Universität der Künste Berlin

Modelica library BuildingSystems

User guide

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CONTENTS

CHAPTER ONE

INTRODUCTION

This user guide shall explain the use of the Modelica library BuildingSystems (http://www.modelica-buildingsystems.de), which is being developed for dynamic simulation of the energetic behavior of single rooms, buildings and whole districts.

One important part of the library consists in an adaptive building model, which is able to adapt its space resolution (0D, 1D, 3D modelling approach) and also its physical model (e.g. pure thermal or a hygro-thermal calculation) to the respective problem of the simulation analysis.

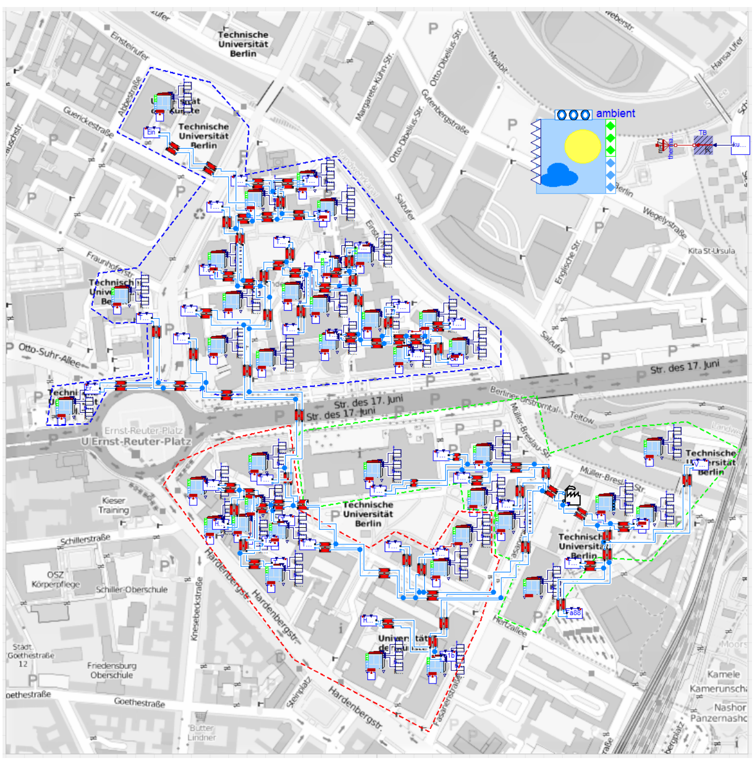


Figure 1.1: *Application of the simplified building model (0D modelling approach) for district modeling: 39 buildings of the Campus Berlin-Charlottenburg are connected by a district heating grid (ATES project).*

Level of detail (LOD) 0D: the adaptive building model works in a strongly simplified and abstracted configuration (low-order or grey box model), which leads to numerical fast calculations. A typical case study is the simultaneous calculation of the thermal energy demand of huge number of single buildings of a district in combination with a district heating network (compare with figure 1.1).

Figure 1.2: *The Rooftop building, which is designed for a placement on the roof of a Berlin old building (UdK Berlin/TU Berlin contribution to the competition Solar Decathlon Europe 2014)*

Level of detail (LOD) 1D: in this case the adaptive building model uses more spatially resolved algorithms and models and also more simulation time for a single building. A typical application are multi-zone-building models, which calculate for each thermal zone the heating and cooling energy demand, the air temperatures and air moistures and also the air exchange between the single thermal zones of a complex building (compare with figure 1.2).

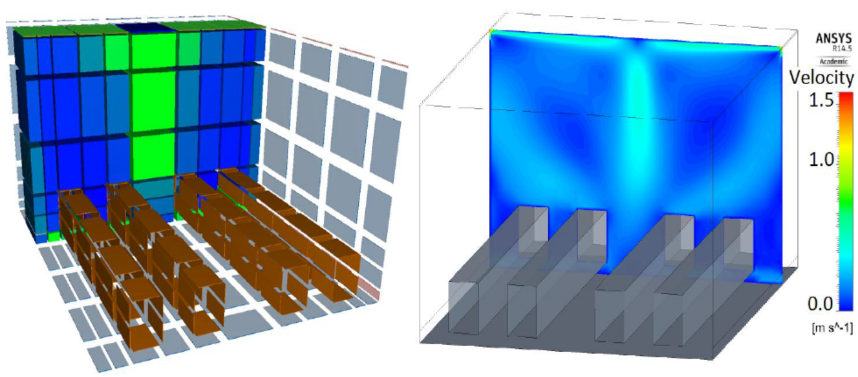


Figure 1.3: *Spatially resolved room model of the Aachen Model Room AMoR modelled with the 3D zonal approach of the BuildingSystems library and with ANSYS CFD (project UCaHS)*

Level of detail (LOD) 3D: the most advance configuration consists in a spatially resolved room model, which describes the three-dimensional air flow within a room volume, the geometrical long-wave and short-wave radiation distribution and also the multidimensional heat transport within the building construction. For example, this model is able to calculate the location-dependent thermal comfort within a room.

The BuildingSystems library supports for all three LODs pure thermal or hygro-thermal calculations. Also a mixed thermal and hygro-thermal simulation analysis and different spatial resolutions for different parts of a building model are supported.

CHAPTER

TWO

SIMPLE BUILDING MODEL

In the first example a simplified building model is connected with an ambient model, which supports the building model with the climate data of a given location (Berlin, Germany). Several fundamental working steps for the application of the BuildingSystems library (together with Dymola 2016 or higher) such as

- the configuration of a system model structure,
- the definition of the building model parameters,
- the definition of the boundary conditions of the building model and
- the performance of a simulation experiment

are explained. The used building model *BuildingSystems.Buildings.BuildingTemplates.Building1Zone1DBox* uses a thermal 1D-modelling approach, that means all models of the building constructions (walls, roof, ground plate etc.) are discretized regarding energy balancing in one dimension and the air space within the zone is modeled with aggregated thermal node.

2.1 Set up the system model structure

Download the BuildingSystems library from https://github.com/UdK-VPT/BuildingSystems. Open the library with Dymola and do following steps:

1. Open dialog: *File* -> *New* -> *Model* and fill in the field *Name:* “SimpleBuilding”.
2. Extend the new model from *Modelica.Icons.Example* and click OK.
3. Mark the new example *SimpleBuilding* in the package browser and save it with *File* -> *Save* in the file *SimpleBuilding.mo* in a folder of your choice.
4. Drag and drop a component model from the Dymola package browser of the class *BuildingSystems.Buildings.BuildingTemplates.Building1Zone1DBox* and rename it to *building*. This component is able to calculate the thermal energy balance of a one zone thermal building model. It fits to our first example because it needs only the definition of few parameters for a simulation analysis.
5. Instantiate in the same manner by drag and drop an ambient model *BuildingsSystems.Buildings.Ambient* and set the climate data (parameter weatherDataFile) to *WeatherDataFile_Germany_Berlin*. Now pre-calculated hourly weather data from Meteonorm

(http://www.meteonorm.com/en/) for Berlin are used to support the building model with ambient values of air temperature, moisture, direct and diffuse radiation, wind speed and wind direction.

