THERMAL MASS MODULE—ENERGYPLUS EXERCISE INSTRUCTIONS

Exercise Introduction and Objectives

The exercise provides a base file for a single-story building, measuring 65′ x 15′, typical of a small office in a strip mall. The building is modeled with one zone.

The objective of this exercise is to study the effect of thermal mass on a building's operative temperature and its energy use. The exercise will modify a base file and create three buildings with nearly identical U-values for walls and roof but with three different thermal masses. The low thermal mass building has EIFS–steel stud walls with U=0.255 and a roof consisting of insulation directly over a metal deck with U = 0.235. The medium thermal mass wall has EIFS–8-inch concrete block walls with U = 0.286 and a 4-inch thick concrete roof slab between the metal deck and the insulation with U = 0.253. The metal deck is directly exposed to the room. The high thermal mass wall is a brick cavity wall with 4-inch brick–8-inch CMU block construction with U = 0.280 and an 8-inch concrete roof slab with U=0.241 and the metal deck directly exposed to the room.

Exercise Procedure

Schedules are a usage study, and the values are usually obtained from the architect's office or from previous simulations of similar buildings. For this exercise, assume that the same schedules available in the base file apply to all the models.

Materials and constructions will be added in this exercise. Material and construction data can be entered directly, but the ASHRAE Handbook has a good selection of common material properties, and much of the data will be copied from a set of this data that comes with EnergyPlus. Walls and roofs are constructed so that they have differing thermal mass but similar U-values, and so they meet the minimum prescriptive requirements of ASHRAE 90.1 energy code. Variations of the wall and roof construction are generated and saved. Simulations are run and temperature and energy-usage data are obtained for analysis.

Output Data

Before proceeding to the simulations, we need to set the idf base file for the desired output data and format. This will help make the idf file ready for output right after we enter construction data, so the process does not have to be repeated for every calculation model. For this exercise we want to plot the outdoor temperature, zone operative temperature, and electric power demand hourly on June 21 and December 21.

We also want to find the yearly energy use with the different constructions. In this part of the exercise we will modify:

- Output: Table: Summary Reports
- Output Control: Table: Style
- Output: Variable

We will use Output: Table to output tables that have the overall energy use of the building and the U-value of the different wall and roof constructions. We will use the Output: Variable to output hourly temperature and power-use data.

Note:

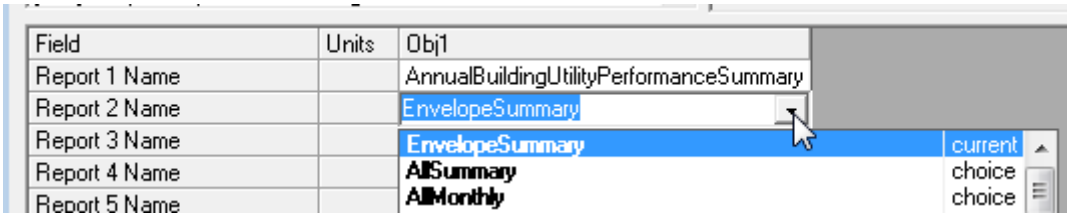
(1) The exercise as written generates hourly data for every day of the entire year. The EnergyPlus input file could be set to do separate runs on just June 21 and December 21, making it easier to find and extract the desired information, but because of the thermal mass effects we are trying to show, the only way to get accurate temperature and energy use predictions is to have had the simulation running for several weeks. Since we want to do an annual simulation to compute total energy use, we have elected to do just a single annual simulation.

(2) These exercise instructions and associated input files have been written to conform with EnergyPlus v5.0.0 format. Use of these instructions and input files with later versions of EnergyPlus may require changes or updates to input objects and location of data sets and weather files.

Instructions

First, we will create the basic reports that allow for a quick analysis of the building's overall energy use and computed U-values for the different wall constructions. More detailed reports can be selected for in depth analysis.

1. Start IDF Editor > File > Open > ThermalMass_base.idf
2. Select Class List > Output Reporting > Output: Table: Summary Reports. Click the **New Obj** button to create a new entry and enter the following information by selecting the values from the pull-down menu available by clicking on a cell.



