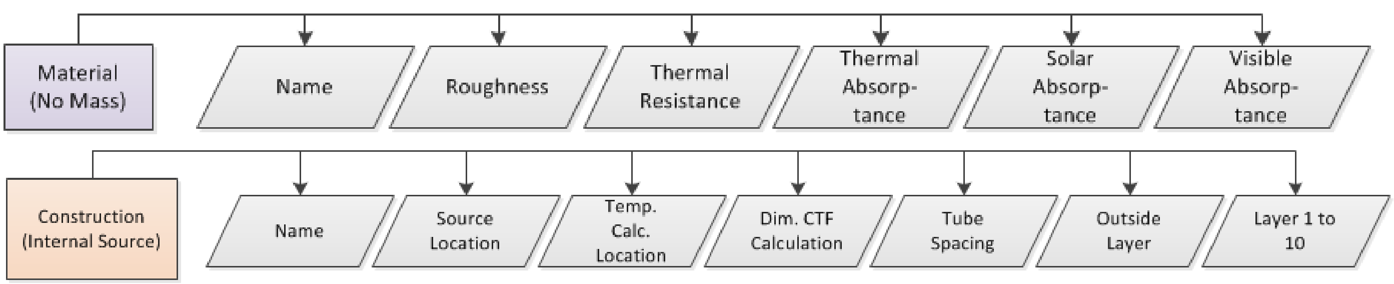
Greater Philadelphia Innovation Cluster
for Energy-Efficient Buildings
A U.S. DOE Energy Innovation Hub

Task 2.2.11 – CMU Report 05:

Analysis of EnergyPlus-Based Building Envelope Modeling

Department of Energy Award # EE0004261



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February 2012

TABLES OF CONTENTS

LIST OF FIGURES

Introduction/Executive Summary

A detailed analysis is conducted on the process of developing building envelope components within EnergyPlus environment with the aim of identifying required input data and the design correlates for opaque and transparent assemblies. Alternative envelope model definition methods are discussed and explained through schemas developed to reveal relationships (hierarchies) between EnergyPlus classes and objects pertaining to a specific definition method. Partial schemas are later appended to provide an overall and comprehensive EnergyPlus input schema that can be used as a guide during model development process for envelope components. Analyzed model definitions methods for opaque assemblies are layer-by-layer definition, C-factor underground wall, F-factor ground floor, and internal source methods. Model definition methods analyzed for transparent assemblies can be listed as simple glazing system, spectral average definition, and spectral methods.

1. Simulation of "Opaque Envelope" with EnergyPlus v6.0 – Model Definition Methods

1.1 Type 1 – "Construction (Layer-by-Layer Definition)"

Definition of the entire opaque envelope assembly (walls, roofs, floors) is needed from individual materials. Each layer of the construction assembly should be chosen materials list in order from outside to inside. Maximum number of material layers is 10 for a single assembly. Outside can be another zone or a semi-condition space. Layer-by-layer definition method requires EnergyPlus objects for materials in the form of full definition, no mass, infrared transparent, air gap, or roof vegetation.

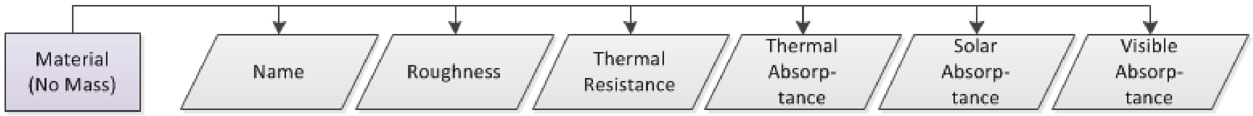
Figure 1 EnergyPlus input schema for material definition

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		1_1_73	1_2_28	1_3_9	3_1_180	3_3_6	5_1_10015
Roughness		Rough	Rough	Rough	Rough	Rough	MediumRough
Thickness	m	0.0127	0.0254	0.1016	0.2032	0.1016	0.0127
Conductivity	W/m-K	0.3	0.028	1.13	1.35	0.62	0.057
Density	kg/m3	1600	35	2000	1800	1700	288
Specific Heat	J/kg-K	2000	1590	1000	1000	800	1339
Thermal Absorptance		0.9	0.9	0.9	0.9	0.9	0.9
Solar Absorptance		0.7	0.6	0.6	0.6	0.7	0.7
Visible Absorptance		0.7	0.6	0.6	0.6	0.7	0.2

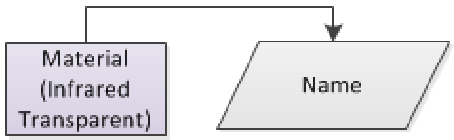
Figure 2 EnergyPlus input screen for standard material definition

Each different material should have a unique name with all the necessary physical, thermo-physical, and optical properties listed.