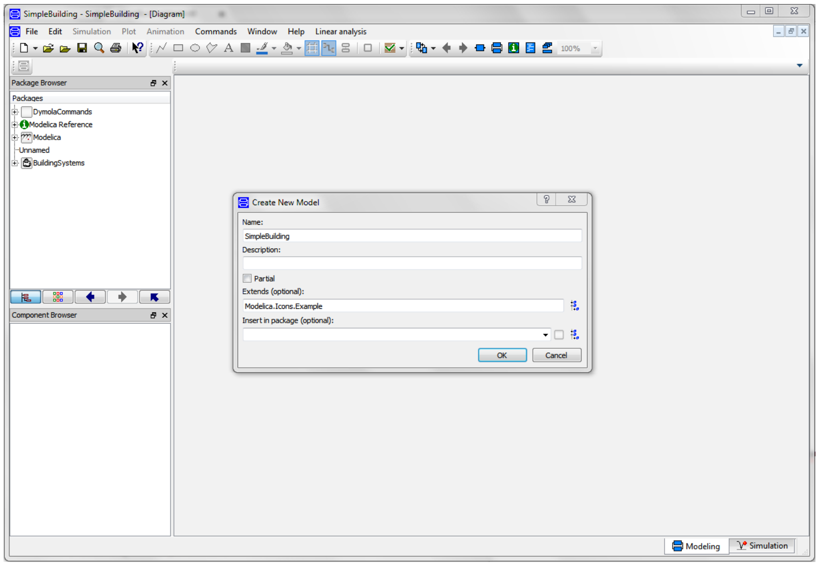


Figure 2.1: *Definition of a new system model in Dymola*

6. Connect the blue connectors *ambient.toAirPorts* and *building.toAmbientAirPorts* of both models. Now the climate boundary conditions which are caused by the ambient air of the building will be considered (convective heat transfer and optional also the moisture transport).

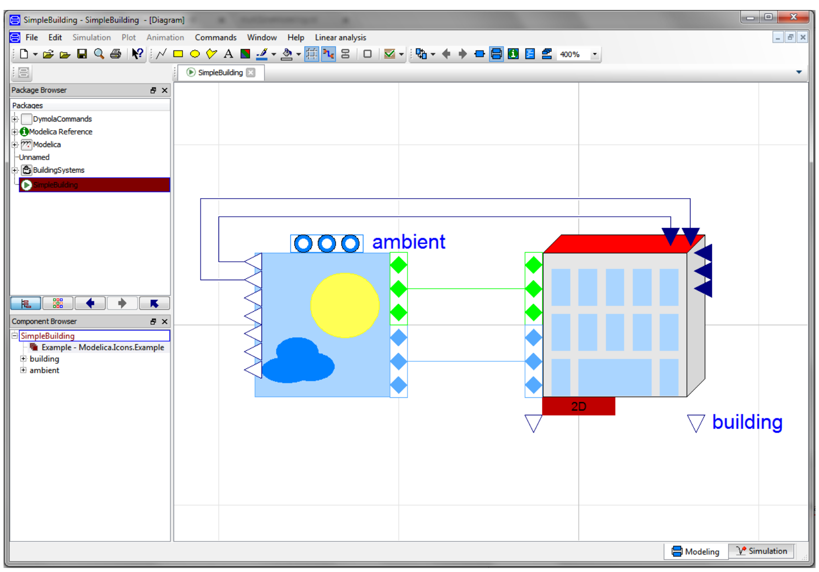


Figure 2.2: *The simulation model, which consists of a building model and an ambient model*

7. Then connect the green connectors *ambient.toSurfacePorts* and *building.toAmbientSurfacePorts* of the ambient and the building model. This enables the ambient model to deliver the boundary conditions for short-wave radiation from the sun and the long-wave radiation exchange with the sky.

8. The ambient model has to know the number of surfaces of the building model, which are in contact with the ambient air. For this purpose double-click on the ambient component and add this information to the parameter *ambient.nSurfaces* by inserting a component reference: building -> extends BuildingSystems.Buildings.BaseClasses.BuildingTemplate -> nSurfacesAmbient.

9. Connect the output variable *ambient.TAirRef* and the input variable *building.TAirAmb* (ambient temperature at a reference height of 10 m) and also *ambient.xAirRef* and *building.xAirAmb* (ambient absolute moisture). Both variables are necessary for the calculation of the energy loss caused by the air exchange of the building.

2.2 Define the building model parameters

1. **Define the building dimensions**. The inner space of the building shall have a dimension of 9 m width, 9 m length and 3 m height (these dimensions are equal to the enclosed air space, the outer dimension of the building model depends on the thickness of the selected wall, roof and base plate constructions). Fill in these values within the tab *General* (group Geometry) in the parameter dialog of the building component.

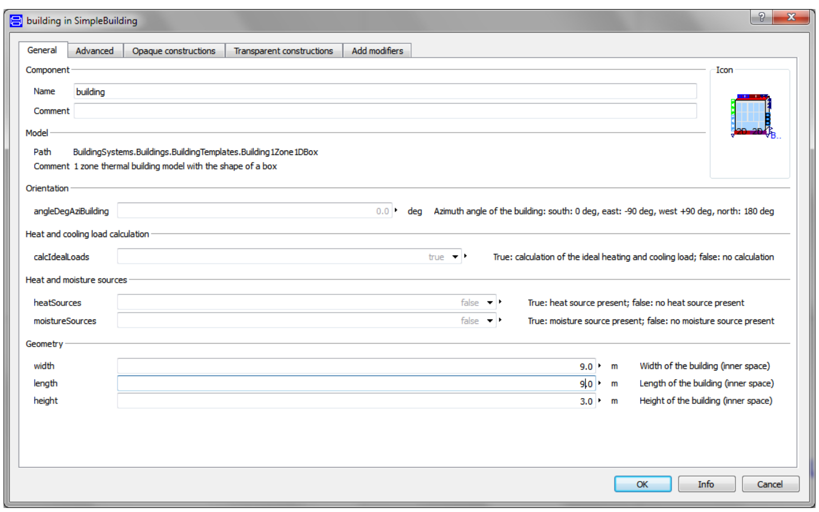


Figure 2.3: *Definition of the geometry of the building model*

2. **Define the type of opaque construction** in the building model component. For this purpose select

   - for all exterior walls (constructionWall1 to constructionWall4) the type *Outer wall construction for single-family house EnEv 2014*,
   - for the roof (constructionCeiling) the type *Roof construction for single-family house EnEv 2014* and
   - for the base plate (constructionBottom) the type *BasePlate construction for single-family house EnEv 2014*

   in the group exterior constructions within the tab *Opaque constructions*. Set the parameters *InteriorWalls* and *InteriorCeilings* to false (group Interior constructions on the same tab), because interior constructions shall be neglected.

