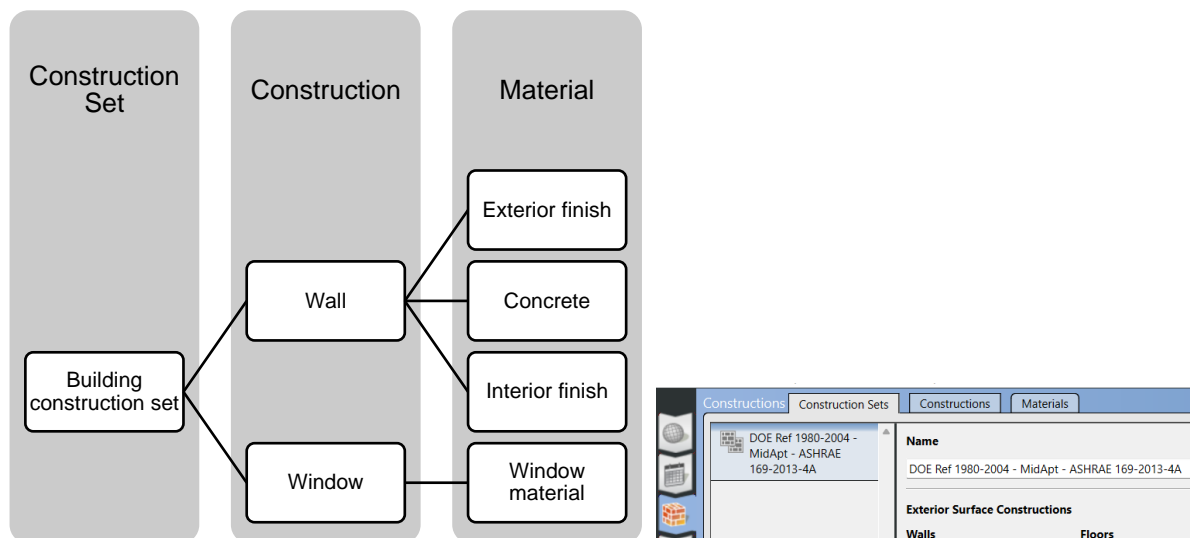# Exercise 4
Building envelope and heat transfer

In this exercise, you will enhance the thermal performance of the apartment building by modifying the thermal properties of the building envelope. To assist you in getting started, here is some information on the general process for working with building materials in OpenStudio.

The Constructions tab is organized as follows: Construction Sets contain different Constructions, which are made from different Materials. Since, in our case, the construction set is applied to the whole building, if you edit one of the constructions or materials that is used within the construction set, you edit the whole building's material properties. The figures below show a visualization of the relationships and the relevant tabs in OpenStudio.

In this exercise, you will be editing the material properties of the windows, walls, and roofs. To simulate alternatives for the windows, walls, and roofs, it is best to create new materials and assign them to the respective constructions. When alternatives involve different ordering of material types, it is best to create new constructions and assign those constructions to the building construction set.

To create new materials or constructions, you can use the button on the bottom left of the page. If you would like to duplicate an existing material or construction, you can use the button. Materials can be assigned to constructions using the Layer properties, arranged from the exterior (exposed to the outside) to the interior (exposed to the inside).

Construction sets are edited by dragging the constructions from the right-hand panel to the respective location in the construction set.
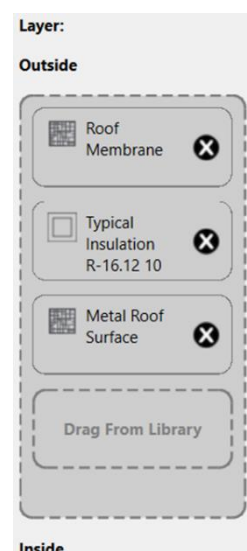
Step 1: Load the model starting point

It is always a good idea to periodically save your model with a new name with OpenStudi; if you named your file (for example) exercise_3.osm, save the model again as exercise_4.osm and work with the new file for this exercise.

