated Air Flow Rate {m3/s}
  0.563,                    !- Rated Air Flow Rate {m3/s}
  ,                         !- Rated Evaporator Fan Power Per Volume Flow
  Cooling Coil Air Inlet Node_unit1,  !- Air Inlet Node Name
  Heating Coil Air Inlet Node_unit1,  !- Air Outlet Node Name
  Cool-Cap-FT,              !- Total Cooling Capacity Function of Tempera
  ConstantCubic,            !- Total Cooling Capacity Function of Flow Fr
  Cool-EIR-FT,              !- Energy Input Ratio Function of Temperature
  ConstantCubic,            !- Energy Input Ratio Function of Flow Fracti
  Cool-PLF-fPLR;            !- Part Load Fraction Correlation Curve Name
```

5, for baseline window run, this field keeps autosize, for other runs, this field replaces with 10628.64

6, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.753625

7, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
Fan:OnOff,
  Supply Fan_unit1,            !- Name
  always_avail,                !- Availability Schedule
  0.7,                         !- Fan Total Efficiency
  400,                         !- Pressure Rise {Pa}
  autosize,                    !- Maximum Flow Rate {m3/
  0.563,                    !- Maximum Flow Rate {m3/s}
  0.8,                         !- Motor Efficiency
  1,                           !- Motor In Airstream Fra
  air loop inlet node_unit1,   !- Air Inlet Node Name
  cooling coil air inlet node_unit1,  !- Air Outlet
  ,                            !- Fan Power Ratio Functi
  ,                            !- Fan Efficiency Ratio F
  General;                     !- End-Use Subcategory
```

8, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
 AirLoopHVAC,
   Central System_unit1,      !- Name
   ,                          !- Controller List Name
   availability list,         !- Availability Manager List Name
   autosize,                  !- Design Supply Air Flow Rate {m3/
   0.563,                  !- Design Supply Air Flow Rate {m3/s}
   Air Loop Branches_unit1,   !- Branch List Name
   ,                          !- Connector List Name
   Air Loop Inlet Node_unit1,  !- Supply Side Inlet Node Name
   Return Air Mixer Outlet_unit1,  !- Demand Side Outlet Node N
   Zone Equipment Inlet Node_unit1,  !- Demand Side Inlet Node
   Air Loop Outlet Node_unit1;  !- Supply Side Outlet Node Nam
```

9, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
!-   ===========  ALL OBJECTS IN CLASS: AIRLOOPHVAC:UNITARYHEATC

 AirLoopHVAC:UnitaryHeatCool,
   ACandF_unit1,              !- Name
   always_avail,              !- Availability Schedule Name
   air loop inlet node_unit1,  !- Unitary System Air Inlet Node
   air loop outlet node_unit1,  !- Unitary System Air Outlet No
   fan_cycle,                 !- Supply Air Fan Operating Mode Sc
   80,                        !- Maximum Supply Air Temperature {
   autosize,                  !- Cooling Supply Air Flow Rate {m
   0.563,                  !- Cooling Supply Air Flow Rate {m3/s
   autosize,                  !- Heating Supply Air Flow Rate {m
   0.563,                  !- Heating Supply Air Flow Rate {m3/s
   0,                         !- No Load Supply Air Flow Rate {m3
   living_unit1,              !- Controlling Zone or Thermostat L
   Fan:OnOff,                 !- Supply Fan Object Type
   Supply Fan_unit1,          !- Supply Fan Name
   BlowThrough,               !- Fan Placement
   Coil:Heating:gas,          !- Heating Coil Object Type
   Main gas Heating Coil_unit1,  !- Heating Coil Name
   Coil:Cooling:DX:SingleSpeed,  !- Cooling Coil Object Type
   DX Cooling Coil_unit1,     !- Cooling Coil Name
   None;                      !- Dehumidification Control Type
```

10, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

11, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
 Branch,
   Air Loop Main Branch_unit1,  !- Name
   autosize,                  !- Maximum Flow Rate {m3/s}
   0.563,                  !- Maximum Flow Rate {m3/s}
   ,                          !- Pressure Drop Curve Name
   AirLoopHVAC:UnitaryHeatCool,  !- Component 1 Object Type
   ACandF_unit1,              !- Component 1 Name
   Air Loop Inlet Node_unit1,  !- Component 1 Inlet Node Name
   Air loop outlet node_unit1,  !- Component 1 Outlet Node Name
   ACTIVE;                    !- Component 1 Branch Control Type
```

12, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.563

```
!-   ===========  ALL OBJECTS IN CLASS: OUTDOORAIR:NODE =========

 OutdoorAir:Node,
   outside air inlet node_unit1,  !- Name
   0.914355407629293;         !- Height Above Ground {m}

 OutdoorAir:Node,
   outdoor air node_unit1,    !- Name
   1;                         !- Height Above Ground {m}

!-   ===========  ALL OBJECTS IN CLASS: COIL:HEATING:GAS ========

 Coil:Heating:Gas,
   Main gas heating coil_unit1,  !- Name
   always_avail,              !- Availability Schedule Name
   0.78,                      !- Gas Burner Efficiency
   autosize,                  !- Nominal Capacity {W}
   16720.73,                  !- Nominal Capacity {W}
   heating coil air inlet node_unit1,  !- Air Inlet Node Name
   air loop outlet node_unit1;  !- Air Outlet Node Name
```

13, for baseline window run, this field keeps autosize, for other runs, this field replaces with 16720.73

```
Pump:VariableSpeed,
  Mains Pressure_unit1,      !- Name
  Mains Inlet Node_unit1,    !- Inlet Node Name
  Mains Pressure Outlet Node_unit1,  !- Outlet Node Name
  autosize,                  !- Design Maximum Flow Rate {m3/s}
  0.000009,                  !- Design Maximum Flow Rate {
  179352,                    !- Design Pump Head {Pa}
  autosize,                  !- Design Power Consumption {
  0.9,                       !- Motor Efficiency
  0,                         !- Fraction of Motor Inefficı
  0,                         !- Coefficient 1 of the Part
  1,                         !- Coefficient 2 of the Part
  0,                         !- Coefficient 3 of the Part
  0,                         !- Coefficient 4 of the Part Load I
  0,                         !- Design Minimum Flow Rate {m3/s}
  Intermittent;              !- Pump Control Type
```

14, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

```
WaterHeater:Mixed,
  Water Heater_unit1,        !- Name
  0.196841372,               !- Tank Volume {m3}
  dhw_setpt,                 !- Setpoint Temperature Schedul
  2,                         !- Deadband Temperature Differe
  50,                        !- Maximum Temperature Limit {C
  Cycle,                     !- Heater Control Type
  autosize,                  !- Heater Maximum Capacity
  11137.8,                   !- Heater Maximum Capacity
  0,                         !- Heater Minimum Capacity
  0,                         !- Heater Ignition Minimum
  ,                          !- Heater Ignition Delay {s
  naturalgas,                !- Heater Fuel Type
  0.8,                       !- Heater Thermal Efficienc
  ,                          !- Part Load Factor Curve N
  ,                          !- Off Cycle Parasitic Fuel Con
  ,                          !- Off Cycle Parasitic Fuel Typ
  ,                          !- Off Cycle Parasitic Heat Fra
  ,                          !- On Cycle Parasitic Fuel Cons
  ,                          !- On Cycle Parasitic Fuel Type
  ,                          !- On Cycle Parasitic Heat Frac
  Zone,                      !- Ambient Temperature Indicato
  ,                          !- Ambient Temperature Schedule
  living_unit1,              !- Ambient Temperature Zone
  ,                          !- Ambient Temperature Outd
  1.3306616,                 !- Off Cycle Loss Coefficie
  1,                         !- Off Cycle Loss Fraction
  1.3306616,                 !- On Cycle Loss Coefficien
  1,                         !- On Cycle Loss Fraction t
  0,                         !- Peak Use Flow Rate {m3/s
  ,                          !- Use Flow Rate Fraction S
  ,                          !- Cold Water Supply Temperatur
  Water Heater use inlet node_unit1,  !- Use Side Inlet No
  Water Heater use outlet node_unit1,  !- Use Side Outlet
  1,                         !- Use Side Effectiveness
  ,                          !- Source Side Inlet Node Name
  ,                          !- Source Side Outlet Node Name
  1,                         !- Source Side Effectiveness
  autosize,                  !- Use Side Design Flow Rate {m
  0.000009,                  !- Use Side Design Flow Rate {m
  0,                         !- Source Side Design Flow Rate
  1.5;                       !- Indirect Water Heating Recov
```

15, for baseline window run, this field keeps autosize, for other runs, this field replaces with 11137.8

16, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