Next, we will select the basic report output style to be HTML so we can view the results with a web browser. Other default styles include comma (which works well for importing data into spreadsheet programs such as Microsoft® Excel®), tab (for word processing programs), fixed, etc.

3. Select > Class List > Output Reporting > Output Control: Table Style. Click the **New Obj** button and enter the following information:

Field	Units	Obj1
Column Separator		HTML
Unit Conversion		

Next, we will set the idf file to have EnergyPlus output the outside temp, the operative temp, and the electric power on an hour-by-hour basis. These data go into a .csv file to load and view in a spreadsheet.

4. Select Class List > Output Reporting > Output: Variable and create three new objects with the following data:

Field	Units	Obj1	Obj2	Obj3
Key Value		*	*	*
Variable Name		Outdoor Dry Bulb	Zone Operative Temperature	Total Electric Demand
Reporting Frequency		Hourly	Hourly	Hourly
Schedule Name				

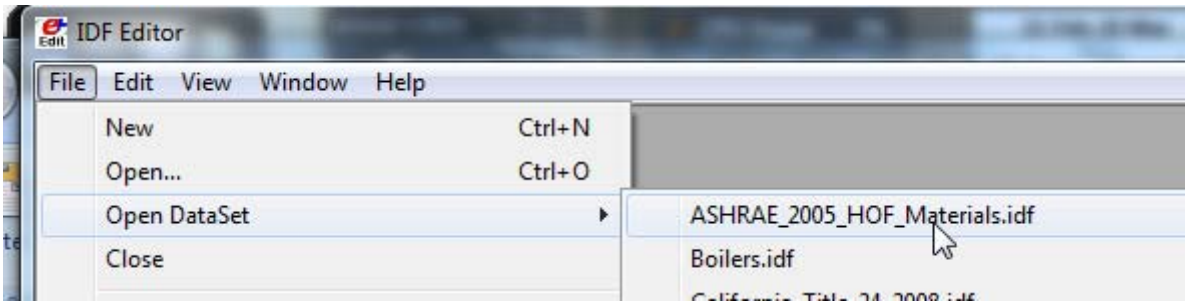
5. Save changes to base file: File > Save

   The idf base file is now ready for material and construction inputs.

   In this part of the exercise, we will show how to copy material data from the EnergyPlus data sets and create new materials and constructions.

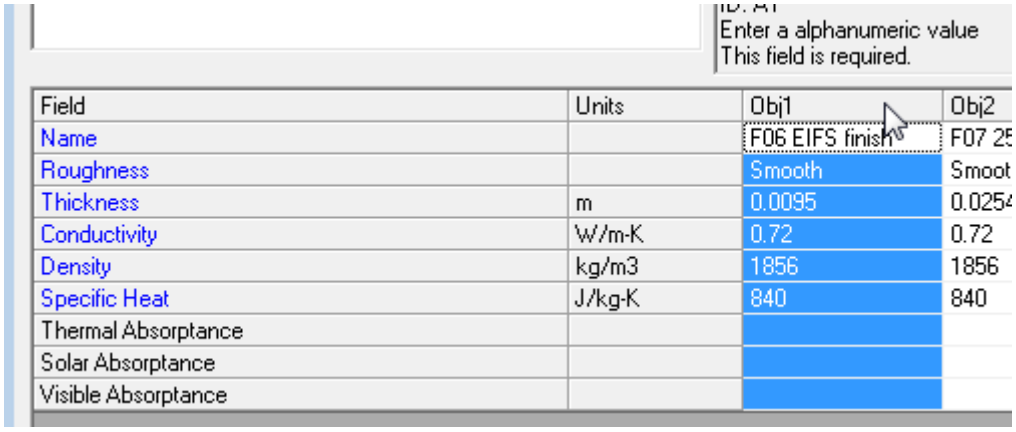
   If the base file is not loaded, load it as in Step 1. Next, we will load in the data set for copying entries:

6. File > Open DataSet > ASHRAE 2005 HOF Materials.idf

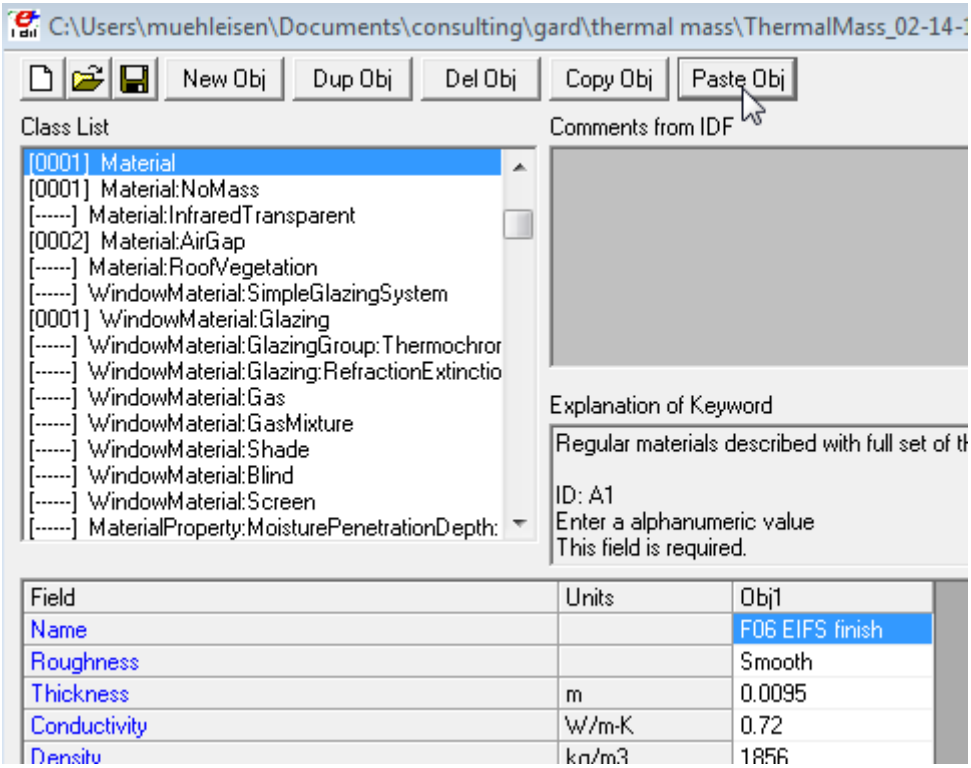


This procedure will open a second idf file in the IDF Editor. These instructions assume that the user knows how to switch between open windows in MS Windows applications.

7. Find the entry for F06 EIFS finish in the Materials: section of the ASHRAE 2005 HOF Materials.idf class list and click the top of the column to highlight it.



8. Click the **Copy Obj** button to copy the material to the clipboard.
9. Go to the thermalmass_base.idf window and click the **Paste Obj** button. The IDF Editor will automatically move to the Materials Class List and insert the object into the idf file. Your screen will look something like the image below:



Repeat this step to copy the following materials from the ASHRAE 2005 HOF Materials.idf database:

F08 Metal Surface, F13 Built-Up Roofing, F16 Acoustical Tile, G01 16mm gypsum, G03 13mm fiberboard, I02 50mm insulation, I04 89mm batt insulation, M01 100mm brick, M03 200mm lightweight concrete block, M11 100 mm lightweight concrete, M13 200 mm lightweight concrete, and M15 200mm heavyweight concrete.

10. Go to the Material: AirGap class list in the ASHRAE 2005 HOF Materials.idf file and copy the F04 Wall air space resistance and F05 Ceiling Air Space resistance to the Thermalmass_base.idf using the method described in the step above.
11. Open the WindowGlassMaterials.IDF data set and copy the entry Clear 3MM to the Thermalmass_base.idf
12. Go to Class List > Material and click the **New Obj** button to create a new entry and add the information shown below:

Field	Units	Obj15
Name		Std Wood
Roughness		MediumSmooth
Thickness	m	0.15
Conductivity	W/m-K	0.12
Density	kg/m3	540
Specific Heat	J/kg-K	1210
Thermal Absorptance		0.9
Solar Absorptance		0.7
Visible Absorptance		0.7