For your group project, the starting model should be updated and include the strategies you implemented for your individual assignment (i.e., the strategy we saw during the previous tutorials: shading and window opening). If there were any mistakes, correct them.

For the group project, consider construction sets for your climatic zone (have a look online for typical construction sets for your location). In this tutorial, we will see only an example of an external wall, window and roof; however, in your group project, there are other "constructions" to change (see image on the side).

Step 2: External walls

The table below provides an example of an external wall.

Material	Thickness [mm]	Conductivity [W/mK]	Density [kg/m³]	Specific Heat [J/kgK]	Visible/ Solar Absorptance	Emissivity (thermal absorptance)	R-value (for air gap only)
Wooden cladding	24	0.15	450	1800	0.50	0.84	
Horizontal wooden slats*	27	0.13	471	1600	0.78	0.84	
Vertical wooden slats*	27	0.13	471	1600	0.78	0.84	
Ventilated air gap	44	0.21	-	-	0.70	0.82	0.93
Waterproofing membrane	0.45	0.17	900	1800	0.60	0.90	
Expanded polystyrene insulation	180	0.031	15	1116	0.60	0.90	
Vapour barrier	0.22	0.40	500	1800	0.60	0.50	
Wooden covering	140	0.13	471	1600	0.78	0.84	
* we will ignore wooden slats in Open Studio simulations; only ventilated air gap should be considered							

1) Navigate to the Constructions Sets tab and then Materials.

   a. Click on Materials.
   b. On the bottom left of the page, click the + to add a new material object.
   c. Rename the material "Wooden cladding."
   d. In:
       Roughness select MediumRough
       Thickness type "0.024"
       Conductivity type "0.15"

Density type "450"
Specific Heat type "1800"
Thermal Absorptance type "0.84"
Solar Absorptance type "0.50"
Visible Absorptance type "0.50"

e. On the bottom left of the page, click the + to add a new material object.

f. Rename the material "Waterproofing membrane."

g. In:
Roughness select Smooth
Thickness type "0.00045"
Conductivity type "0.17"
Density type "900"
Specific Heat type "1800"
Thermal Absorptance type "0.90"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

h. On the bottom left of the page, click the + to add a new material object.

i. Rename the material "Expanded polystyrene insulation."

j. In:
Roughness select MediumRough
Thickness type "0.180"
Conductivity type "0.031"
Density type "15"
Specific Heat type "1116"
Thermal Absorptance type "0.90"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

k. On the bottom left of the page, click the + to add a new material object.

l. Rename the material "Vapour barrier."

m. In:
Roughness select Smooth
Thickness type "0.00022"
Conductivity type "0.4"
Density type "500"
Specific Heat type "1800"
Thermal Absorptance type "0.50"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

n. On the bottom left of the page, click the + to add a new material object.

o. Rename the material "Wooden covering."

p. In:
Roughness select MediumRough
Thickness type "0.140"
Conductivity type "0.13"
Density type "471"
Specific Heat type "1600"
Thermal Absorptance type "0.84"

        Solar Absorptance type "0.78"
        Visible Absorptance type "0.78"

q. Click on Air Gap Materials.
r. On the bottom left of the page, click the + to add a new material object.

s. Rename the material "Ventilated air gap."
t. In Thermal Resistance type "0.93"

2) Navigate to the Constructions.

    a. Click on Constructions.
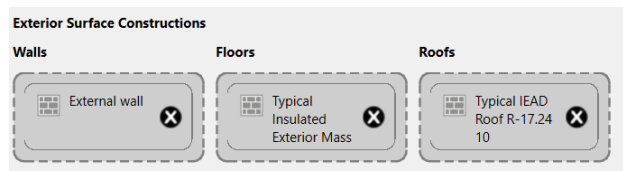   b. On the bottom left of the page, click the + to add a new construction object.

    c. Rename the construction "External wall."
    d. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Materials tab. Expand the drop-down icon to find the materials we just created. Select Wooden cladding and drag this to the box named "Drag From Library."
    e. Click on the Air Gap Materials tab. Expand the drop-down icon to find Ventilated air gap, select it and drag this to the box named "Drag From Library."
    f. Click on the Materials tab. Expand the drop-down icon to find Waterproofing membrane, select it and drag and drag this to the box named "Drag From Library." Find Expanded polystyrene insulation, select it and drag this to the box named "Drag From Library." Find Vapour barrier, select it and drag and drag this to the box named "Drag From Library." Find Wooden covering, select it and drag and drag this to the box named "Drag From Library."