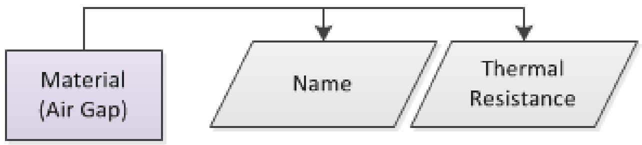
Other types of individual building material definitions are no mass : to represent light-weight materials ignoring thermal mass effect, infrared material: to represent low resistance materials which have high absorptance in short and long-wave radiation, air gap: to represent air spaces in opaque construction (e.g., air-walls or virtual partitions), roof vegetation: to represent vegetated roofs including soil and plant layers. In addition to these, standard material properties can be coupled with special material property entries for advanced modeling of moisture transfer, variable thermal conductivity, as well as phase change properties.



No Mass



Infrared Transparent



Air Gap

Roof Vegetation

Figure 3 EnergyPlus input schema for material definition - alternatives

Material infrared links with an existing material layer (with standard definition) but applies modified calculation procedures.

1.2 Type 2 – "Construction (C-Factor Underground Wall)"

This is an alternative method for defining underground wall constructions only. Individual material entries are not needed. However, user should provide C-factor and the height of each different underground wall construction existing in the building model. Building energy codes and standards (ASHRAE 90.1, California Title 24) require certain maximum limits for C-factor of underground assemblies.

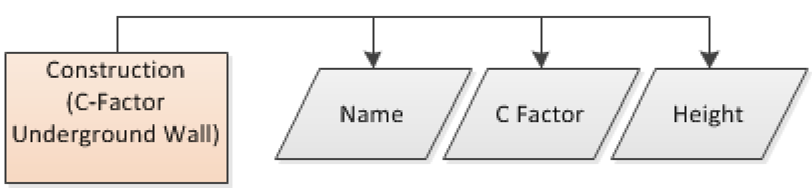


Figure 4 EnergyPlus input schema for C-factor underground wall types

Field	Units	Obj1
Name		Under_Ground_Wall_1
C-Factor	W/m2-K	0.623
Height	m	2.76

Figure 5 EnergyPlus input screen for C-factor underground walls

A new EnergyPlus object should be created for different underground wall assembly (differentiated by both their C-factors and their height).

1.3 Type 3 – "Construction (F-factor Ground Floor)"

This is an alternative and simplified approach to model ground floor constructions only without recourse to layer-by-layer definition methods. This method is suitable when only the floor area, exposed perimeter and the maximum F-factor of the related construction is available.

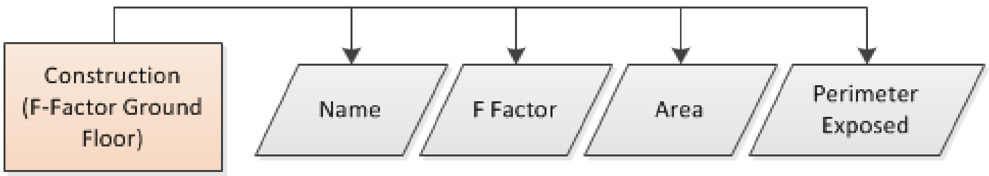


Figure 6 EnergyPlus input schema for F-factor slab-on-grade/underground floors

Field	Units	Obj1
Name		Ground_Floor_1
F-Factor	W/m-K	1.264
Area	m2	35
PerimeterExposed	m	87

Figure 7 EnergyPlus input screen for F-factor slab-on-grade/underground floors

1.4 Type 4 – "Construction (Internal Source)"

This is a special construction assembly definition approach to model radiant systems which have constructions including resistance wires/hydronic tubing. Heat is either added or removed from the building element. In the case of building-integrated photovoltaic elements energy is removed in the form electricity will form a heat sink. This method also requires definition of individual material layers. The user should define the order of material layers, location of the heat source or sink, location of internal temperature calculation, dimension of CTF (conduction transfer functions) calculation, and tube spacing (if any).