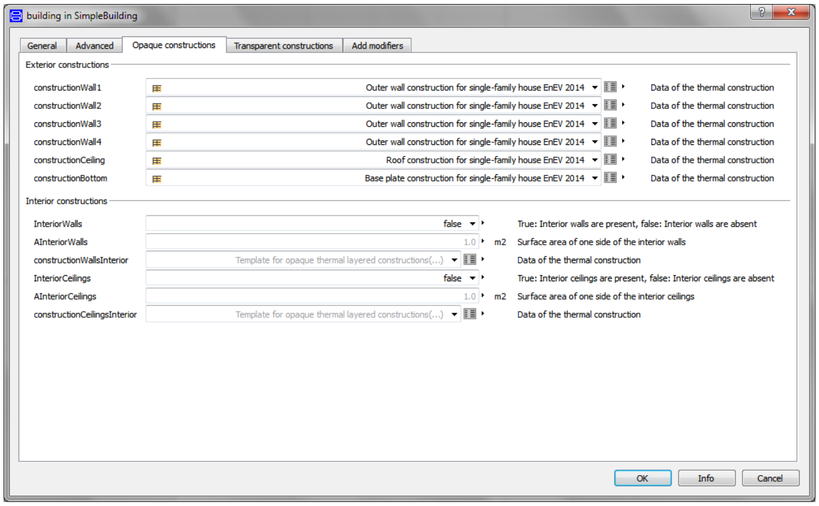


Figure 2.4: *Definition of the opaque constructions*

3. **Define the type of transparent constructions** in the building model. Select for all windows (window1 to window4) the type *Heat protection double glazing with UValGla=1.4W/(m2.K) and g=0.58*. Define the size of *window1* to 3 m width by 1 m height and for the *window2*, *window3* and *window4* to 1 m width by 1 m height.

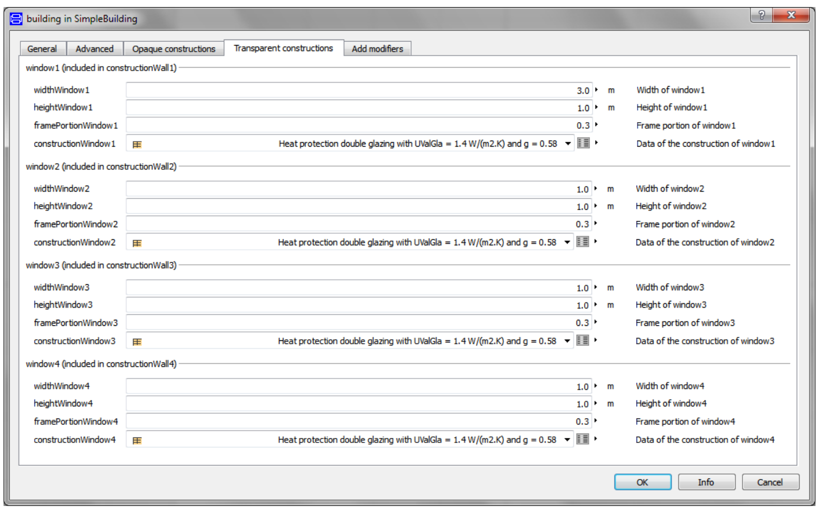


Figure 2.5: *Definition of the transparent constructions*

2.3 Set the boundary conditions of the building model

1. **Define the set temperatures for heating and cooling** and the **air change rate**. Therefor add three instances of the MSL model class *Modelica.Blocks.Sources.Constant* to the system model. Rename them to *TSetHeating*, *TSetCooling* and *airchange* and parametrize them with 273.15 + 20.0 (20 degree Celsius) 273.15 + 24.0 (24 degree Celsius) and 0.5 (half air change per hour). Connect the output of the three blocks with the corresponding input variables *building.TSetHeating*, *building.TSetCooling*

and *building.airchange* of the building model.

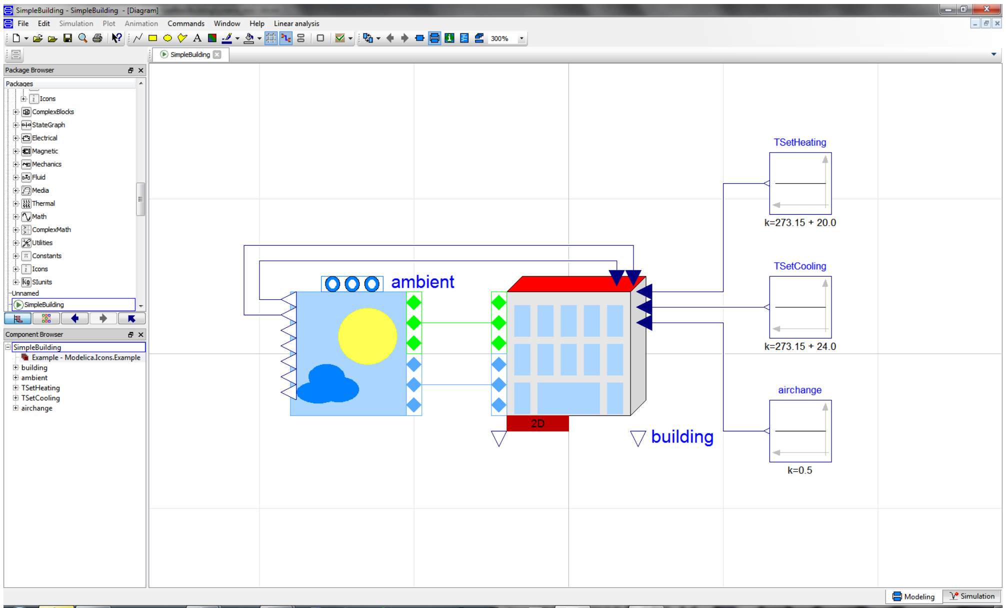


Figure 2.6: Completed system model with boundary condition (set temperatures, air change rate)

2.4 Simulate the system model

Now the model is 100 percent prepared for a simulation analysis. Simulate the model over a time period of one year. For this purpose select the experiment *SimpleBuilding* in the package browser of Dymola and switch to the simulation mode.