3) Navigate to the Construction Sets.

    a. Click on DOE Ref 1980-2004 - MidApt - ASHRAE 169-2013-4A.
    b. On the bottom left of the page, click the x2 to duplicate the construction set object.
    c. Rename the construction "Apartment construction set."
    d. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Constructions tab. Expand the drop-down icon to find the construction we just created. Select External wall and drag this to the box appropriate box, that is, in Exterior Surface Constructions, under Walls.

Step 3: Windows

The image below provides an example of window.

1) Navigate to the Constructions Sets tab and then Materials.

    a. Click on Simple Glazing System Window Materials.
    b. On the bottom left of the page, click the + to add a new material object.

    c. Rename the material "Double pane."
    d. In:
        U-Factor type "1.0"
        Solar Heat Gain Coefficient type "0.85"
        Visible Transmittance type "0.51"

4) Navigate to the Constructions.
   a. Click on Constructions.
    b. On the bottom left of the page, click the + to add a new construction object.

    c. Rename the construction "Window double pane."
    d. On the right-hand sidebar, ensure My Model is selected at the top and scroll
        down to find the Simple Glazing System Window Materials tab. Expand the drop-
        down icon to find the materials we just created. Select Double pane and drag
        this to the box named "Drag From Library."

5) Navigate to the Construction Sets.

    a. Click on Apartment construction set.
    b. On the right-hand sidebar, ensure My Model is selected at the top and scroll
        down to find the Constructions tab. Expand the drop-down icon to find the
        construction we just created. Select Double pane and drag this to the box
        appropriate box, that is, in Exterior Sub Surface Constructions, under Fixed
        Windows and Operable Windows.
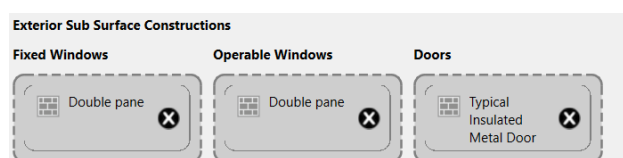
Step 4: Roof

The table below provides an example of roof.

Material	Thickness [mm]	Conductivity [W/mK]	Density [kg/m³]	Specific Heat [J/kgK]	Visible/ Solar Absorptance	Emissivity (thermal absorptance)
Gravel	16	0.36	1840	840	0.29	0.28
Bitumen elastomeric membrane	4	0.23	1100	1000	0.60	0.95
Polyurethane insulation	180	0.034	35	1400	0.60	0.90
Vapour barrier	0.22	0.5	980	1800	0.60	0.56
OSB panels	25	0.13	650	1700	0.60	0.92

1) Navigate to the Constructions Sets tab and then Materials.

     a. Click on Materials.
     b. On the bottom left of the page, click the + to add a new material object.

     c. Rename the material "Gravel."
     d. In:
        Roughness select MediumRough
        Thickness type "0.016"
        Conductivity type "0.36"
        Density type "1840"
        Specific Heat type "840"
        Thermal Absorptance type "0.28"
        Solar Absorptance type "0.29"
        Visible Absorptance type "0.29"
     e. On the bottom left of the page, click the + to add a new material object.

     f. Rename the material "Bitumen elastomeric membrane."
     g. In:
        Roughness select Smooth
        Thickness type "0.004"
        Conductivity type "0.23"
        Density type "1100"
        Specific Heat type "1000"
        Thermal Absorptance type "0.95"
        Solar Absorptance type "0.60"
        Visible Absorptance type "0.60"
     h. On the bottom left of the page, click the + to add a new material object.

     i. Rename the material "Polyurethane insulation."
     j. In:
        Roughness select MediumRough
        Thickness type "0.180"