13. Go to Class List > Material: NoMass and click the **New Obj** button to create a new entry and add the information shown below:

Field	Units	Obj1
Name		CP02 CARPET PAD
Roughness		VeryRough
Thermal Resistance	m2-K/W	0.2165
Thermal Absorptance		0.9
Solar Absorptance		0.7
Visible Absorptance		0.8

Now we are going to create new 75mm insulation and 100mm insulation entries by duplicating and modifying the existing 50mm insulation entry

14. Go to the ThermalMass_base.idf window and find the Class List > Material entry of I02 50mm insulation and highlight it by clicking on the Obj header:

	Obj9	Obj
fiberboar	I02 50mm insulation	I04
	MediumRough	Ver
	0.0508	0.0
	0.03	0.0
	43	19
	1210	960

15. Click the **Dup Obj** button twice to create two copies of the entry in the same ThermalMass_base.idf file
16. Edit the new entries by changing the names and thicknesses so the information is the following:

Field	Units	Obj14	Obj15	Obj16
Name		Std Wood	I07 75 mm insulation board	I08 100 mm insulation board
Roughness		MediumSmooth	MediumRough	MediumRough
Thickness	m	0.15	0.075	0.1
Conductivity	W/m-K	0.12	0.03	0.03
Density	kg/m3	540	43	43
Specific Heat	J/kg-K	1210	1210	1210
Thermal Absorptance		0.9		

Now we can begin creating the constructions from the materials. To do this, we create an entry and assign element layers working from the outside to the inside.

17. Go to Class List > Construction and click the **New Obj** button to create a new entry and add the info shown below by using the pull-down menus that pop up in each entry location to create a metal deck roof assembly and the EIFS stud wall.

Field	Units	Obj1	Obj2	Obj3
Name		Metal Deck Roof	EIFS Stud Wall	Brick
Outside Layer		F13 Built-up roofing	F06 EIFS finish	M01
Layer 2		G03 13mm fiberboar	I02 50mm insulation	F04
Layer 3		I08 100 mm insulatic	G03 13mm fiberboar	I02 5
Layer 4		F08 Metal surface	I04 89mm batt insul	M03
Layer 5		F05 Ceiling air spac	G01 16mm gypsum	I04 8
Layer 6		F16 Acoustic tile		G01
Layer 7				

18. Repeat the last step to create the constructions Brick Cavity Wall, EIFS Concrete Wall, LW Concrete Deck Roof, and HW Concrete Deck Roof.

Field	Units	Obj3	Obj4	Obj5	Obj6	C
Name		Brick Cavity Wall	EIFS Concrete Wall	LW Concrete Deck Roof	HW Concrete Deck Roof	F
Outside Layer		M01 100mm b	F06 EIFS finish	F13 Built-up roofing	F13 Built-up roofing	S
Layer 2		F04 Wall air space	I08 75mm insulation	G03 13mm fiberboard shea	G03 13mm fiberboard sheat	
Layer 3		I02 50mm insulatic	G03 13mm fiberboar	I08 100 mm insulation boa	I08 100mm insulation board	
Layer 4		M03 200mm lightv	M03 200mm lightwei	M11 100mm lightweight cc	M13 200mm lightweight cor	
Layer 5		I04 89mm batt insu	F04 Wall air space re	F08 Metal surface	F08 Metal surface	
Layer 6		G01 16mm gypsur	G01 16mm gypsum b	F05 Ceiling air space resist	F05 Ceiling air space resista	
Layer 7				F16 Acoustic tile	F16 Acoustic tile	

19. Repeat the last step to create the constructions Furnishings, Floor, South Wall Window as shown below:

Field	Units	Obj7	Obj8	Obj9
Name		Furnishings	South Wall Window	Floor
Outside Layer		Std Wood	CLEAR 3MM	M15 200mm heavyweight cor
Layer 2				CP02 CARPET PAD
Layer 3				

20. Save changes to base file: File > Save
    Our last step is to assign window construction and interior furnishing constructions to our building.
21. Go to Class List > Thermal Zones and Surfaces > FenestrationSurface:Detailed
    You will see four entries for our windows with blank spaces in the entry Construction Name. Click on the entries and assign South Wall Window to each of the surfaces. The list should look like the following:

Field	Units	Obj1	Obj2	Obj3	Obj4
Name		window 4	window2	window 3	window1
Surface Type		Window	Window	Window	Window
Construction Name		South Wall Window	South Wall Window	South Wall Window	South Wall Window
Building Surface Name		ZN_1_Wall_2	ZN_1_Wall_2	ZN_1_Wall_2	ZN_1_Wall_2
Outside Boundary Condition Objec					
View Factor to Ground		autocalculate	autocalculate	autocalculate	autocalculate
Shading Control Name					

22. Go to Class List > Thermal Zones and Surfaces > Internal Mass. Assign the construction Furnishings to this entry:

Field	Units	Obj1
Name		ZN_1_InternalMass
Construction Name		Furnishings
Zone Name		ZN_1
Surface Area	m2	181.0634

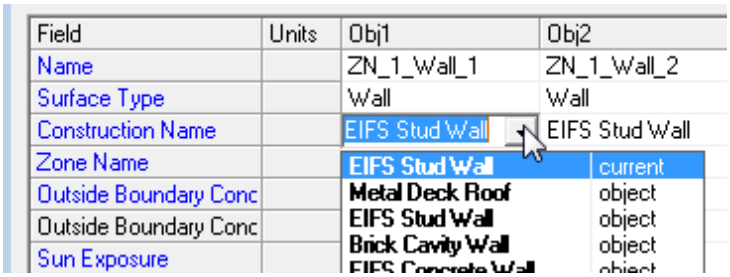
23. Save changes to base file: File > Save
    Our base file is complete and ready to have constructions assigned for low, medium and high thermal mass.

Creating Three Different Thermal Mass Buildings

Now will assign our wall, floor and roof constructions. We will generate three different constructions: low thermal mass, medium thermal mass and high thermal mass.

Begin to create the low thermal mass construction by making sure you have the base file properly loaded as per Step 1 in the previous section. Immediately save this as a new file, Thermalmass_low.idf

1. File > Save As > Thermalmass_low.idf
2. Go to Class List > Thermal Zones and Surfaces > BuildingSurface:Detailed. There will be six surfaces: 4 walls, a floor and a roof. Assign the constructions by changing the Construction Name entry using the pull-down menu that appears when you click on an entry as shown below:



Assign EIFS Stud Wall to the walls, Floor to the floor and Metal Deck Roof to the roof. The list should look like the following:

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		ZN_1_Wall_1	ZN_1_Wall_2	ZN_1_Wall_3	ZN_1_Wall_4	ZN_1_Floor	ZN_1_Ceiling
Surface Type		Wall	Wall	Wall	Wall	Floor	Roof
Construction Name		EIFS Stud Wall	EIFS Stud Wall	EIFS Stud Wal	EIFS Stud Wall	Floor	Metal Deck R
Zone Name		ZN_1	ZN_1	ZN_1	ZN_1	ZN_1	ZN_1
Outside Boundary Cond		Outdoors	Outdoors	Outdoors	Outdoors	Ground	Outdoors
Outside Boundary Cond							
Sun Exposure		SunExposed	SunExposed	SunExposed	SunExposed	NoSun	SunExposed

3. Use File > Save to save the changes.
4. Now we create the medium thermal mass building. Resave the file with a new name: File > Save As > Thermalmass_med.idf
5. Reassign the walls as EIFS Concrete Wall, floor as Floor and roof as LW Concrete Deck. The list should now look like this:

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		ZN_1_Wall_1	ZN_1_Wall_2	ZN_1_Wall_3	ZN_1_Wall_	ZN_1_Fl	ZN_1_Ceiling
Surface Type		Wall	Wall	Wall	Wall	Floor	Roof
Construction Name		EIFS Concrete V	EIFS Concrete V	EIFS Concrete	EIFS Concre	Floor	LW Concrete Deck
Zone Name		ZN_1	ZN_1	ZN_1	ZN_1	ZN_1	ZN_1