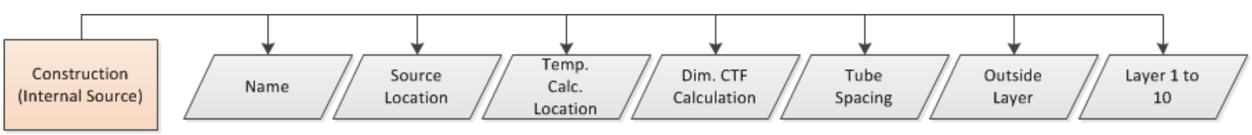


Figure 8 EnergyPlus input schema for constructions with internal source

Field	Units	Obj1	Obj2	Obj3
Name		ZonesOtherSlab_Interior	ZonesOtherSlab_Exterior	Zone146900_Slab
Source Present After Layer Number		3	4	2
Temperature Calculation Requested After Layer Numbe		3	4	2
Dimensions for the CTF Calculation		1	1	1
Tube Spacing	m	0.1524	0.1524	0.1524
Outside Layer		3_4_27	3_4_27	XPS_Insulation_4INCH
Layer 2		19_RVAL_2	21_2_10004	11_1_182
Layer 3		3_2_36	21_RVAL_3	11_2_182
Layer 4		3_1_34	21_4_36	
Layer 5			21_4_34	
Layer 6				
Layer 7				
Layer 8				
Layer 9				
Layer 10				

Figure 9 EnergyPlus input screen for constructions with internal source

Each different floor construction (with internal heat source/sink) should be defined separately.

1.5 Creating opaque envelope constructions assemblies and assignment to building surfaces

For standard construction assemblies (except for C-factor, F-factor types), individual material layers should be grouped together to form the final assembly. Opaque envelope modeling can be finalized by assignment of developed constructions to specific building surfaces (geometrically defined).

Field	Units	Obj26	Obj27	Obj28	Obj29	Obj30
Name		25	26	1001	1002	Shaded_Glazing
Outside Layer		25_1_71	Gypsum_Board	IGDB_6254_Flippec	2	IGDB_6254_Flippec
Layer 2		25_2_8	insulation_layer_1	Mid_Pane_Argon		Mid_Pane_Argon
Layer 3		insulation_layer_2	25_3_9	IGDB_6254_Norma		IGDB_6254_Norma
Layer 4		25_3_9	insulation_layer_2			Roller_Shade
Layer 5		insulation_layer_1	25_2_8			
Layer 6		Gypsum_Board	25_1_71			
Layer 7						
Layer 8						
Layer 9						
Layer 10						

Figure 10 EnergyPlus input screen for opaque envelope construction definitions

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		F_146009_0_0_0	C_146009_1_0_0	F_151915_0_0_10(	W_146009_2_0_0	W_146009_3_0_0	W_14600(
Surface Type		Floor	Ceiling	Floor	Wall	Wall	Wall
Construction Name		146009_floor	ZoneOtherSlab_Int_	ZonesOtherSlab_Int	5	5	5
Zone Name		146009	146009	151915	146009	146009	146009
Outside Boundary Condition		Outdoors	Surface	Surface	Ground	Ground	Ground
Outside Boundary Condition Object			F_151915_0_0_10(	C_146009_1_0_0			
Sun Exposure		SunExposed	NoSun	NoSun	NoSun	NoSun	NoSun
Wind Exposure		WindExposed	NoWind	NoWind	NoWind	NoWind	NoWind
View Factor to Ground		1	0	0	0.5	0.5	0.5
Number of Vertices		6	6	6	4	4	4
Vertex 1 X-coordinate	m	5.8644088100	1.4705061006	5.8644088100	7.1704162381	6.0992743638	0.2557414
Vertex 1 Y-coordinate	m	-3.6251759824	-4.0004500076	-3.6251759824	-2.6688160832	1.3297398138	-0.2370301
Vertex 1 Z-coordinate	m	-2.6675454035	0	0	-2.6675454035	-2.6675454035	-2.667545
Vertex 2 X-coordinate	m	1.4705061006	5.8644088100	1.4705061006	6.0992743638	0.2557414839	1.4705061
Vertex 2 Y-coordinate	m	-4.0004500076	-3.6251759824	-4.0004500076	1.3297398138	-0.2370301023	-4.000450
Vertex 2 Z-coordinate	m	-2.6675454035	0	0	-2.6675454035	-2.6675454035	-2.667545
Vertex 3 X-coordinate	m	0.2557414839	5.7130659884	0.2557414839	6.0992743638	0.2557414839	1.4705061
Vertex 3 Y-coordinate	m	-0.2370301023	-3.0593119057	-0.2370301023	1.3297398138	-0.2370301023	-4.000450
Vertex 3 Z-coordinate	m	-2.6675454035	0	0	0	0	0
Vertex 4 X-coordinate	m	6.0992743638	7.1704162381	6.0992743638	7.1704162381	6.0992743638	0.2557414
Vertex 4 Y-coordinate	m	1.3297398138	-2.6688160832	1.3297398138	-2.6688160832	1.3297398138	-0.2370301
Vertex 4 Z-coordinate	m	-2.6675454035	0	0	0	0	0
Vertex 5 X-coordinate	m	7.1704162381	6.0992743638	7.1704162381			
Vertex 5 Y-coordinate	m	-2.6688160832	1.3297398138	-2.6688160832			
Vertex 5 Z-coordinate	m	-2.6675454035	0	0			
Vertex 6 X-coordinate	m	5.7130659884	0.2557414839	5.7130659884			
Vertex 6 Y-coordinate	m	-3.0593119057	-0.2370301023	-3.0593119057			
Vertex 6 Z-coordinate	m	-2.6675454035	0	0			
Vertex 7 X-coordinate	m						