```
PlantLoop,
  DHW Loop_unit1,            !- Name
  Water,                     !- Fluid Type
  ,                          !- User Defined Fluid Type
  DHW Loop Operation_unit1,!- Plant Equipment Operati
  DHW Supply Outlet Node_unit1,  !- Loop Temperature S
  100,                       !- Maximum Loop Temperatur
  0,                         !- Minimum Loop Temperatur
  autosize,                  !- Maximum Loop Flow Rate {
  0.000009,                  !- Maximum Loop Flow Rate {
  0,                         !- Minimum Loop Flow Rate {m3/s}
  autocalculate,             !- Plant Loop Volume {m3}
  0.006851,                  !- Plant Loop Volume {m3}
  Mains Inlet Node_unit1,    !- Plant Side Inlet Node Name
  DHW Supply Outlet Node_unit1,  !- Plant Side Outlet
  DHW Supply Branches_unit1,   !- Plant Side Branch Li
  DHW Supply Connectors_unit1,   !- Plant Side Connect
  DHW Demand Inlet Node_unit1,   !- Demand Side Inlet N
  Mains Makeup Node_unit1,  !- Demand Side Outlet Node
  DHW Demand Branches_unit1,   !- Demand Side Branch L
  DHW Demand Connectors_unit1,   !- Demand Side Connec
  Optimal;                   !- Load Distribution Scheme
```

17, for baseline window run, this field keeps autosize, for other runs, this field replaces with 0.000009

18, for baseline window run, this field keeps autocalculate, for other runs, this field replaces with 0.006851

Appendix D: Cooling and Heating Season Definition

Table D1. Cooling and Heating Season Definition for Heating and Cooling EP

Minneapolis			Houston		
	Start	End		Start	End
Winter	November 1	January 31	Winter	December 1	February 28
Spring	February 1	April 30	Spring	March 1	May 31
Summer	May 1	July 31	Summer	June 1	August 31
Autumn	August 1	October 31	Autumn	September 1	November 30
Heating	September 15	March 16	Heating	October 16	April 14
Cooling	March 17	September 14	Cooling	April 15	October 15

Appendix E: ESCalc XML Schema

ESCalc XML schema describes interface between AERCalc and calculation module ESCalc.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2016 rel. 2 sp1 (x64) (http://www.altova.com) by D. Charlie Curcija (Lawrence Berkeley National Laboratory) -->
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" xmlns:vc="http://www.w3.org/2007/XMLSchema-versioning" elementFormDefault="qualified" attributeFormDefault="unqualified" version="1.1" vc:minVersion="1.1">
  <xs:element name="ESCalc">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="Input" minOccurs="0">
          <xs:annotation>
            <xs:documentation>ESCalc Inputs</xs:documentation>
          </xs:annotation>
          <xs:complexType>
            <xs:sequence>
              <xs:element name="Selection" maxOccurs="3">
                <xs:annotation>
                  <xs:documentation>Selection of calculation type. EA: Adiabatic Windows Run; EB: Baseline WIndows Runb; ES: Window Attachment Run</xs:documentation>
                </xs:annotation>
                <xs:simpleType>
                  <xs:restriction base="xs:string">
                    <xs:minLength value="2"/>
                    <xs:maxLength value="2"/>
                  </xs:restriction>
                </xs:simpleType>
              </xs:element>
              <xs:element name="Climate">
                <xs:annotation>
                  <xs:documentation>Selection of climate. Cooling: Houston climate data and assumptions; Heating: Minneapolis climate data and assumptions</xs:documentation>
                </xs:annotation>
                <xs:simpleType>
                  <xs:restriction base="xs:string">
                    <xs:minLength value="7"/>
                    <xs:maxLength value="7"/>
                  </xs:restriction>
                </xs:simpleType>
              </xs:element>
              <xs:element name="AttachmentType" minOccurs="0">
                <xs:annotation>
                  <xs:documentation>Selection of Attachment type. RollerShades; CellularShades; SolarScreens; AppliedFilms;  VenetianBlinds; VerticalBlinds; WindowPanels; and PleatedShades</xs:documentation>
                </xs:annotation>
                <xs:simpleType>
                  <xs:restriction base="xs:string">
                    <xs:minLength value="12"/>
                    <xs:maxLength value="14"/>
                  </xs:restriction>
                </xs:simpleType>
              </xs:element>
              <xs:element name="NoCSVFiles" type="xs:integer">
                <xs:annotation>
                  <xs:documentation>Number of supplied CSV IDF files. 1 file for EA, EB, or ES for fixed attachments; 2 files for 1D shades; and 7 files for 2D shades</xs:documentation>
                </xs:annotation>
              </xs:element>
              <xs:element name="CSVFile" maxOccurs="7">
                <xs:complexType>
                  <xs:sequence>
                    <xs:element name="CSVFileName" type="xs:string">
                      <xs:annotation>
                        <xs:documentation>Arbitrary CSV File name for each E+ run</xs:documentation>
                      </xs:annotation>
                    </xs:element>
                    <xs:element name="DeploymentState" minOccurs="0">
                      <xs:annotation>
```

```
                                    <xs:documentation>Deployment State: Open (only for 1-D and 2-D shades), Half (only for 1-D and 2-D shades), or Full (for all shades)</xs:documentation>
                                 </xs:annotation>
                                 <xs:simpleType>
                                    <xs:restriction base="xs:string">
                                       <xs:minLength value="4"/>
                                       <xs:maxLength value="4"/>
                                    </xs:restriction>
                                 </xs:simpleType>
                              </xs:element>
                              <xs:element name="SlatAngle" type="xs:integer" minOccurs="0">
                                 <xs:annotation>
                                    <xs:documentation>Slat Angle for Louvered Blinds: 0, -45, 45, 90</xs:documentation>
                                 </xs:annotation>
                              </xs:element>
                           </xs:sequence>
                        </xs:complexType>
                     </xs:element>
                  </xs:sequence>
               </xs:complexType>
            </xs:element>
            <xs:element name="Output" minOccurs="0">
               <xs:annotation>
                  <xs:documentation>ESCalc Outputs</xs:documentation>
               </xs:annotation>
               <xs:complexType>
                  <xs:sequence>
                     <xs:element name="E_HVAC" type="xs:float"/>
                     <xs:element name="EP" type="xs:float" minOccurs="0"/>
                  </xs:sequence>
               </xs:complexType>
            </xs:element>
         </xs:sequence>
      </xs:complexType>
   </xs:element>
</xs:schema>
```

The following Figure shows schematic presentation of the Schema.

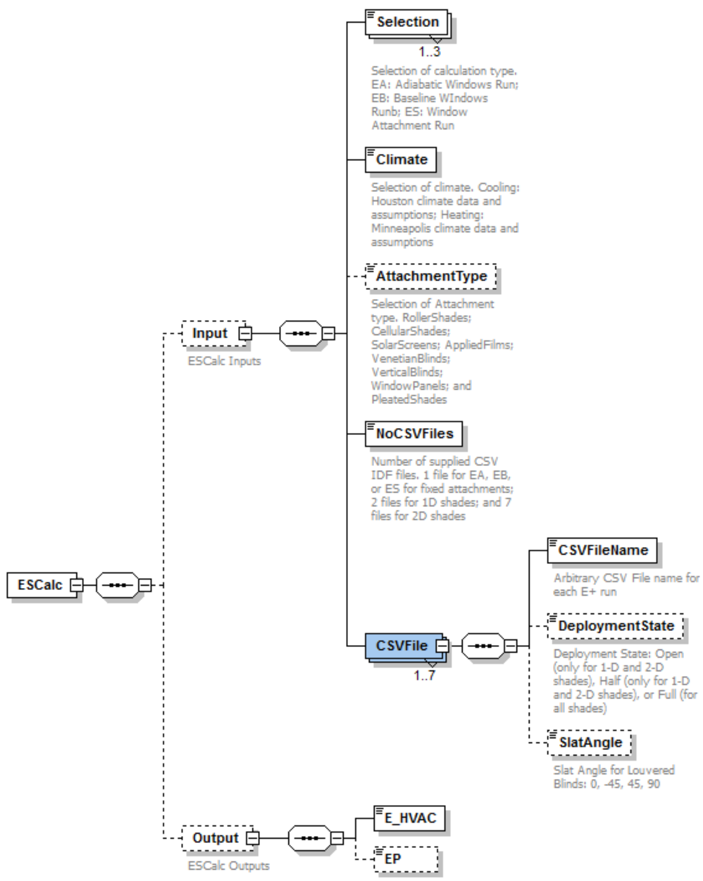


Figure E1. Schematic Presentation of the ESCalc Schema

Examples of the schema for fixed window attachment and venetian blinds products are shown next, respectively:

<u>Example of a fixed window attachment XML file:</u>

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2016 rel. 2 sp1 (x64) (http://www.altova.com) by D. Charlie Curcija (Lawrence Berkeley National Laboratory) -->
<!-- Based on XML schema ESCalc.xsd.-->
<ESCalc xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="ESCalc_v3.xsd">
  <Input>
    <Selection>ES</Selection>
    <Climate>Houston</Climate>
    <AttachmentType>SolarScreens</AttachmentType>
    <NoCSVFiles>1</NoCSVFiles>
    <CSVFile>
      <CSVFileName>Test-File-Name-1_SS</CSVFileName>
    </CSVFile>
  </Input>
  <Output>
    <E_HVAC>115.92</E_HVAC>
    <EP>53.2</EP>
  </Output>
</ESCalc>
```

Example of venetian blind window attachment XML file:


```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2016 rel. 2 sp1 (x64) (http://www.altova.com) by D. Charlie Curcija (Lawrence Berkeley National Laboratory) -->
<!-- Based on XML schema ESCalc.xsd.-->
<ESCalc xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="ESCalc_v3.xsd">
  <Input>
    <Selection>ES</Selection>
    <City>Minneapolis</City>
    <AttachmentType>VenetianBlinds</AttachmentType>
    <NoCSVFiles>7</NoCSVFiles>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Open_0</CSVFileName>
      <DeploymentState>Full</DeploymentState>
      <SlatAngle>0</SlatAngle>
    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Full_-45</CSVFileName>
      <DeploymentState>Full</DeploymentState>
      <SlatAngle>-45</SlatAngle>
    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Full_45</CSVFileName>
      <DeploymentState>Full</DeploymentState>
      <SlatAngle>45</SlatAngle>

    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Full_90</CSVFileName>
      <DeploymentState>Full</DeploymentState>
      <SlatAngle>90</SlatAngle>
    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Half_-45</CSVFileName>
      <DeploymentState>Half</DeploymentState>
      <SlatAngle>-45</SlatAngle>
    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Half_45</CSVFileName>
      <DeploymentState>Half</DeploymentState>
      <SlatAngle>45</SlatAngle>
    </CSVFile>
    <CSVFile>
      <CSVFileName>Test-File-Name-2_VB_Half_90</CSVFileName>
      <DeploymentState>Half</DeploymentState>
      <SlatAngle>90</SlatAngle>
    </CSVFile>
  </Input>
  <Output>
    <E_HVAC>127.32</E_HVAC>
    <EP>34.6</EP>
  </Output>
</ESCalc>
```

Appendix F: EnergyPlus Window configuration file for baseline window B

```
!- Window_configuration_baseline.inc
!- There are 4 seperated windows on each floor each orientation

  FenestrationSurface:Detailed,
    Window_ldf1_1_Bot.unit1, !- Name
    Window,                  !- Surface Type
    AERC_Doubleclear_Baseline,       !- Construction Name
    Wall_ldf1_1.unit1,       !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    ,                        !- View Factor to Ground
    ,                        !- Shading Control Name
    AERC_Wood_Frame,         !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    2.500000000000,0.000000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
    3.823210000000,0.000000000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
    3.823210000000,0.000000000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
    2.500000000000,0.000000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    Window_ldf1_1_Top.unit1, !- Name
    Window,                  !- Surface Type
    AERC_Doubleclear_Baseline,       !- Construction Name
    Wall_ldf1_1.unit1,       !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    ,                        !- View Factor to Ground
    ,                        !- Shading Control Name
    AERC_Wood_Frame,         !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    2.500000000000,0.000000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
    3.823210000000,0.000000000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
    3.823210000000,0.000000000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
    2.500000000000,0.000000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    Window_ldf1_2_Bot.unit1, !- Name
    Window,                  !- Surface Type
    AERC_Doubleclear_Baseline,       !- Construction Name
    Wall_ldf1_1.unit1,       !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    ,                        !- View Factor to Ground
    ,                        !- Shading Control Name
    AERC_Wood_Frame,         !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    6.600000000000,0.000000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
    7.923210000000,0.000000000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
    7.923210000000,0.000000000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
    6.600000000000,0.000000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    Window_ldf1_2_Top.unit1, !- Name
    Window,                  !- Surface Type
    AERC_Doubleclear_Baseline,       !- Construction Name
    Wall_ldf1_1.unit1,       !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    ,                        !- View Factor to Ground
    ,                        !- Shading Control Name
    AERC_Wood_Frame,         !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    6.600000000000,0.000000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
    7.923210000000,0.000000000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
    7.923210000000,0.000000000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
    6.600000000000,0.000000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

```
FenestrationSurface:Detailed,
 Window_ldb1_1_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_1.unit1,      !- Building Surface Name
 ,                    !- Outside Boundary Condition Object
 ,                    !- View Factor to Ground
 ,                    !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                    !- Multiplier
 4,                    !- Number of Vertices
 8.000000000000,10.558580000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
 6.676790000000,10.558580000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
 6.676790000000,10.558580000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
 8.000000000000,10.558580000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldb1_1_Top.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_1.unit1,      !- Building Surface Name
 ,                    !- Outside Boundary Condition Object
 ,                    !- View Factor to Ground
 ,                    !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                    !- Multiplier
 4,                    !- Number of Vertices
 8.000000000000,10.558580000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
 6.676790000000,10.558580000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
 6.676790000000,10.558580000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
 8.000000000000,10.558580000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldb1_2_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_1.unit1,      !- Building Surface Name
 ,                    !- Outside Boundary Condition Object
 ,                    !- View Factor to Ground
 ,                    !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                    !- Multiplier
 4,                    !- Number of Vertices
 3.900000000000,10.558580000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
 2.576790000000,10.558580000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
 2.576790000000,10.558580000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
 3.900000000000,10.558580000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldb1_2_Top.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_1.unit1,      !- Building Surface Name
 ,                    !- Outside Boundary Condition Object
 ,                    !- View Factor to Ground
 ,                    !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                    !- Multiplier
 4,                    !- Number of Vertices
 3.900000000000,10.558580000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
 2.576790000000,10.558580000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
 2.576790000000,10.558580000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
 3.900000000000,10.558580000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdr1_1_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdr1_1.unit1,      !- Building Surface Name
 ,                    !- Outside Boundary Condition Object
 ,                    !- View Factor to Ground
```

```
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  10.558580000000,2.500000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  10.558580000000,3.823210000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  10.558580000000,3.823210000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  10.558580000000,2.500000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_sdr1_1_Top.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdr1_1.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  10.558580000000,2.500000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  10.558580000000,3.823210000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  10.558580000000,3.823210000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  10.558580000000,2.500000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_sdr1_2_Bot.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdr1_1.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  10.558580000000,6.600000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  10.558580000000,7.923210000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  10.558580000000,7.923210000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  10.558580000000,6.600000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_sdr1_2_Top.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdr1_1.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  10.558580000000,6.600000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
  10.558580000000,7.923210000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
  10.558580000000,7.923210000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
  10.558580000000,6.600000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_sdl1_1_Bot.unit1, !- Name
  Window,              !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdl1_1.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                   !- Multiplier
  4,                   !- Number of Vertices
  0.000000000000,8.000000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
  0.000000000000,6.676790000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
  0.000000000000,6.676790000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
  0.000000000000,8.000000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