6. Use File > Save to save the changes.
7. Now we create the high thermal mass building. Resave the file with a new name: File > Save As > Thermalmass_high.idf
8. Reassign the walls as Brick Cavity Wall, floor as Floor and roof as HW Concrete Deck. The list should now look like this:

Field	Units	Obj1	Obj2	Obj3	Obj4	Obj5	Obj6
Name		ZN_1_Wall_1	ZN_1_Wall_2	ZN_1_Wall_3	ZN_1_Wall_	ZN_1_Fl	ZN_1_Ceiling
Surface Type		Wall	Wall	Wall	Wall	Floor	Roof
Construction Name		Brick Cavity Wa	Brick Cavity Wa	Brick Cavity W	Brick Cavity	Floor	HW Concrete Deck
Zone Name		ZN_1	ZN_1	ZN_1	ZN_1	ZN_1	ZN_1
Outside Boundary Cond		Outdoors	Outdoors	Outdoors	Outdoors	Ground	Outdoors

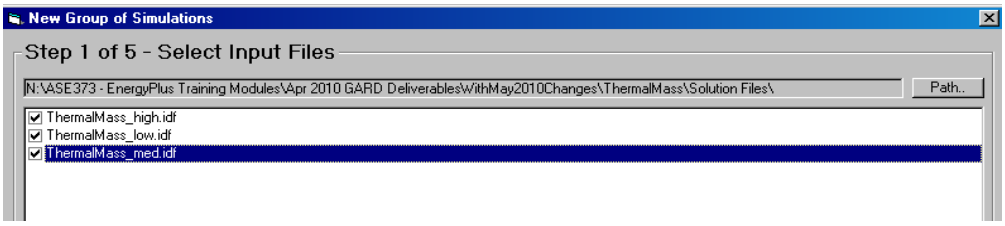
9. Use File > Save to save the changes.

Running the Simulations

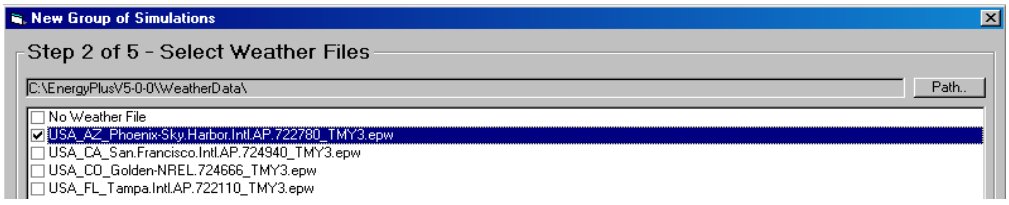
To run these simulations we are going to utilize the Group File option of the EP-Launch program.

Start EP-Launch and click on the Group of Input Files tab.

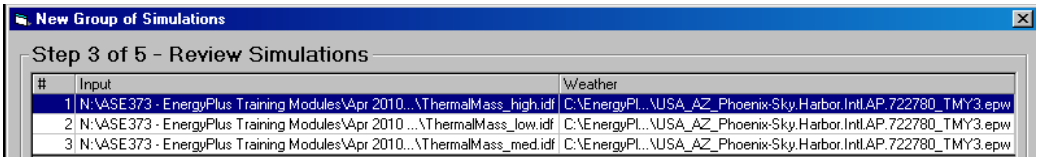
1. Click the **New Group** button and select the three files we just created and click **Next** to go to the next step.



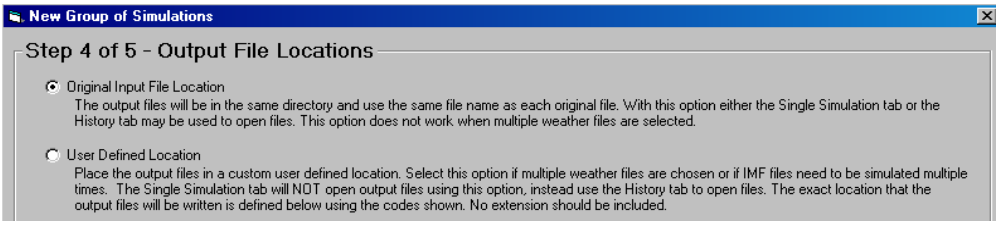
2. Select the Phoenix weather file and click **Next**.