1. Open the *Simulation Setup* dialog and fill in 31536000 (3600 seconds/hour x 24 hours/day x 365 days/year = 31536000 seconds) into the *Stop time* entry field and perform the simulation experiment.

2. Study the simulation results: the next both diagrams show the main important temperatures (outside and inside air temperature, operative temperature) and the ideal heating and cooling power for the building, which guarantees the indoor air temperature in the wished area between 20 to 24 degree Celsius.

The first diagram illustrates that the indoor air temperature and the operative temperature (the mean value of the indoor air temperature and the mean surface temperature within the zone) are close together. The reason is the insulated construction of the walls, the ceiling and the base plate regarding the present German energy code (EnEV 2014). Only during some summer days the indoor air temperature reaches maximum values of 24 degree Celsius.

At the location Berlin the thermal energy demand is close to 100 percent caused by heating energy. Only during some the hot summer days a small amount of cooling energy is needed.

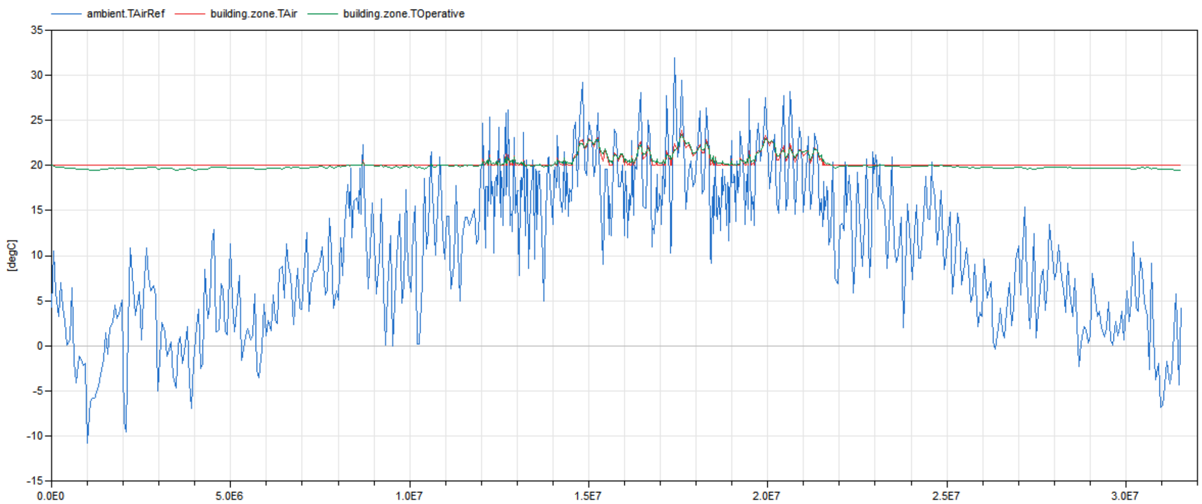


Figure 2.7: *Air temperature, operative temperature and ambient air temperature during the yearly simulation (location Berlin, Germany)*

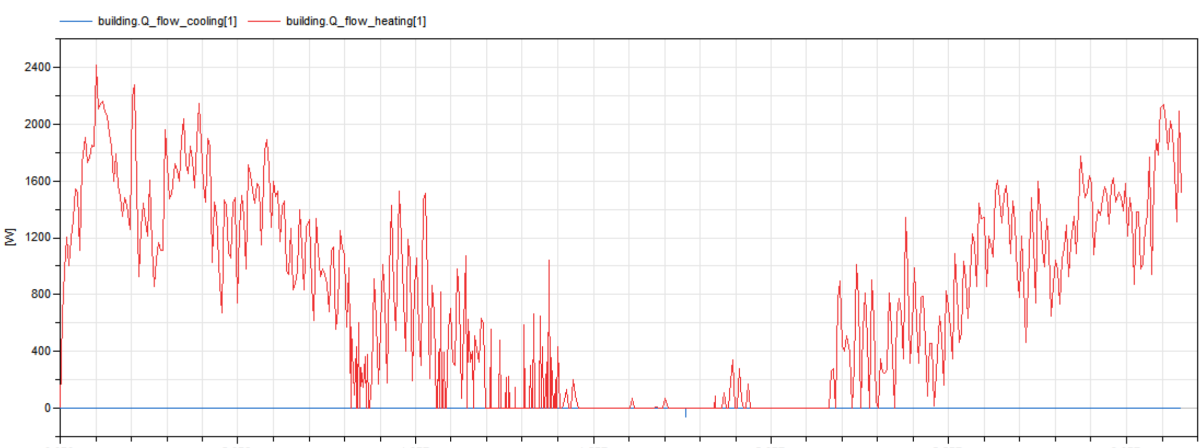


Figure 2.8: *Thermal energy demand for heating and cooling during the yearly simulation (location Berlin, Germany)*

2.5 Change the climate location

In the next step the location shall be changed to study the impact of a hot and dry climate on the thermal energy demand of the building model in comparison to the moderate climate of Berlin. For this purpose change the parameter weatherDataFile within the ambient component to *WeatherDataFile_Iran_Hashtgerd* (Hashtgerd is a city in north Iran 100 km west of Theran).

In comparison to Berlin the outside temperature is close to 40 degree Celsius during the summer (Berlin 32 degree Celsius). This leads to a significant cooling demand in summer, but there is still a relevant heating demand in winter.

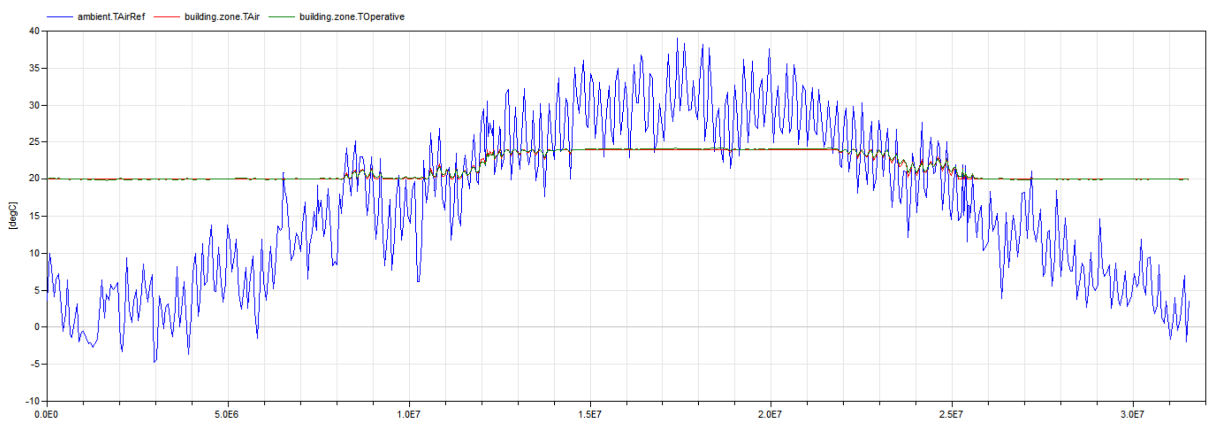


Figure 2.9: *Air temperature, operative temperature and ambient air temperature during the yearly simulation (location Hashtgerd, Iran)*