```
FenestrationSurface:Detailed,
 Window_sdl1_1_Top.unit1, !- Name
 Window,                  !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdl1_1.unit1,       !- Building Surface Name
 ,                        !- Outside Boundary Condition Object
 ,                        !- View Factor to Ground
 ,                        !- Shading Control Name
 AERC_Wood_Frame,         !- Frame and Divider Name
 1,                       !- Multiplier
 4,                       !- Number of Vertices
 0.000000000000,8.000000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
 0.000000000000,6.676790000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
 0.000000000000,6.676790000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
 0.000000000000,8.000000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdl1_2_Bot.unit1, !- Name
 Window,                  !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdl1_1.unit1,       !- Building Surface Name
 ,                        !- Outside Boundary Condition Object
 ,                        !- View Factor to Ground
 ,                        !- Shading Control Name
 AERC_Wood_Frame,         !- Frame and Divider Name
 1,                       !- Multiplier
 4,                       !- Number of Vertices
 0.000000000000,3.900000000000,0.600000000000,  !- X,Y,Z ==> Vertex 1 {m}
 0.000000000000,2.576790000000,0.600000000000,  !- X,Y,Z ==> Vertex 2 {m}
 0.000000000000,2.576790000000,1.273210000000,  !- X,Y,Z ==> Vertex 3 {m}
 0.000000000000,3.900000000000,1.273210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdl1_2_Top.unit1, !- Name
 Window,                  !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdl1_1.unit1,       !- Building Surface Name
 ,                        !- Outside Boundary Condition Object
 ,                        !- View Factor to Ground
 ,                        !- Shading Control Name
 AERC_Wood_Frame,         !- Frame and Divider Name
 1,                       !- Multiplier
 4,                       !- Number of Vertices
 0.000000000000,3.900000000000,1.350000000000,  !- X,Y,Z ==> Vertex 1 {m}
 0.000000000000,2.576790000000,1.350000000000,  !- X,Y,Z ==> Vertex 2 {m}
 0.000000000000,2.576790000000,2.023210000000,  !- X,Y,Z ==> Vertex 3 {m}
 0.000000000000,3.900000000000,2.023210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldf2_1_Bot.unit1, !- Name
 Window,                  !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldf1_2.unit1,       !- Building Surface Name
 ,                        !- Outside Boundary Condition Object
 ,                        !- View Factor to Ground
 ,                        !- Shading Control Name
 AERC_Wood_Frame,         !- Frame and Divider Name
 1,                       !- Multiplier
 4,                       !- Number of Vertices
 2.500000000000,0.000000000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
 3.823210000000,0.000000000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
 3.823210000000,0.000000000000,3.873210000000,  !- X,Y,Z ==> Vertex 3 {m}
 2.500000000000,0.000000000000,3.873210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldf2_1_Top.unit1, !- Name
 Window,                  !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldf1_2.unit1,       !- Building Surface Name
 ,                        !- Outside Boundary Condition Object
 ,                        !- View Factor to Ground
```

```
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  2.500000000000,0.000000000000,3.950000000000,  !- X,Y,Z ==> Vertex 1 {m}
  3.823210000000,0.000000000000,3.950000000000,  !- X,Y,Z ==> Vertex 2 {m}
  3.823210000000,0.000000000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
  2.500000000000,0.000000000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_ldf2_2_Bot.unit1, !- Name
  Window,                  !- Surface Type
  AERC_Doubleclear_Baseline,       !- Construction Name
  Wall_ldf1_2.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  6.600000000000,0.000000000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
  7.923210000000,0.000000000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
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  Window_ldf2_2_Top.unit1, !- Name
  Window,                  !- Surface Type
  AERC_Doubleclear_Baseline,       !- Construction Name
  Wall_ldf1_2.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  6.600000000000,0.000000000000,3.950000000000,  !- X,Y,Z ==> Vertex 1 {m}
  7.923210000000,0.000000000000,3.950000000000,  !- X,Y,Z ==> Vertex 2 {m}
  7.923210000000,0.000000000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
  6.600000000000,0.000000000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
  Window_ldb2_1_Bot.unit1, !- Name
  Window,                  !- Surface Type
  AERC_Doubleclear_Baseline,       !- Construction Name
  Wall_ldb1_2.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  8.000000000000,10.558580000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
  6.676790000000,10.558580000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
  6.676790000000,10.558580000000,3.873210000000,  !- X,Y,Z ==> Vertex 3 {m}
  8.000000000000,10.558580000000,3.873210000000;  !- X,Y,Z ==> Vertex 4 {m}

 FenestrationSurface:Detailed,
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  Window,                  !- Surface Type
  AERC_Doubleclear_Baseline,       !- Construction Name
  Wall_ldb1_2.unit1,       !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  8.000000000000,10.558580000000,3.950000000000,  !- X,Y,Z ==> Vertex 1 {m}
  6.676790000000,10.558580000000,3.950000000000,  !- X,Y,Z ==> Vertex 2 {m}
  6.676790000000,10.558580000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
  8.000000000000,10.558580000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

```
FenestrationSurface:Detailed,
 Window_ldb2_2_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_2.unit1,      !- Building Surface Name
 ,                       !- Outside Boundary Condition Object
 ,                       !- View Factor to Ground
 ,                       !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                      !- Multiplier
 4,                      !- Number of Vertices
 3.900000000000,10.558580000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
 2.576790000000,10.558580000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
 2.576790000000,10.558580000000,3.873210000000,  !- X,Y,Z ==> Vertex 3 {m}
 3.900000000000,10.558580000000,3.873210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_ldb2_2_Top.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_ldb1_2.unit1,      !- Building Surface Name
 ,                       !- Outside Boundary Condition Object
 ,                       !- View Factor to Ground
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 2.576790000000,10.558580000000,3.950000000000,  !- X,Y,Z ==> Vertex 2 {m}
 2.576790000000,10.558580000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
 3.900000000000,10.558580000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdr2_1_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdr1_2.unit1,      !- Building Surface Name
 ,                       !- Outside Boundary Condition Object
 ,                       !- View Factor to Ground
 ,                       !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                      !- Multiplier
 4,                      !- Number of Vertices
 10.558580000000,2.500000000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
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 10.558580000000,3.823210000000,3.873210000000,  !- X,Y,Z ==> Vertex 3 {m}
 10.558580000000,2.500000000000,3.873210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdr2_1_Top.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdr1_2.unit1,      !- Building Surface Name
 ,                       !- Outside Boundary Condition Object
 ,                       !- View Factor to Ground
 ,                       !- Shading Control Name
 AERC_Wood_Frame,        !- Frame and Divider Name
 1,                      !- Multiplier
 4,                      !- Number of Vertices
 10.558580000000,2.500000000000,3.950000000000,  !- X,Y,Z ==> Vertex 1 {m}
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 10.558580000000,3.823210000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
 10.558580000000,2.500000000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}

FenestrationSurface:Detailed,
 Window_sdr2_2_Bot.unit1, !- Name
 Window,                 !- Surface Type
 AERC_Doubleclear_Baseline,      !- Construction Name
 Wall_sdr1_2.unit1,      !- Building Surface Name
 ,                       !- Outside Boundary Condition Object
 ,                       !- View Factor to Ground
```

```
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  10.558580000000,6.600000000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
  10.558580000000,7.923210000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
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  Window_sdr2_2_Top.unit1, !- Name
  Window,                !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdr1_2.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
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  10.558580000000,7.923210000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
  10.558580000000,6.600000000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}

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  Window_sdl2_1_Bot.unit1, !- Name
  Window,                !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdl1_2.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
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  0.000000000000,6.676790000000,3.200000000000,  !- X,Y,Z ==> Vertex 2 {m}
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  Window_sdl2_1_Top.unit1, !- Name
  Window,                !- Surface Type
  AERC_Doubleclear_Baseline,      !- Construction Name
  Wall_sdl1_2.unit1,      !- Building Surface Name
  ,                    !- Outside Boundary Condition Object
  ,                    !- View Factor to Ground
  ,                    !- Shading Control Name
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  AERC_Wood_Frame,        !- Frame and Divider Name
  1,                    !- Multiplier
  4,                    !- Number of Vertices
  0.000000000000,3.900000000000,3.200000000000,  !- X,Y,Z ==> Vertex 1 {m}
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  0.000000000000,2.576790000000,3.873210000000,  !- X,Y,Z ==> Vertex 3 {m}
  0.000000000000,3.900000000000,3.873210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