3. Review simulations should show the idf files to be simulated and the weather files to be used. Click **Next**.

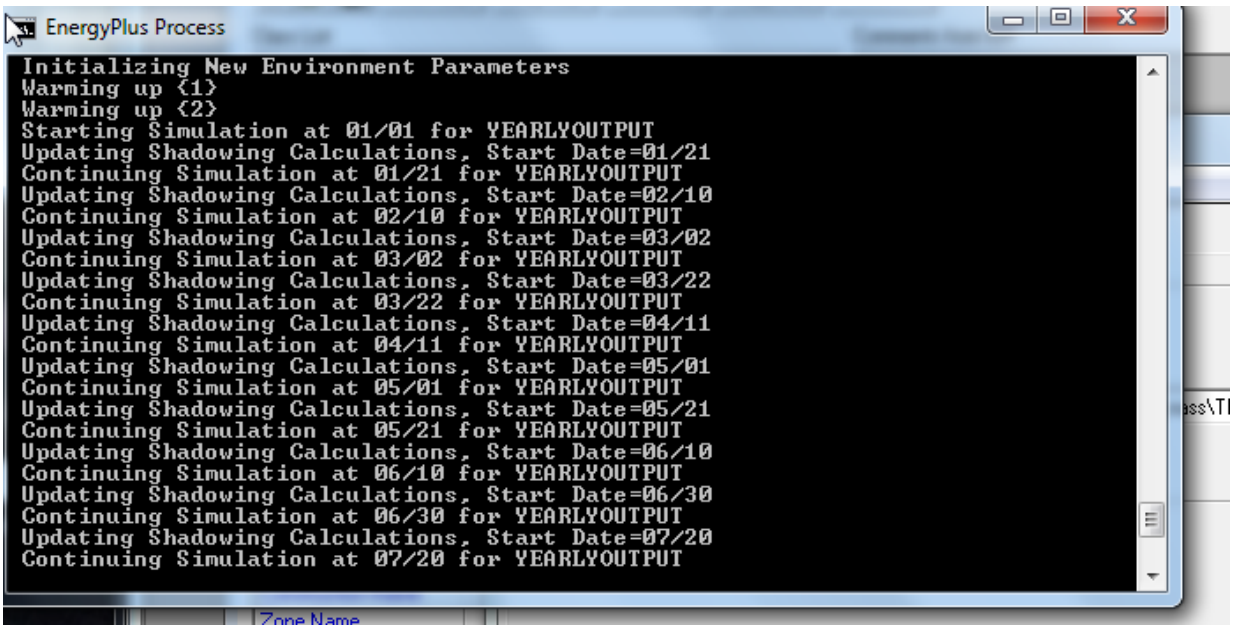


4. In this step you set the location for the output of the simulations. For now we'll assume you put the output in the same directory as the input files, so make sure the Original Input File Location button is selected and click **Next**.



5. Save the simulation group with a filename of Thermalmass.epg.

6. Click the button **Simulate Group** to begin the simulation. You'll see a command window pop up with the EnergyPlus simulation output being displayed.



All three simulations should run without errors or warnings. Unlike a single simulation, the group simulation does not give you a dialog box telling you the number of warnings and errors and the time elapsed.

Analyzing Results

The output files can be analyzed to extract the desired information. In particular, you can view the html files to find the overall energy use of the buildings and the U-values of the different constructions.

The Thermalmass_low.html file will show the total energy info as seen below:

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	2.34	0.00	0.00	0.00	0.00
Cooling	12.11	0.00	0.00	0.00	0.00	0.00
Interior Lighting	11.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	7.78	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.78	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	31.68	2.34	0.00	0.00	0.00	0.00

It also shows the following Envelope Information where we can get the U-values:

	Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross A
ZN_1_WALL_1	EIFS STUD WALL	0.30	0.255	0.265	
ZN_1_WALL_2	EIFS STUD WALL	0.30	0.255	0.265	
ZN_1_WALL_3	EIFS STUD WALL	0.30	0.255	0.265	
ZN_1_WALL_4	EIFS STUD WALL	0.30	0.255	0.265	
ZN_1_FLOOR	FLOOR	0.30	1.774	3.118	
ZN_1_CEILING	METAL DECK ROOF	0.30	0.235	0.246	