Figure 11 EnergyPlus input screen for construction assignment to building surfaces

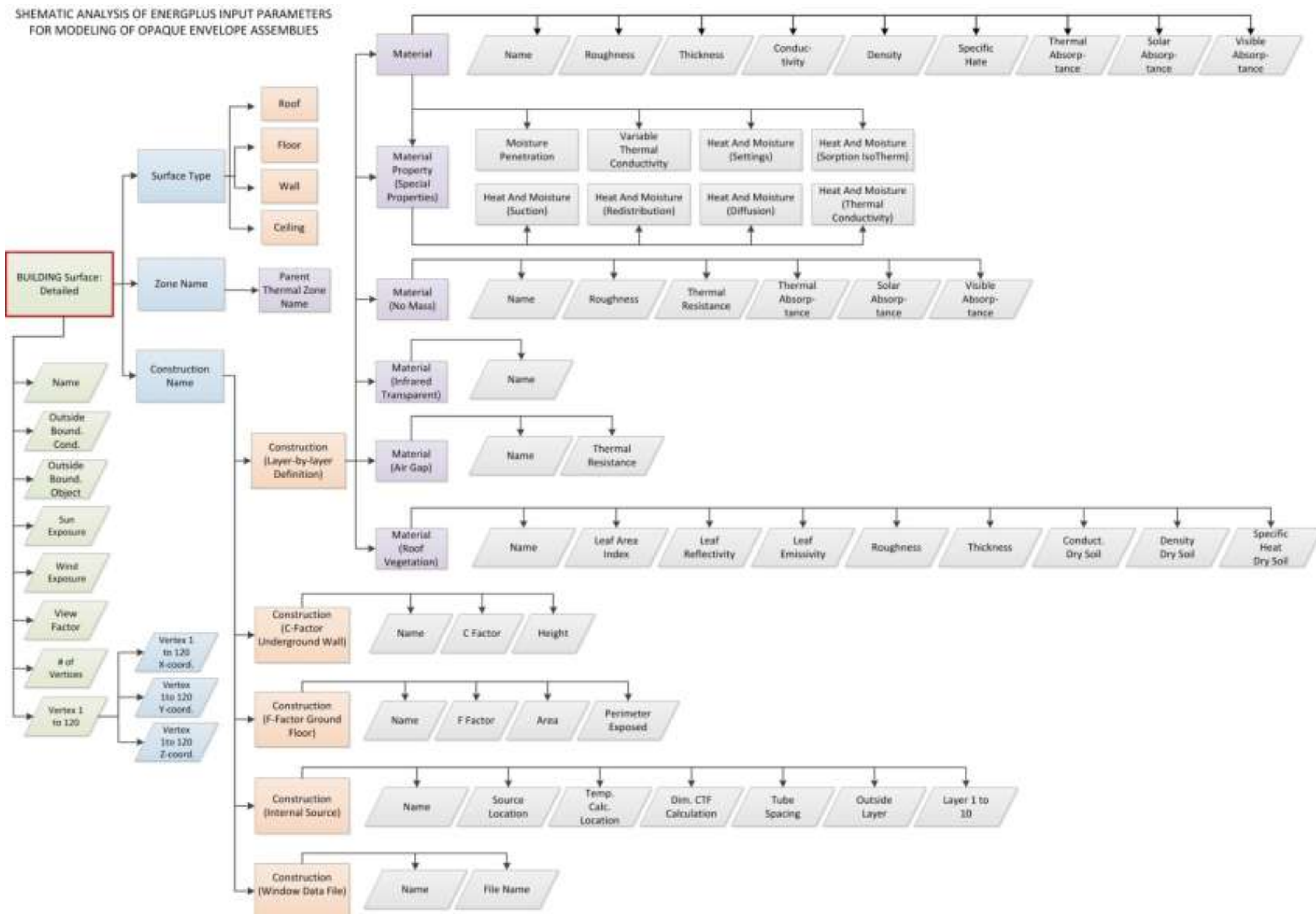


Figure 12 Overall EnergyPlus input schema for complete opaque envelope modeling

2. Simulation of Windows with EnergyPlus v6.0 – Model Definition Methods

2.1 Type 1 – "Window Material: Simple Glazing System"

Definition of the entire glazing system instead of individual layers (glass panes, coatings, mid-pane gas). Overall performance indices are used to characterize thermal and optical behavior of the system. The model definition produces an equivalent window glazing without a layer, if overall performance indices includes frame effect then window frame objects should be excluded from the building model. Significant performance differences are reported with respect to more detailed window system definitions.