```
FenestrationSurface:Detailed,
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  Window,                  !- Surface Type
  AERC_Doubleclear_Baseline,       !- Construction Name
  Wall_sdl1_2.unit1,       !- Building Surface Name
  ,                        !- Outside Boundary Condition Object
  ,                        !- View Factor to Ground
  ,                        !- Shading Control Name
  AERC_Wood_Frame,         !- Frame and Divider Name
  1,                       !- Multiplier
  4,                       !- Number of Vertices
  0.000000000000,3.900000000000,3.950000000000,  !- X,Y,Z ==> Vertex 1 {m}
  0.000000000000,2.576790000000,3.950000000000,  !- X,Y,Z ==> Vertex 2 {m}
  0.000000000000,2.576790000000,4.623210000000,  !- X,Y,Z ==> Vertex 3 {m}
  0.000000000000,3.900000000000,4.623210000000;  !- X,Y,Z ==> Vertex 4 {m}
```

Appendix G: Energy Use for Adiabatic and Baseline Window Runs

In AERCalc 1.1 baseline energy use is calculated for adiabatic, E_A and baseline window cases, E_B. are calculated once and applied for calculations of EP_H and EP_C.

Adiabatic Windows Runs

The pre-calculated values for E_A are:

Houston: E_A = 58.9154 GJ

Minneapolis: E_A = 90.5778 GJ

Baseline Windows Runs

The pre-calculated values for E_B are:

Houston: E_B = 116.2636 GJ

Minneapolis: E_B = 122.8133 GJ

Appendix H – Modeling Procedure for Window Awnings

(Reproduced from *"Modeling Procedure for Window Awnings",* Lawrence Berkeley National Laboratory, Berkeley CA, 2020.)

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BERKELEY LAB
ENVIRONMENTAL ENERGY
TECHNOLOGIES DIVISION

Modeling Procedure for Window Awnings

Lawrence Berkeley National Laboratory
Environmental Energy and Technology Division
Windows and Daylighting Group
Berkeley, California

Charlie Curcija, Simon Vidanovic, Taoning Wang, Robin Mitchell with contributions from the AERC Technical Committee

September 22, 2020

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TABLE OF CONTENTS:

INTRODUCTION

Awnings are special types of shading systems that are projecting from the window, rather than being co-planar with the glazing surface. This required different approach from other co-planar shading systems, so that calculated SHGC (Solar Heat Gain Coefficient) and VT (Visible Transmittance) are based on the blend of typical sun angles, rather than standard normal incidence and they will be labeled $SHGC_{ANNUAL}$ and VT_{ANNUAL}. The set of angles used for awnings is based on prior work for tubular daylighting devices, where normal incidence also do not represent good reference. $SHGC_{ANNUAL}$ and VT_{ANNUAL} are intended to be used as a indices of performance for awnings as a direct comparison to the normal incidence SHGC and VT, in the same manner that they are used for tubular daylighting devices. In this document, $SHGC_{ANNUAL}$ and VT_{ANNUAL} will be interchangeably used with SHGC and VT, representing the same quantity.

DETERMINATION OF $SHGC_{ANNUAL}$ AND VT_{ANNUAL}