The Thermalmass_med.html file will show the total energy info as seen below:

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	1.26	0.00	0.00	0.00	0.00
Cooling	11.93	0.00	0.00	0.00	0.00	0.00
Interior Lighting	11.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	7.78	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.71	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	31.43	1.26	0.00	0.00	0.00	0.00

It also shows the following Envelope Information where we can get the U-values:

	Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gros
ZN_1_WALL_1	EIFS CONCRETE WALL	0.30	0.286	0.298	
ZN_1_WALL_2	EIFS CONCRETE WALL	0.30	0.286	0.298	
ZN_1_WALL_3	EIFS CONCRETE WALL	0.30	0.286	0.298	
ZN_1_WALL_4	EIFS CONCRETE WALL	0.30	0.286	0.298	
ZN_1_FLOOR	FLOOR	0.30	1.774	3.118	
ZN_1_CEILING	LW CONCRETE DECK ROOF	0.30	0.253	0.266	

The Thermalmass_high.html file will show the total energy info as seen below:

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	1.07	0.00	0.00	0.00	0.00
Cooling	12.27	0.00	0.00	0.00	0.00	0.00
Interior Lighting	11.01	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	7.78	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.73	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	31.78	1.07	0.00	0.00	0.00	0.00

It also shows the following Envelope Information where we can get the U-values:

	Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross
ZN_1_WALL_1	BRICK CAVITY WALL	0.30	0.280	0.292	
ZN_1_WALL_2	BRICK CAVITY WALL	0.30	0.280	0.292	
ZN_1_WALL_3	BRICK CAVITY WALL	0.30	0.280	0.292	
ZN_1_WALL_4	BRICK CAVITY WALL	0.30	0.280	0.292	
ZN_1_FLOOR	FLOOR	0.30	1.774	3.118	
ZN_1_CEILING	HW CONCRETE DECK ROOF	0.30	0.241	0.253	

The temperature and electricity use on June 21 and December 21 can be extracted from the generated .csv files. Here we can see the zone operative temp data from December 21 highlighted.

	A	B	C	D	E	F
8496	12/20 23:	14.065	21.70219	301.8327		
8497	12/20 24:	13.3	21.73583	248.419		
8498	12/21 01:	12.42	21.65953	248.419		
8499	12/21 02:	11.7	21.55907	248.419		
8500	12/21 03:	10.765	21.4565	248.419		
8501	12/21 04:	9.67	21.32463	248.419		
8502	12/21 05:	11.27	21.27619	248.419		
8503	12/21 06:	11.865	21.28236	301.8327		
8504	12/21 07:	11.1	21.19169	600.8984		
8505	12/21 08:	10.825	21.19856	808.934		
8506	12/21 09:	11.205	21.72563	1714.875		
8507	12/21 10:	12.91	22.46974	1763.36		
8508	12/21 11:	14.505	23.1206	1802.425		
8509	12/21 12:	15	23.55363	1825.235		
8510	12/21 13:	15.33	23.83708	1792.09		
8511	12/21 14:	15.875	23.93187	1859.505		
8512	12/21 15:	16.705	23.84528	1885.15		
8513	12/21 16:	16.925	23.75152	1888.157		
8514	12/21 17:	16.095	23.59695	1856.526		
8515	12/21 18:	15.27	22.75852	1175.945		
8516	12/21 19:	14.67	22.18442	875.6369		
8517	12/21 20:	14.125	21.93684	856.9988		
8518	12/21 21:	13.9	21.73701	736.6026		
8519	12/21 22:	12.36	21.58677	715.5451		
8520	12/21 23:	10.165	21.81524	301.8327		
8521	12/21 24:	9.4	21.76139	248.419		

Data for temperatures and energy demand are cut from the output .csv tables and copied into the analysis spreadsheet.

This material is based upon work supported by the U.S. Department of Energy under Award Number DE-FG26-07NT43330 to the Alliance to Save Energy.