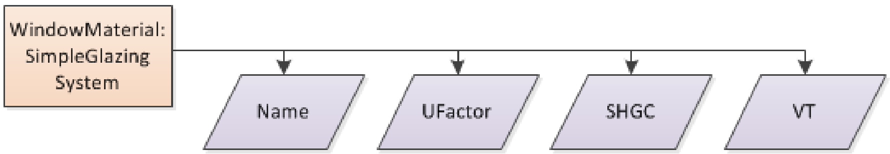


Figure 13 EnergyPlus input schema for simplified glazing

Field	Units	Obj1
Name		NonRes Fixed Assembly Window
U-Factor	W/m2-K	3.23646
Solar Heat Gain Coefficient		0.39
Visible Transmittance		

Figure 14 EnergyPlus input screen for simplified glazing

Visible Transmission (Vt) is an optional entry

2.2 Type 2 – "Window Material: Glazing – Spectral Average"

This is a definition of the entire glazing system with individual layers. Spectral average type allows the user to define glazing pane solar transmission and reflectance data (at normal incidence) in broadband form where the input data reflects averages across all wavelengths of the solar spectrum.

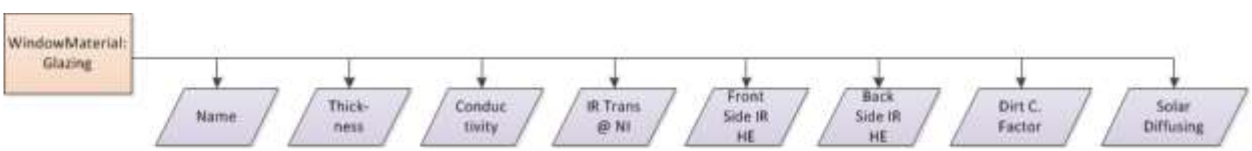


Figure 15 EnergyPlus input schema for spectral average

Field	Units	Obj1	Obj2	Obj3	Obj4
Name		2	100	IGDB_6254_Normal	IGDB_6254_Flipped
Optical Data Type		SpectralAverage	SpectralAverage	SpectralAverage	SpectralAverage
Window Glass Spectral Data Set Name					
Thickness	m	0.003	0.003	0.00566	0.00566
Solar Transmittance at Normal Incidence		0.837	0.99	0.63334	0.63334
Front Side Solar Reflectance at Normal Incidence		0.075	0.005	0.211	0.253
Back Side Solar Reflectance at Normal Incidence		0.075	0.005	0.253	0.211
Visible Transmittance at Normal Incidence		0.898	0.99	0.861318	0.861318
Front Side Visible Reflectance at Normal Incidence		0.081	0.005	0.060999	0.060999
Back Side Visible Reflectance at Normal Incidence		0.081	0.005	0.057384	0.057384
Infrared Transmittance at Normal Incidence		0	0.99	0	0
Front Side Infrared Hemispherical Emissivity		0.84	0.005	0.84	0.84
Back Side Infrared Hemispherical Emissivity		0.84	0.005	0.094531	0.094531
Conductivity	W/m-K	0.9	5	1	1
Dirt Correction Factor for Solar and Visible Transmittanc		1	1	1	1
Solar Diffusing					

Figure 16 EnergyPlus input screen for spectral average

Each different glass pane is listed with the required data inputs. Optical data type is selected as ”Spectral Average”.

Layer by layer window model definition also requires necessary input data about mid-pane gas layers (if any) as well as frames and dividers that completes the entire window assembly. Besides, and type of shading device should also be defined as separate EnergyPlus objects.

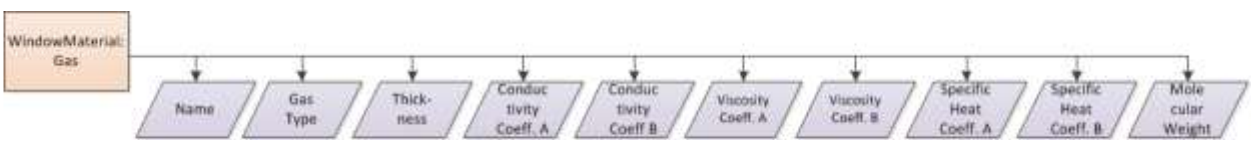


Figure 17 EnergyPlus input schema for Mid-pane Gas definition

Field	Units	Obj1
Name		Mid_Pane_Argon
Gas Type		Argon
Thickness	m	0.0127
Conductivity Coefficient A	W/m-K	0.00228500
Conductivity Coefficient B	W/m-K2	0.00005149
Viscosity Coefficient A	g/m-s	0.0000033970
Viscosity Coefficient B	g/m-s-K	0.0000000645
Specific Heat Coefficient A	J/kg-K	521.9290
Specific Heat Coefficient B	J/kg-K2	0.0000
Molecular Weight		39.948

Figure 18 EnergyPlus input screen for Mid-pane Gas

Each different gas material used in glazing units (IGU) is listed with the required data inputs.