Conductivity type "0.034"
Density type "35"
Specific Heat type "1400"
Thermal Absorptance type "0.90"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

k. On the bottom left of the page, click the + to add a new material object.

l. Rename the material "Vapour barrier_roof."
m. In:
Roughness select Smooth
Thickness type "0.00022"
Conductivity type "0.5"
Density type "980"
Specific Heat type "1800"
Thermal Absorptance type "0.56"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

n. On the bottom left of the page, click the + to add a new material object.

o. Rename the material "OSB panels."
p. In:
Roughness select MediumRough
Thickness type "0.025"
Conductivity type "0.13"
Density type "650"
Specific Heat type "1700"
Thermal Absorptance type "0.92"
Solar Absorptance type "0.60"
Visible Absorptance type "0.60"

2) Navigate to the Constructions.
a. Click on Constructions.
b. On the bottom left of the page, click the + to add a new construction object.

c. Rename the construction "Roof."
d. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Materials tab. Expand the drop-down icon to find the materials we just created. Select Gravel and drag this to the box named "Drag From Library." Find Bitumen elastomeric membrane, select it and drag and drag this to the box named "Drag From Library." Find Polyurethane insulation, select it and drag and drag this to the box named "Drag From Library." Find Vapour barrier_roof, select it and drag and drag this to the box named "Drag From Library." Find OSB panels, select it and drag this to the box named "Drag From Library."

3) Navigate to the Construction Sets.

a. Click on Apartment construction set.
b. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Constructions tab. Expand the drop-down icon to find the
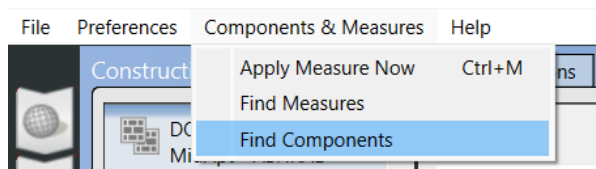
construction we just created. Select Roof and drag this to the box appropriate box, that is, in Exterior Surface Constructions, under Roofs.
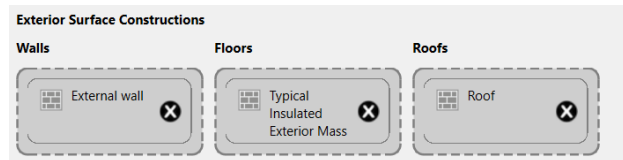
Step 5: Load component

Instead of creating materials by hand, it is possible to import existing materials from the OS library

1) In the top bar, click on Components & Measures and then Find Components

2) Go in Material and then Opaque

    a. Search for the material of interest and select it.
    b. Click Download.
    c. Close the current window and return to the main OpenStudio window.
    d. On the right-hand panel, ensure Library is selected at the top and scroll down to find the Materials tab. Expand the drop-down icon to find the materials we just downloaded. Select it and drag it to the box named "Drag From Library."
    e. Now, the material should be added to the model.

3) If you cannot add the material to your model by following these steps, there is a workaround. Go to the following link:
https://github.com/BuildingComponentLibrary/nrel-components/tree/v0.3/lib/components/Material/Opaque

    a. Browse and search the material of interest.
    b. Select the file "<material_of_interest>.osm" and download it by clicking on the three dots in the top-right corner. Save the file within your project folder.
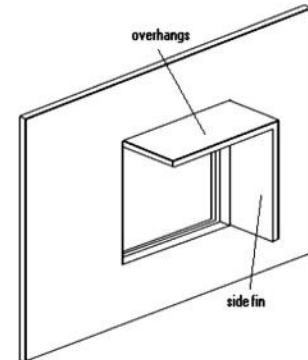

    c. In the top bar, click on File and then Load Library
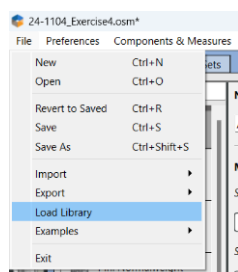
     d.   Search for the file you just downloaded and open it.

     e.   On the right-hand panel, ensure Library is selected at the top and scroll down to find the Materials tab. Expand the drop-down icon to find the materials we just imported. Select it and drag it to the box named "Drag From Library."

     f.   Now, the material is added to the model.