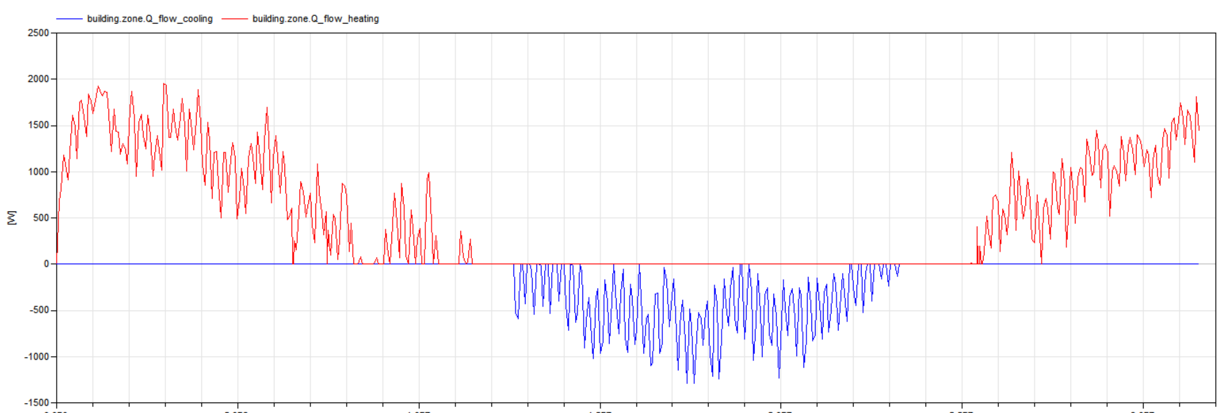


Figure 2.10: *Thermal energy demand for heating and cooling during the yearly simulation (location Hashtgerd, Iran)*

2.6 Visualization of the model

An additional package of the BuildingSystems library, the BuildingSystems_Vis3D library enables a 3D visualization of the building and energy plant models. The package can be downloaded from https://github.com/UdK-VPT/BuildingSystems_Vis3D.

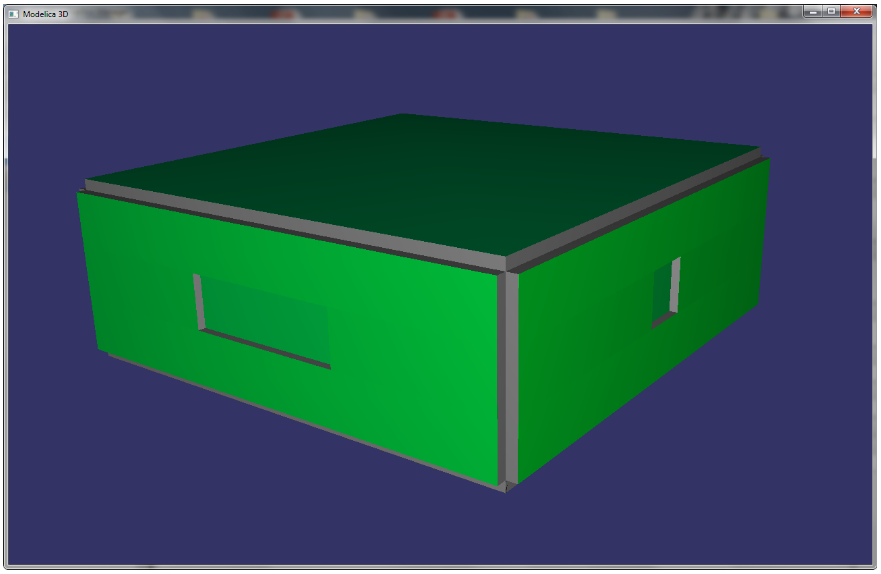


Figure 2.11: *Visualisation of the building model of the previous paragraph. The color illustrates the surface temperatures of the building constructions.*

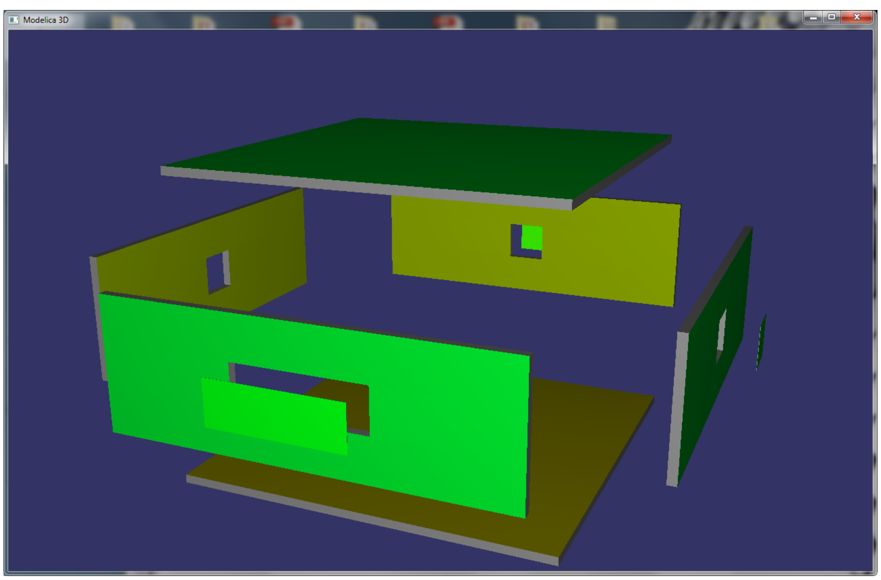


Figure 2.12: *Visualisation of the building model in the explode model. To obtain this kind of exploded visualisation the parameter explode of the building model has to be set to true. A second parameter explodeDistance was set to 2.0, that means all building constructions are shifted 2 m away from their original positions.*

CHAPTER THREE

MULTI-ZONE BUILDING MODELING

In this chapter the application of the BuildingSystems library for multi-zone building modeling is demonstrated.