Detailed frame and divider information should be provided for accurate window system modeling.

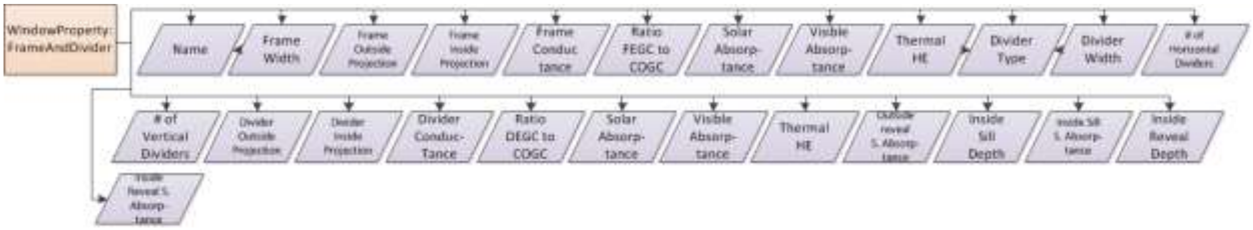


Figure 19 EnergyPlus input schema for Window Frame and Divider Definitions

Field	Units	Obj1	Obj2	Obj3
Name		1	2	3
Frame Width	m	0.04	0.04	3.30200000E-02
Frame Outside Projection	m	0	0	0
Frame Inside Projection	m	0	0	0
Frame Conductance	W/m2-K	9.5	9.5	23.85254
Ratio of Frame-Edge Glass Conductance to Center-Of-(		1	1	1
Frame Solar Absorptance		0.78	0.78	0.3
Frame Visible Absorptance		0.78	0.78	0.3
Frame Thermal Hemispherical Emissivity		0.9	0.9	0.3
Divider Type		DividedLite		
Divider Width	m	0.02	0.02	1.90500000E-02
Number of Horizontal Dividers		1	1	1
Number of Vertical Dividers		1	1	1
Divider Outside Projection	m	0	0	0
Divider Inside Projection	m	0	0	0
Divider Conductance	W/m2-K	9.5	9.5	23.85254
Ratio of Divider-Edge Glass Conductance to Center-Of-		1	1	1
Divider Solar Absorptance		0.78	0.78	0.3
Divider Visible Absorptance		0.78	0.78	0.3
Divider Thermal Hemispherical Emissivity		0.9	0.9	0.3
Outside Reveal Solar Absorptance		0.78	0.78	0.3
Inside Sill Depth	m	0	0	0
Inside Sill Solar Absorptance		0.78	0.78	0.3
Inside Reveal Depth	m	0	0	0
Inside Reveal Solar Absorptance		0.78	0.78	0.3

Figure 20 EnergyPlus input screen for Frames and Dividers

Each different frame and divider type is listed with specific object names.

2.3 Type 3 – "Window Material: Glazing – Spectral"

This is the most detailed and accurate glazing type definition where solar transmission and reflectance data is defined for a range of wavelengths (between 0.5 to 2.50 microns) of the solar spectrum. These are up to 800 sets of normal incidence measured values that can be derived from International Glazing Database (IGDB v3.0).

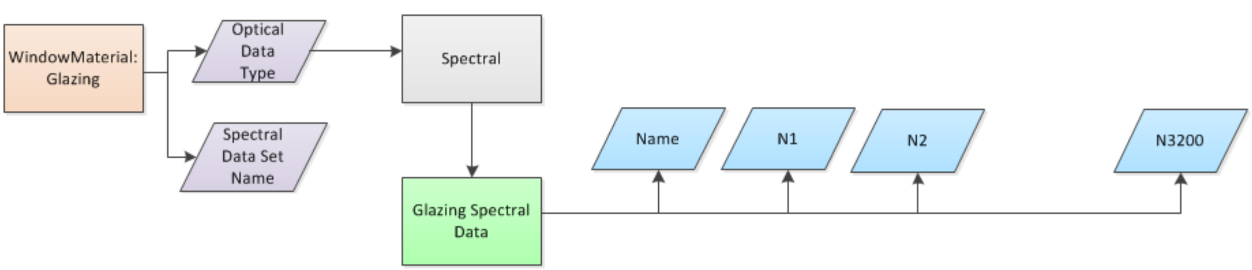


Figure 21 EnergyPlus input schema for Spectral Data Entry

Figure 22 EnergyPlus input screen for spectral data

Each different spectral data for a specific glass pane is given with a list of 800 data points. It should be noted that with spectral data type selection, user also needs to provide model inputs for mid-pane gas, frame and dividers as mentioned in previous slides. Analysis of a glass laminate with analysis of full spectral characteristics from 0.5 to 2.50 microns. Full data obtained from specialized software (Optics 5.1) can be imported to Design Builder v3.0 as well as EnergyPlus v6.0.