Step 6: Overhang and Sidefin

Sidefins and overhangs are traditional building forms and when properly designed can prove solar control and enhancing daylighting. Overhangs and sidefins can be characterised in terms of a projection factor. For examples, for overhangs the projection factor is the ratio of the projection of the overhang from the window surface to the distance from the window sill to the bottom of the overhang.

More information about overhang anf fin can be found at the following link https://bigladdersoftware.com/epx/docs/8-6/input-output-reference/group-thermal-zone-description-geometry.html#shadingoverhangprojection
(search for "Shading:Overhang:Projection" and "Shading:Fin:Projection." Note: the majoirity of the option described here are not available in OpenStudio)

1) Navigate to the Geometry tab and select the Editor tab at the top of the page.

     a.   Select Components at the top of the page.

     b.   Click on th expand button and for the window "W_160.140" set Overhang Projection Factor to 0.5, and Fin Projection Factors to 0.25. The Overhang Projection Factor allows for specifying the depth of the overhang as a fraction of the window's height. The Fin Projection Factors allows for specifying the depth of the overhang as a fraction of the window's width. This object allows for specification of both fins for the window. This object allows.

     c.   Merge your model again by clicking Merge with Current OSM.
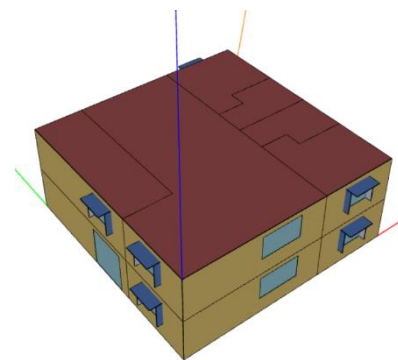
2) Navigate to the Constructions Sets tab and then Constructions.

     a.   Click on Constructions.

     b.   On the bottom left of the page, click the + to add a new construction object.

     c.   Rename the construction "Shading_space."

    d. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Materials tab. Expand the drop-down icon to find F08 Metal surface. Select it and drag it to the box named "Drag From Library."

3) Navigate to the Construction Sets.

    a. Click on Apartment construction set.
    b. On the right-hand sidebar, ensure My Model is selected at the top and scroll down to find the Constructions tab. Expand the drop-down icon to find the construction we just created. Select Shading_space and drag this to the box appropriate box, that is, in Other Constructions, under Space Shading.
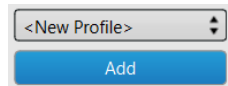

4) Navigate to the Schedules tab

    a. Navigate to Schedules (not Schedule Sets)
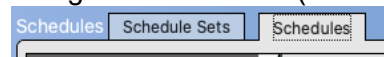
    b. On the bottom left of the page, click the + to add a new schedule object.

    c. Under Schedule Type, select Franctional
    d. Rename the schedule "Overhang schedule."
    e. Next to Run Period Profiles click the + and then

    click Add.
   f. In Schedule Rule Name rename the schedule to "Summer." In Date Range type "05/01" and "09/30." In Apply to select S, M, T, W, T, F and S.

    g. In Schedule Day Name rename the schedule to "Summer."
    a. Change the value. To do this, hover your mouse over the horizontal line at the top of the graph, type 0, and hit enter. (A value of 0 imply an opaque element).
    h. Click on Default.
    a. Change the value. To do this, hover your mouse over the horizontal line at the top of the graph, type 1, and hit enter. (A value of 1 imply a transparent element).

5) Navigate to the Spaces tab

    a. Navigate to Shading
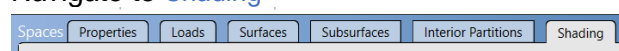
a. Select the My Model tab on the right-hand panel and navigate to the newly created Overhang schedule under Ruleset Schedules. Drag the schedule to the box labelled Transmittance Schedule in the row corresponding to 0-A1.B. Assign the schedule manually one at the time. If you attempt to assign multiple schedules at a time using the Apply to Selected the program will crash.