$SHGC_{ANNUAL}$ and VT_{ANNUAL} in case of awnings will be calculated as an average over multiple angles of incidence, based on the set of solar angles, developed earlier for tubular daylighting devices (Goudey et al. 2012, McCluney and duPont 2010), shown in Table 1. Solar-Surface angle definitions are shown in Figure 1 (ASHRAE 2017).

Table 1. *Set of angles and time-constants for tubular daylighting devices (TDD)*

			Solar Azimuth (φ)		
Solar Altitude (β)	range applied		=0 to <15	=15 to <45	=45 to <75
	Angle	Middle point	0	30	60
	=15 to <25	20	0.000	0.106	0.084
	=25 to <35	30	0.074	0.097	0.072
	=35 to <45	40	0.034	0.064	0.068
	=45 to <55	50	0.026	0.053	0.078
	=55 to <65	60	0.023	0.051	0.074
	=65 to <75	70	0.029	0.055	0.012

Solar altitude angle is measured from the horizontal plane (ground) and is equal to 0° for Sun at the horizon (parallel to the ground) and is equal to 90° for the Sun directly above.

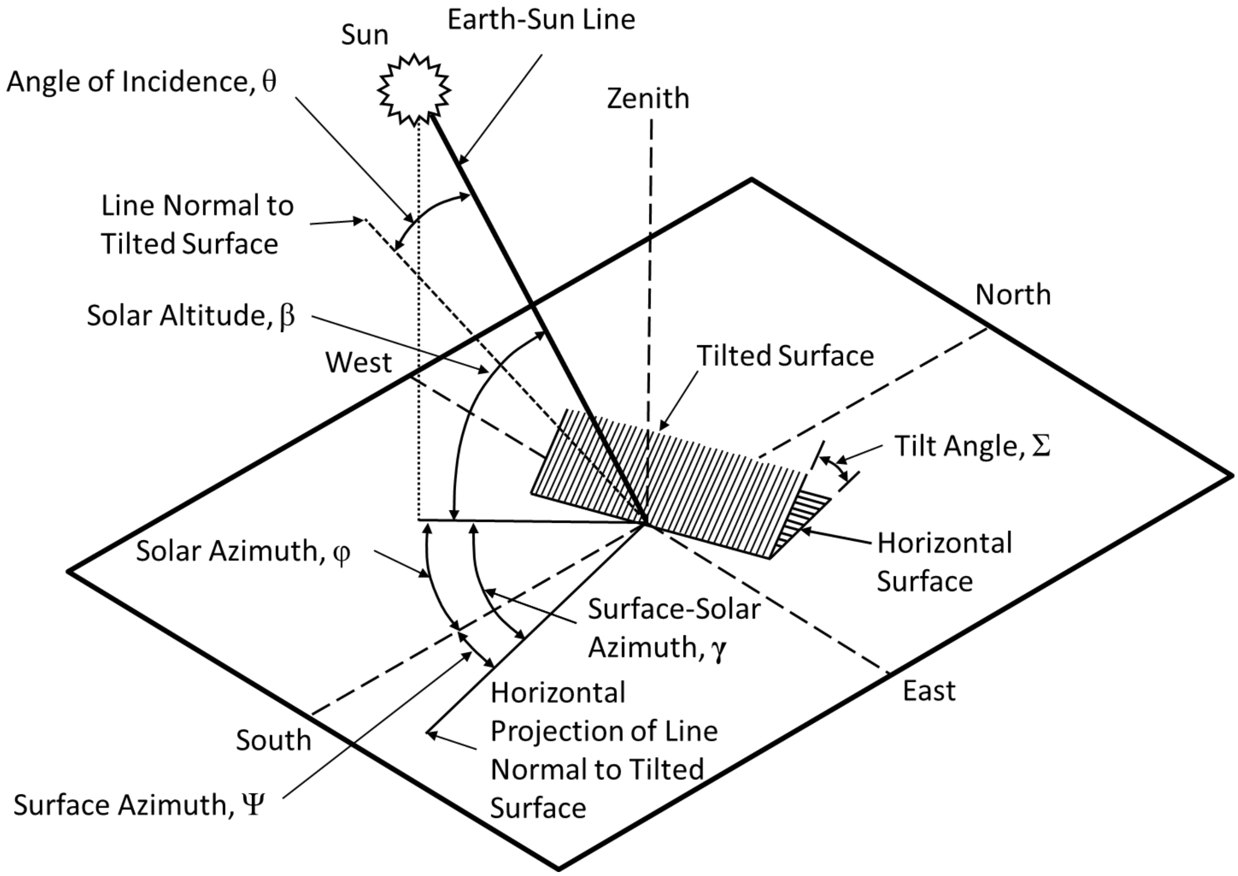

__Figure 1:__ Solar-Surface Angle Definitions

Sum of all time-constants from the above table add to 1.000. Based on these and considering that there may not be symmetry in terms of Azimuth, the following table (Table 2) of sun angles and time constants is developed for awnings that includes both East and West Solar positions

Table 2. *Time-constants (W_i) for the set of angles for awnings*

			Azimuth (φ)				
Altitude (β)	range applied		75 > φ ≤ 45	45 > φ ≤ 15	15 > φ ≤ -15	-15 > φ ≤ -45	-45 > φ ≤ -75
	Angle	Middle point	60	30	0	-30	-60
	25 > β ≤ 15	20	0.042	0.053	0	0.053	0.042
	35 > β ≤ 25	30	0.036	0.0485	0.074	0.0485	0.036
	45 > β ≤ 35	40	0.034	0.032	0.034	0.032	0.034
	55 > β ≤ 45	50	0.039	0.0265	0.026	0.0265	0.039
	65 > β ≤ 55	60	0.037	0.0255	0.023	0.0255	0.037
	75 > β ≤ 65	70	0.006	0.0275	0.029	0.0275	0.006

The sum of all of time constants, W_i is still 1.000.

Optical calculations are done using BSDF (Bi-Directional Scattering Distribution Function) definition of incident and outgoing direction of radiation, where each layer is represented by the BSDF matrix. Figure 2 and Figure 3 shows BSDF representation of incident and outgoing hemisphere, where around the plane of a shading layer.

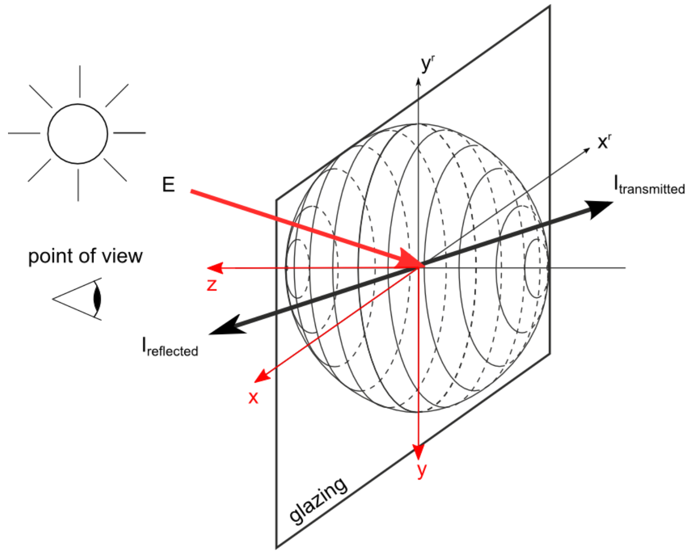

Figure 2: Incoming directions coordinate system

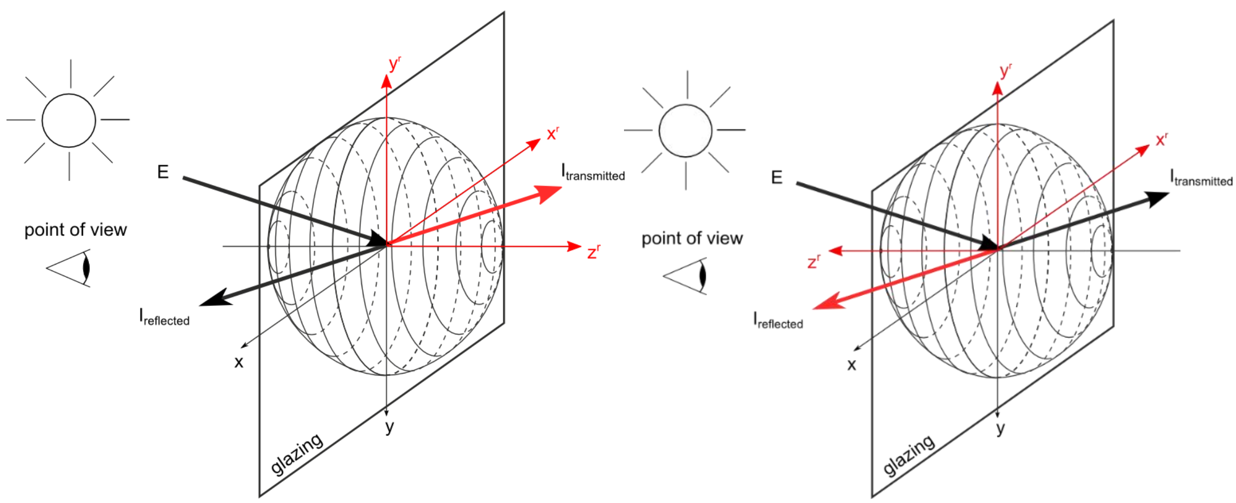

Figure 3: Outgoing directions coordinate system (transmittance and reflectance)

Each BSDF hemisphere is represented by so-called Klems basis, which has 149 incoming and outgoing patches. These patches are represented and numbered in the 2-D representation of each hemisphere, shown in Figure 4.

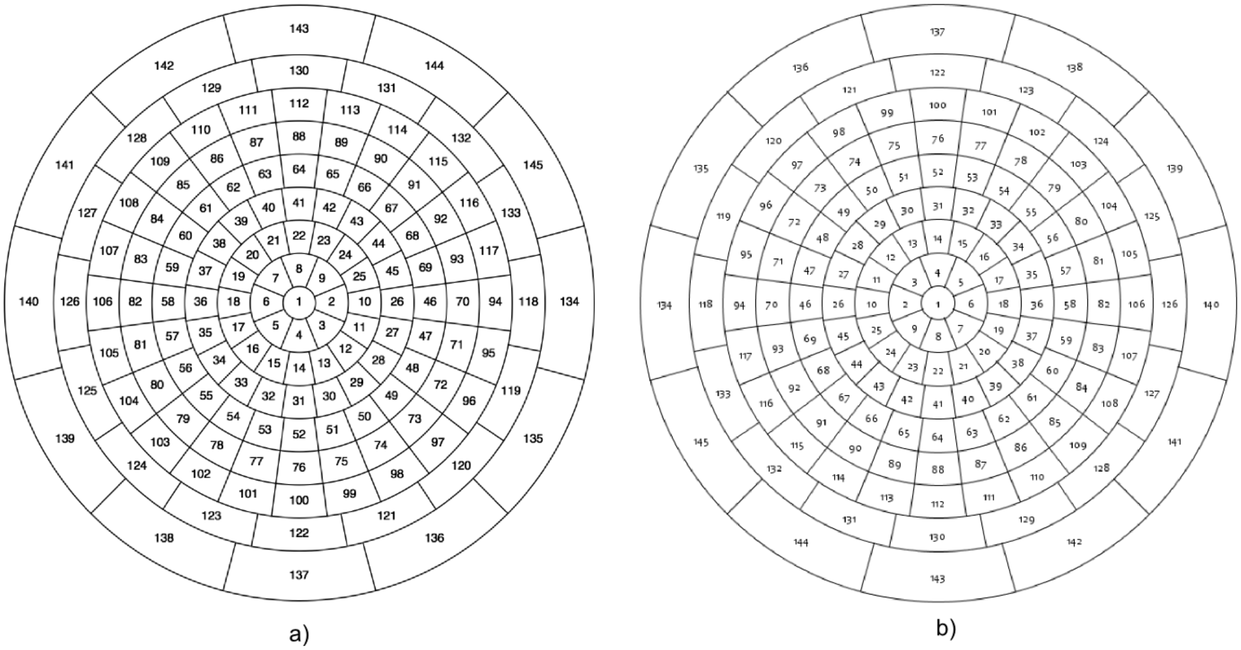

Figure 4: BSDF patches for a) incoming and b) outgoing directions.

In order to apply set of angles shown in Table 2, conversion between BSDF patches and set of angles is done, resulting in the following set of patches.

Table 3. *BSDF Patch Number Mapping for the Set of Angles for Awnings*

			Azimuth (φ)				
	range applied		75 > φ ≤ 45	45 > φ ≤ 15	15 > φ ≤ -15	-15 > φ ≤ -45	-45 > φ ≤ -75
	Angle	Middle point	60	30	0	-30	-60
Altitude (β)	25 > β ≤ 15	20	107	60	22	68	117