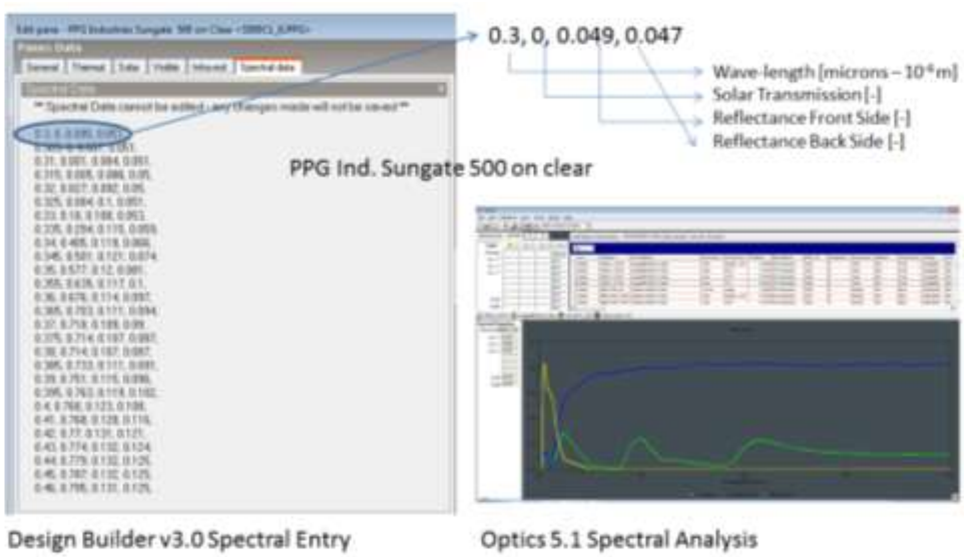


Figure 23 Spectral data input analysis

2.4 Creating window assemblies and assignment to fenestration surfaces

Individual layers (created with alternative methods) should be grouped together to form the final window assembly/construction. Window modeling within EnergyPlus can be finalized by assignment of developed window constructions to specific fenestration surfaces.

Field	Units	Obj8	Obj9	Obj10	Obj11	Obj12	Obj13	Obj14	Obj15	Obj16
Name		7	8	9	10	1001	Mass Non-res Ext V	InteriorFurnishings	GlzSys_5	GlzSys_5
Outside Layer		7_1_10003	5_1_10001	3_1_10000	3_1_10000	NonRes Fixed Asse	1IN Stucco	Std Wood 6inch	Glass_2599_Layer	Glass_2599_Layer
Layer 2		7_2_10004	7_3_10005				8IN Concrete HW		Gap_1_W_0_0127	Gap_1_W_0_0127
Layer 3		7_3_10005	7_2_10004				Mass NonRes Wall		Glass_103_Layer	Glass_103_Layer
Layer 4		5_1_10001	7_1_10003				1/2IN Gypsum		Gap_1_W_0_0127	Gap_1_W_0_0127
Layer 5									Glass_103_Layer	Glass_103_Layer
Layer 6										
Layer 7										
Layer 8										
Layer 9										
Layer 10										

Figure 24 EnergyPlus input screen for window construction definition

Field	Units	Obj1	Obj2	Obj3
Name		W_10810_5_0_0_0_0_0_Win	W_11020_5_0_0_0_0_0_Win	W_11078_5_0_0_0_0_0_Win
Surface Type		Window	Window	Window
Construction Name		1001	1001	1001
Building Surface Name		W_10810_5_0_0	W_11020_5_0_0	W_11078_5_0_0
Outside Boundary Condition Object				
View Factor to Ground		autocalculate	autocalculate	autocalculate
Shading Control Name				
Frame and Divider Name				
Multiplier		1	1	1
Number of Vertices		4	4	4
Vertex 1 X-coordinate	m	5.6998122124	5.6998122124	5.6998122124
Vertex 1 Y-coordinate	m	2.2211443695	2.2211443695	2.2211443695
Vertex 1 Z-coordinate	m	8.8766	4.9166	0.9566
Vertex 2 X-coordinate	m	8.6158122124	8.6158122124	8.6158122124
Vertex 2 Y-coordinate	m	2.2211443695	2.2211443695	2.2211443695
Vertex 2 Z-coordinate	m	8.8766	4.9166	0.9566
Vertex 3 X-coordinate	m	8.6158122124	8.6158122124	8.6158122124
Vertex 3 Y-coordinate	m	2.2211443695	2.2211443695	2.2211443695
Vertex 3 Z-coordinate	m	10.3776	6.4176	2.4576
Vertex 4 X-coordinate	m	5.6998122124	5.6998122124	5.6998122124
Vertex 4 Y-coordinate	m	2.2211443695	2.2211443695	2.2211443695
Vertex 4 Z-coordinate	m	10.3776	6.4176	2.4576