For this purpose a thermal building model of the *Thermal Model House* (http://www.thermisches-modellhaus.de) with two thermal zones shall be created:

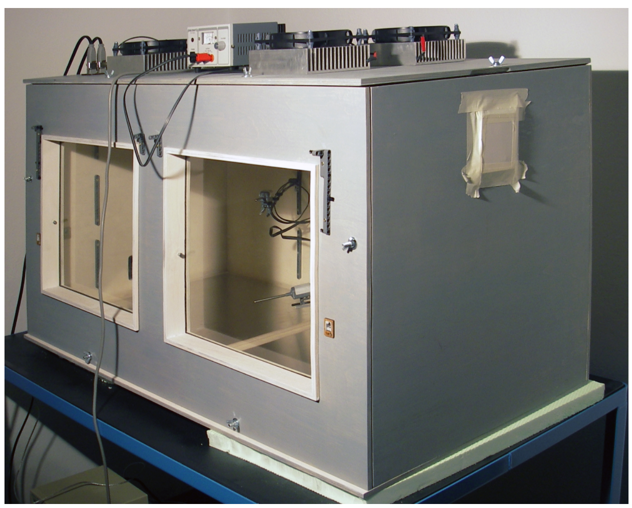


Figure 3.1: *Thermal Model house: a portable experimental test facility for building physics studies, developed by UdK Berlin.*

The *Thermal Model House* (THM) is a portable experimental test facility with a simple geometry and a compact size of approximateley 1 m length, 0.5 m depth and 0.5 m height. This small thermal box is able to reproduce different phenomena of building climatization within physical experiments. Due to its manifold configuration options, experiments about the energy balance of rooms, about the heat and air transport processes within rooms, about ventilation, heating and cooling of buildings as well as about building control are enabled. The THM is being developed at the Institute of Architecture and Urban Planning at UdK Berlin. It is used for the education of architect and engineering students and also for research.

One configuration of the THM works with a inner partition wall, which divides the air volume of the box into two different thermal zones. These zones can be separately heated or cooled by individual heating surfaces on the bottom and cooling surfaces on the ceiling. Exactly this configuration shall be modelled in the present case.

The modelling and simulation process is described using the Modelica simulation environment Dymola (version Dymola 2016). First of all the Modelica library *BuildingSystems* has to be loaded into Dymola. After that, the library will occur in the library three in addition to the other present Modelica libraries.

The creation and configuration of a new thermal building model takes place in the following steps:

- Configuration of the building model structure (topology of the construction of the buildings model)
- Definition of the building model parameters (building geometry and physical parameters of the construction elements)
- Definition of the boundary conditions of the system model (climate conditions of the building ambient, set temperatures for heating and cooling for each thermal zone)

3.1 Set up the building model structure

1. **Create a new package** for your simulation experiment

- Open dialog: *File -> New -> Package* and fill in the field *Name of new package:* “ThermalModelHouse” and click OK
- Mark the new package *ThermalModelHouse* in the package browser and save it with *File -> Save* in the file *ThermalModelHouse.mo* in a folder of your choice.

2. **Create a new building model**, based on the template model class *BuildingTemplate*. Therefore insert a new building model in the previous defined package as follows:

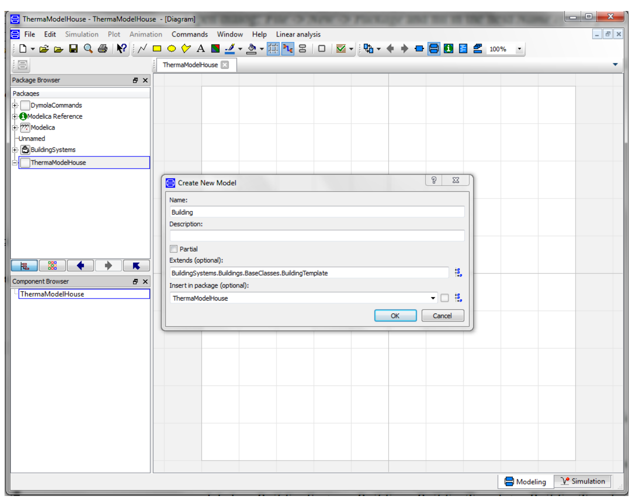


Figure 3.2: Definition of a building model based on a building template

- Open dialog: *File -> New -> Model* and fill in the field *Name of new model:* “Building”. Then click on the button right of the field *Extends (optional):* and navigate to the model class *BuildingSystems.Buildings.BaseClasses.BuildingTemplate* and click OK. Further click on the button right of the field *Insert in Package (optional):* and navigate to the package *ThermalModelHouse* on the top level and click OK (compare the Dymola screenshoot above).

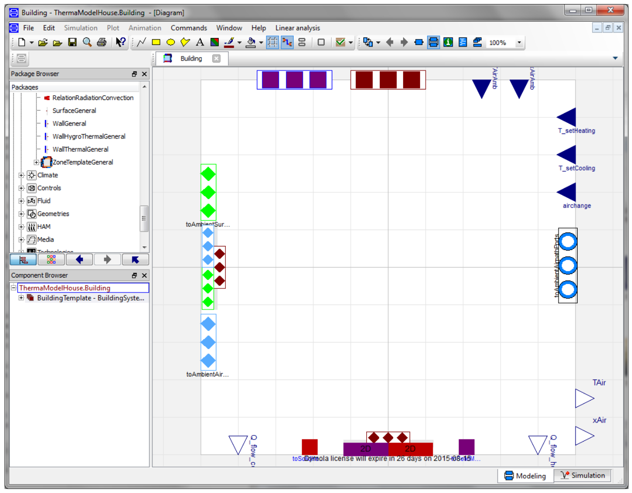


Figure 3.3: *View on the empty building model*

As a result you can see now the inner structure (the *Diagram view* in Dymola) of the empty building model. On the left side you see the interfaces to the building ambient, below the interfaces to the ground of the building and on the right side the input signals for the set temperatures for heating and cooling of each zone and the interfaces of the air pathes to the ambient.

3. **Instantiate two thermal zones**, which shall represent the left and right part of the TMH.

   For this purpose drag and drop a component model from the class *BuildingSystems.Buildings.Zones.ZoneTemplateAirvolumeMixed* into the building model and rename it to *zone1*. Add *zone2* in the same manner:

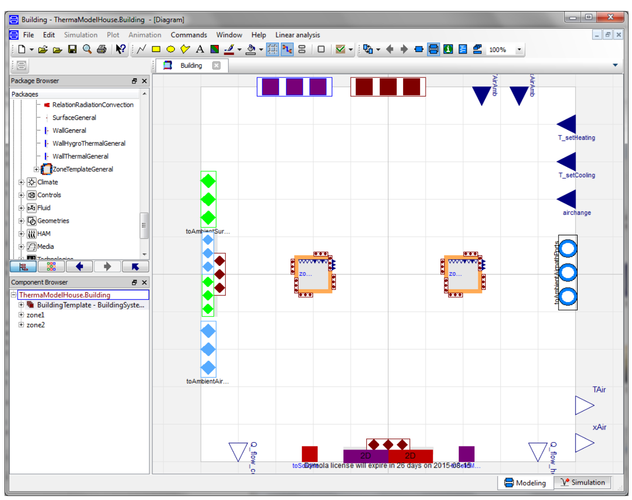


Figure 3.4: *Building model with two thermal zones*

4. **Instantiate construction elements**.