	35 > β ≤ 25	30	108	61	41	67	116
	45 > β ≤ 35	40	128	86	64	90	132
	55 > β ≤ 45	50	128	86	88	90	132
	65 > β ≤ 55	60	129	111	112	113	131
	75 > β ≤ 65	70	129	111	130	113	131

Note that the center of each Klems patch corresponds to the closest altitude and azimuth angle set, as the Klems BSDF definition is fixed and cannot be adjusted to coincide with those angles. The combined system (combined glazing and shading system) properties are calculated using matrix multiplication (Klems 1994a and Klems 1994b) where each BSDF matrix represents individual layer (whether it is glass or shading layer) and the resulting BSDF matrix represents optical properties of the combined glazing and shading system.

For awnings, separate Radiance ray-tracing modeling is done to generate BSDF of the awning, in effect reducing all of the awnings geometry and optical properties of awnings material into the equivalent shading layer as if it was parallel to the glass. This allows the application of matrix multiplication for awnings. The resulting BSDF after matrix multiplication is used to calculate Tsol and Tvis of the window with the awning, as well as SHGC. Both standard VT and SHGC are calculated for normal incidence (patch 1 in the BSDF), as well as annual values of these quantities.

The $SHGC_{ANNUAL}$ and VT_{ANNUAL} *are* calculated from the set of angles in Table 2 (set of patches in Table 3). If we label time constants as W_i, the equations for $SHGC_{ANNUAL}$ and VT_{ANNAUL} become:

$$SHGC_{ANNUAL} = \sum_{i=1}^{29}\left(T_{sol,i} + \frac{q_{in,i(I_S=0)} - q_{in}}{I_{s,i}}\right)\cdot W_i$$

$$VT_{ANNUAL} = \sum_{i=1}^{29}\left(T_{vis,i}\right)\cdot W_i$$

Direct solar incidence radiation is set at the fixed number of 783 W/m^2, according to NFRC 100

AWNINGS GEOMETRY AND MODELING PARAMETERS

Awnings geometry is shown in Figure 5. Parameters indicated in the figure are user-entered values.

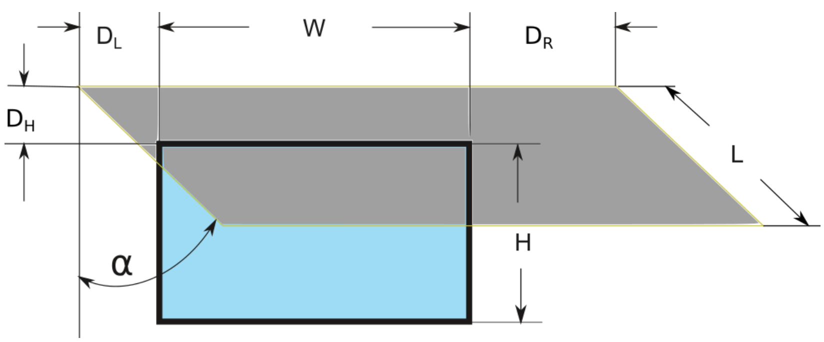

Figure 5: *Definition of Various Input Parameters*

W = Window width
H = Window height
L = Awning length
D_L = Left awning offset
D_R = Right awning offset
D_H = Top awning offset
α = Awnings angle from vertical (90° means horizontal awning)

Solar-optical modeling of awnings in WINDOW is done by Radiance ray-tracing software tool. Frads (LBNL 2019) module of Radiance (Ward and Shakespeare 1998.) performs forward ray-tracing calculation for non-coplanar surfaces to produce BSDF of the awning shade.

In Frads input, these parameters are translated into XYZ coordinates. Each corner of the baseline window and each corner of the awning rectangle are denoted by XYZ coordinates.

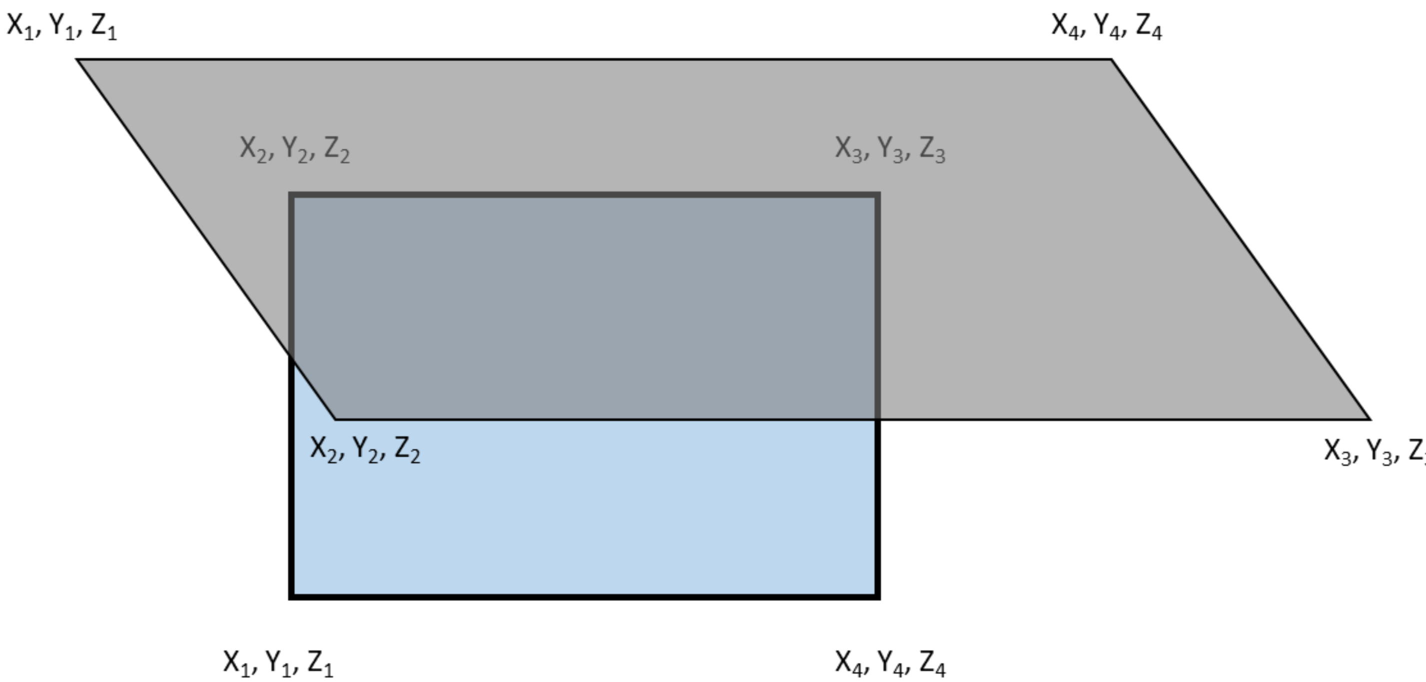

Figure 6: *Coordinate numbering for the window and awning polygons*

Frads inputs for the window and awning are provided in window.rad and awning.rad files:

<u>Window.rad definition:</u>

This file contains window polygon information. No material definition is needed, since it is only used for ray generation surface. Below is expected content of this file:

```
# geometry definition
void polygon window1 # modifier type identifier
# string argument, always zero in our case
# integer argument, always zero
# number of values that follows, 12 = number of vertices * 3
x1 y1 z1 # First vertex
x2 y2 z2 # Second vertex
x3 y3 z3 # Third vertex
x4 y4 z4 # Fourth vertex
```

window.rad example:

```
void polygon window1
0
0
12
0,0,0;
0,H,0;
W,H,0;
W,0,0
```

Awning.rad definition

This file contains awnings polygon information and material definition as a link to xml file. Below is expected content of this file:

```
# modifier type identifier # material definition, can be
substituted with other Radiance material
# thickness, BSDF.xml file, up vector (0 1 0, this vector can't
be the same as awning surface normal defined below
# always zero
# always zero
# geometry definition
#modifier type identifier
# string argument, always zero in our case
# integer argument, always zero
# number of values that follows, 12 = number of vertices * 3
# x1 y1 z1
# x2 y2 z2
# x3 y3 z3
# x4 y4 z4
```

awning.rad example:

```
6 0 C:\Users\Public\LBNL\WINDOW7.8\AwningBSDF\Material.xml 0 0 1
0
0
fabric polygon awning
  0
  0
  12
-DL,H+DH,0;
-DL,H+DH-L*Cos(α),L*sin(α);
W+DR,H+DH-L*Cos(α), L*sin(α);
W+DR,H+DH,0
```

Per AERC rules, the following data is used for input parameters:

W = 1.2 m
H = 1.5 m

$D_L = 0$
$D_R = 0$
$D_H = 0$
α and L are defined for four distinct cases shown in Figure 7 and Table 4.

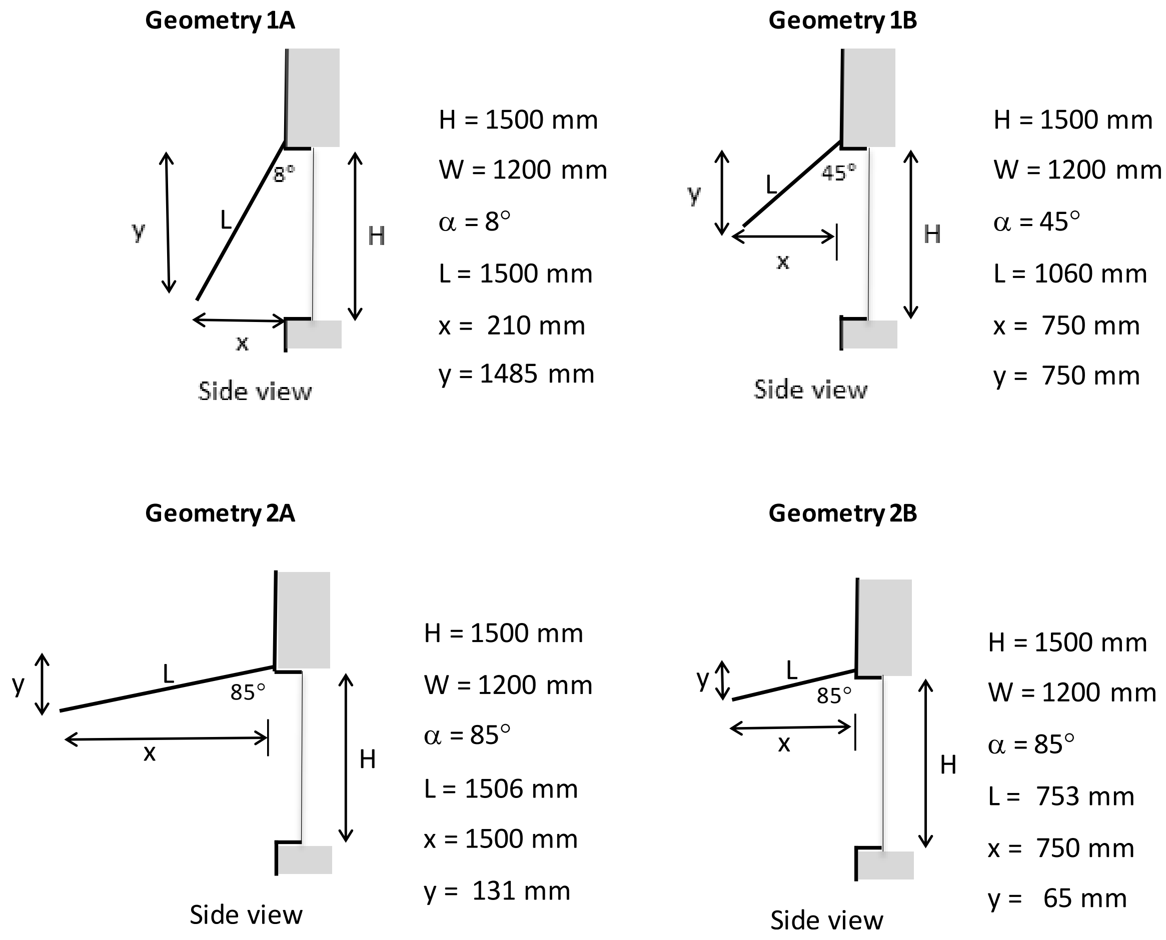

Figure 7: *Awnings Geometry and Positions*

Table 4. *Dimensions for Different Awning Geometries*

	Geometry Set 1 (1A+1B) Typical Operable Drop-arm Window Awnings Fully deployed (1A) and midpoint deployed (1B)		Geometry Set 2 (2A+2B) Typical Operable Folding-arm Window Awnings Fully deployed (2A) and midpoint deployed (2B)	
Fixed awnings might have any one of these four geometries.				
	Position 1A	Position 1B	Position 2A	Position 2B
Angle α	8°	45°	85°	85°
Cover length L	1500 mm	1060 mm	1506 mm	753 mm
Projection x-axis	0.14 x H	0.50 x H	1.00 x H	0.50 x H
Projection Drop y-axis	0.99 x H	0.50 x H	0.087 x H	0.043 x H

Fabric width	1.00 x W	1.00 x W	1.00 x W	1.00 x W
H = window recess height (1500 mm) W = window recess width (1200 mm)				

EP CALCULATION

EP is calculated based on the new schedule for awnings. There are three distinct schedules, based on the awnings type:

In the tables below

- M = Morning
- A = Afternoon
- N = Night

Table 5. *permanently-installed, fixed awning*

Minneapolis	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading												
Deployed – each of 1A, 1B, 2A, 2B	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Houston	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading												
Deployed – each of 1A, 1B, 2A, 2B	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6. *seasonally-installed fixed awning*

Minneapolis	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading							1.00	1.00	1.00	1.00	1.00	1.00
Deployed – each of 1A, 1B, 2A, 2B	1.00	1.00	1.00	1.00	1.00	1.00						
Houston	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading							1.00	1.00	1.00	1.00	1.00	1.00
Deployed – each of 1A, 1B, 2A, 2B	1.00	1.00	1.00	1.00	1.00	1.00						

***Table 7.** operable awning:*

Minneapolis	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading	0.30	0.20	0.30	0.40	0.30	0.40	0.75	0.65	0.75	0.75	0.65	0.75
Half-deployed – each of 1B, 2B	0.60	0.60	0.60	0.60	0.60	0.60	0.25	0.35	0.25	0.25	0.35	0.25
Deployed – each of 1A, 2A	0.10	0.20	0.10	0.00	0.10	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Houston	Cooling Weekday			Cooling Weekend			Heating Weekday			Heating Weekend		
Deployment	M	A	N	M	A	N	M	A	N	M	A	N
Retracted - no shading	0.30	0.20	0.30	0.30	0.20	0.30	0.65	0.55	0.65	0.65	0.55	0.65
Half- deployed – each of 1B, 2B	0.60	0.60	0.60	0.60	0.60	0.60	0.35	0.45	0.35	0.35	0.40	0.35
Deployed – each of 1A, 2A	0.10	0.20	0.10	0.10	0.20	0.10	0.00	0.05	0.00	0.00	0.05	0.00

For permanently-installed fixed awnings, and seasonally-installed fixed awnings each of the four geometries, 1A, 1B, 2A, and 2B, shown in Figure 7, will be considered separately (separate product with individual rating, SHGC, VT). When calculating EP rating indices, for permanent and seasonal schedules each of the four positions is modeled using schedules in Table 5 for permanently-installed fixed awnings (always deployed) and Table 6 for seasonally-installed fixed awnings (no awning in the Winter and deployed in the Summer).

For operable awnings Table 7 lists 3 positions, retracted (no shading), half-deployed and deployed, resulting in two rated products; Geometry 1 and Geometry 2 with retracted (no awning), Half-deployed (1B for Geometry 1, and 2B for Geometry 2) and deployed (1A for Geometry 1, and 2A for Geometry 2). For each geometry parent-child relationship will be established, where parent record will show EP, while child records will show component properties (e.g., U, SHGC, VT, AL), similar to how results are shown for venetian blinds.

Naming Convention:

Naming of individual products, required for properly importing and calculating EP is listed in Table 8. Each of the fixed and seasonal products are calculated and shown individually. For operable awnings, Geometry 1 and Geometry 2 would be parent records with child records named as per Table 8.

Table 8. Naming of records

Geometry		**Fixed (AY)**	**Fixed Seasonal (AS)**	**Operable (AO)**
1	1A	AY1A	AS1A	AO1A, AO1B
	1B	AY1B	AS1B	
2	2A	AY2A	AS2A	AO2A, AO2B
	2B	AY2B	AS2B	

Example of the naming for permanently-installed fixed awning:

`Awning 1A Permanent - Dark::AY1A::O::BW-B`

Where, “O” means Outdoor position, and “BW-B” means Baseline Window B.

Example of the naming for Seasonally-installed fixed awning:

`Awning 1A Seasonal - Dark::AS1A::O::BW-B`

Example of the naming for Operable awning:

`Awning 1A Operable - Dark::AO1A::O::BW-B`

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