Figure 25 EnergyPlus input screen for window assignment to fenestration surfaces

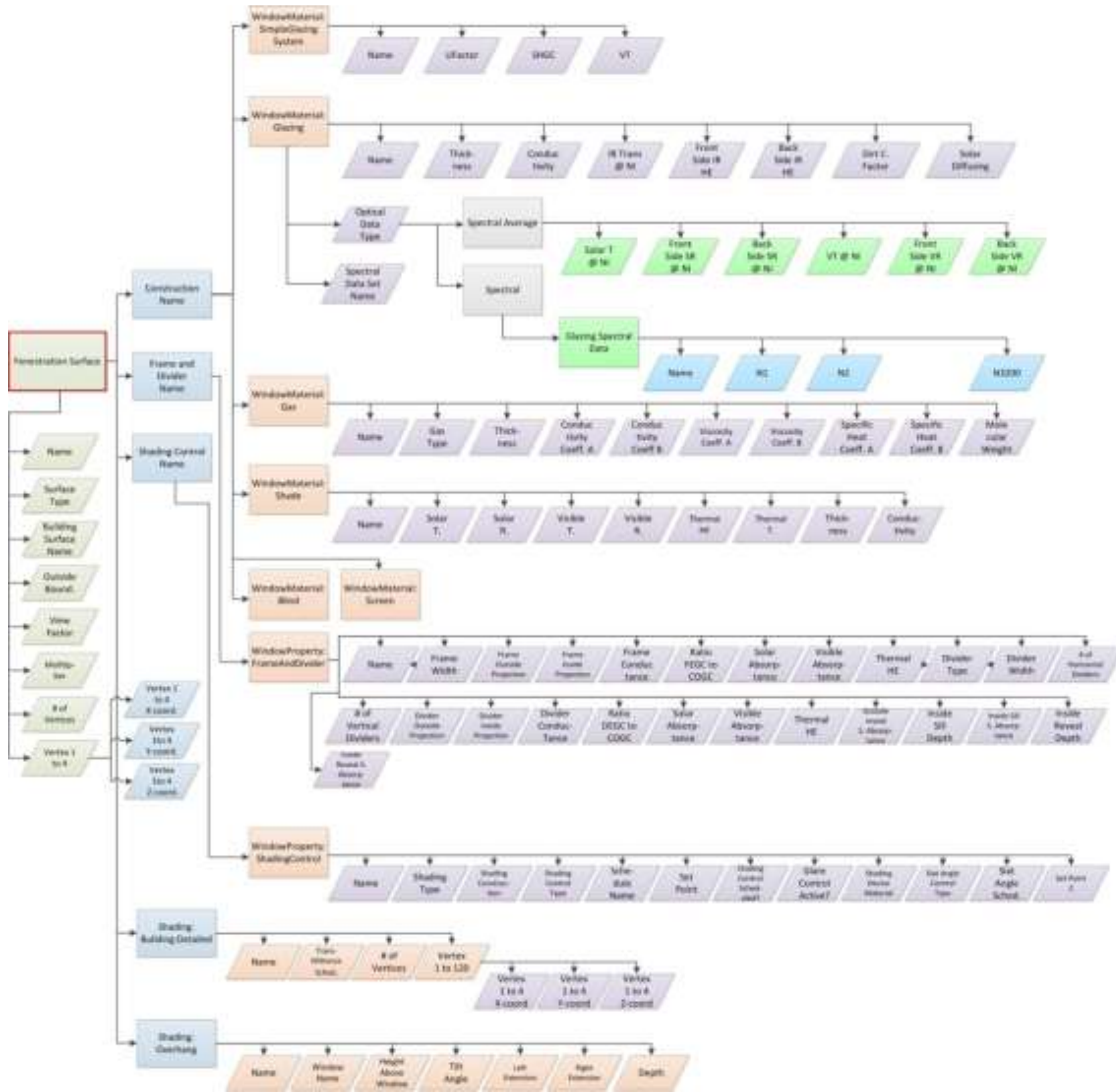


Figure 26 Overall EnergyPlus input schema for complete window modeling