   For the opaque constructions (walls, bottoms, ceilings etc.) use the model class *BuildingSystems.Buildings.Constructions.Walls.WallThermal1DNodes* and for the transparent constructions (windows) the model class *BuildingSystems.Buildings.Constructions.Windows.Window*.

Notice, that each component comes with a blue line (which indicates side 1) and has the connector *toSurfacePort_1*. The other unmarked side 2 owns the connector *toSurfacePort_2*. The blue line helps you to distinguish both component sides, e.g. if you want to define single layers of a construction in a certain order. In our case we bring all component models in a position, that all blue lines show to the zones respectively in the case of the partition wall to *zone1* and to the adjacent *zone2*.

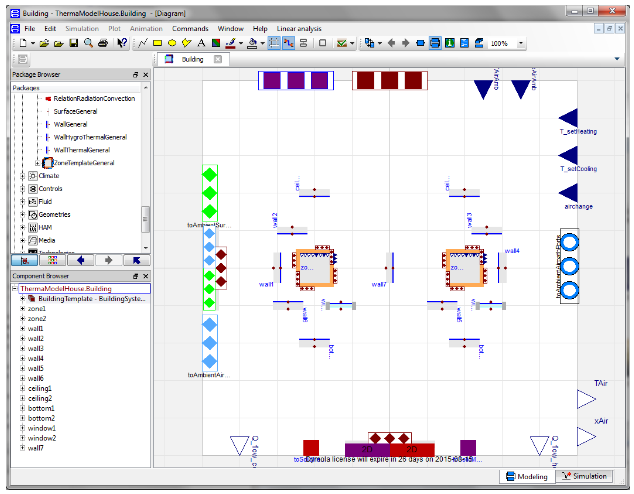


Figure 3.5: Building model with zone and construction models

In our case we have to instantiate seven walls (*wall1* to *wall7*), two bottoms (*bottom1* and *bottom2*), two ceilings (*ceiling1* and *ceiling2*) and two windows models (*window1* and *window2*).

5. **Connect construction elements**.

   Now connect the connectors of all "blue sides" with the zone models as in the following picture:

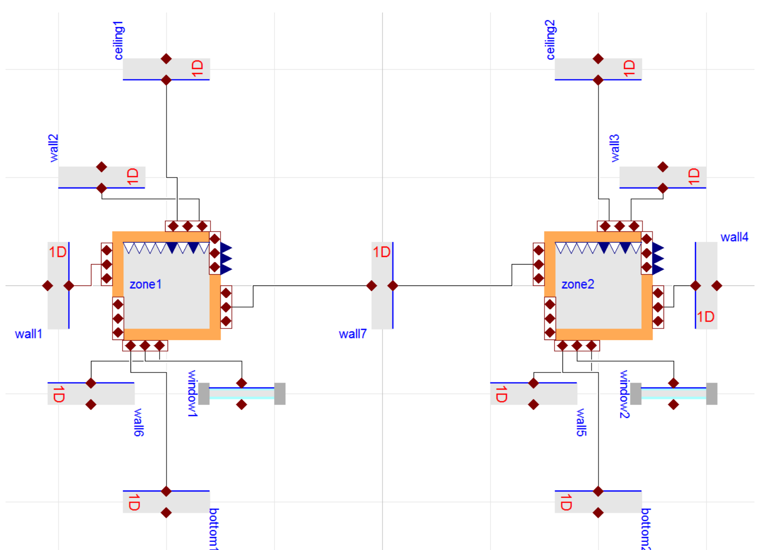


Figure 3.6: Building model with connected construction elements

Here each zone model offers you six different positions for connections to the construction elements (*toConstructionPorts1* to *toConstructionPorts6*) to enable a simplification of the graphical diagram.

In a further step connect the connectors of the other sides of all construction elements to the construction connector of the building model (*toConstructionPorts* on the left side).

Finally connect the input values of *T_setHeating* and *T_setCooling* (four connections) and the output values *Q_flow_heating* and *Q_flow_cooling* (again four connections) from the building model two both zone models. Now your topology of your building model is completely specified:

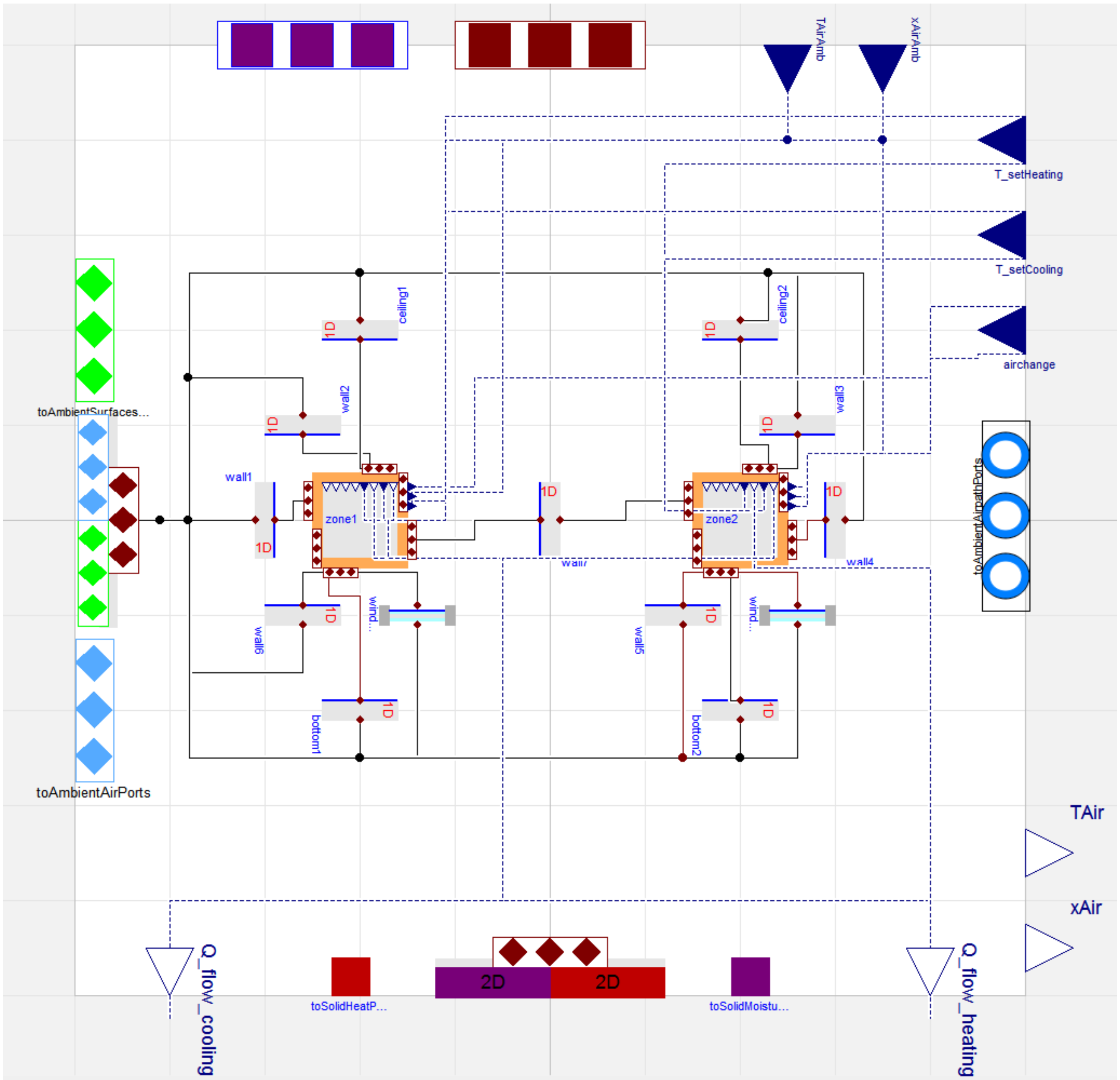


Figure 3.7: *Completed topology of the building model with two thermal zones*

3.2 Define the building model parameters

Now the building model has to be completed with parameters, which exactly describe the problem. The first type are geometrical parameters, e.g. the size of the construction elements or the volumes of the zones. The second type are physical parameters which define the building constructions (e.g. the heat conductivity or specific heat capacity of the used materials).

1. Geometrical parameters

   The THM has a strong simplified geometry. In our problem each thermal zone describe a half of the THM, which has in total an inner dimension of 1.0 m x 0.5 m x 0.5 m. So each opaque construction element (walls, bottoms and ceilings) has a height of 0.5 m and a width of 0.5 m. Double-click on each component and fill in these values in the *General tab* in the *Geometry* group.

   Both thermal zones have an air volume of 0.5 m x 0.5 m x 0.5 m = 0.125 m3. The height of the zone is 0.5 m. Fill in these values into the zone models *zone1* and *zone2*.

   Each of the windows of the THM has a width of 0.378 m and a height of 0.33 m, which leads to a window area of approx. 0.125 m2. The thickness of the window pane is 0.003 m. Assign these three values to both window models.

   Because *window1* is enclosed in *wall6* and *window2* in *wall5* the area of the window models has to be communicated from the window to the wall models. Double-click on *wall6* and fill in the Parameter field *nInnSur* 1 and in the field *AInnSur* using the *Edit Text* option

   ```
   aInnSur={window1.A)
   ```

   Do the same with *wall5* and *window2*.

   Finally add the parameter values for the orientation of each construction elements, which face to the ambient by setting the azimuth angle and the tilt angle. The default values for each construction element (walls and windows are 90.0 degree for the tilt angle and 0.0 degree for the azimuth angle. North is defined by an azimuth angle of 180 degree, east by -90 degree and west by + 90 degree:

element	angleAzi	angleTil	element	angleAzi	angleTil
wall1	90.0	90.0	bottom1	0.0	180.0
wall2	180.0	90.0	bottom2	0.0	180.0
wall3	180.0	90.0	ceiling1	0.0	0.0
wall4	-90.0	90.0	ceiling2	0.0	0.0
wall5	0.0	90.0	window1	0.0	90.0
wall6	0.0	90.0	window2	0.0	90.0
wall7	default	default			

2. Construction parameters

   All the opaque constructions elements except the partition *element wall7* share the same construction. For this reason a common construction type shall be configured, which will be later assigned to each individual construction.

   - Definition of a construction type

     Extend a child record from the general parent record for opaque constructions *BuildingSystems.Buildings.Data.Constructions.OpaqueThermalConstruction* and rename it to *Construc-*

tion1THM. Then include it in the package *ThermalModelHouse*.

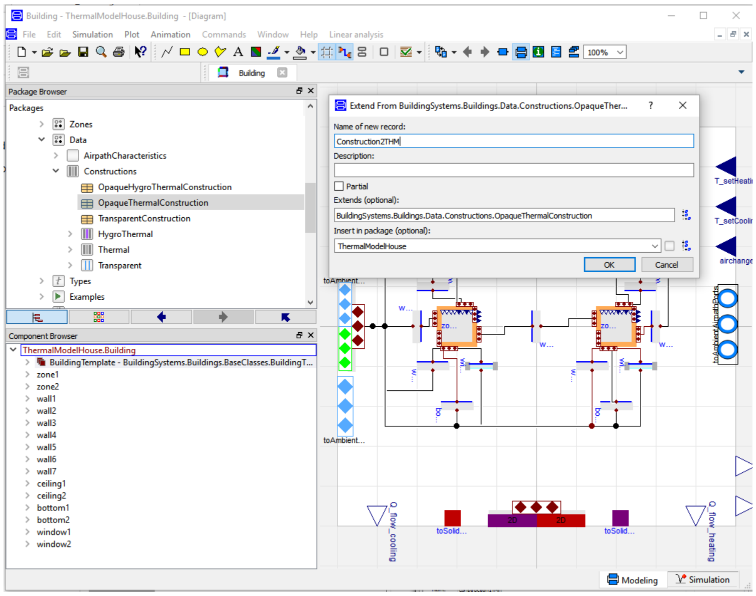


Figure 3.8: *Definition of a construction type based on template for opaque constructions*

The *Construction1THM* shall have three layers. The materials of the three layers are 0.006 m wood, 0.030 m insulation and again 0.009 m wood. The layer order is counted from inside (zone) to outside (building ambient). The BuildingSystems library contains in the package *BuildingSystems.HAM.Data.MaterialProperties* a database with pre-defined thermal and hygrothermal material property sets.

Double-click now on the construction type record *Construction1THM* left in the package browser and adapt the parameterization of the construction direct in the Modelica source code editor of Dymola with the help of the pre-defined materials:

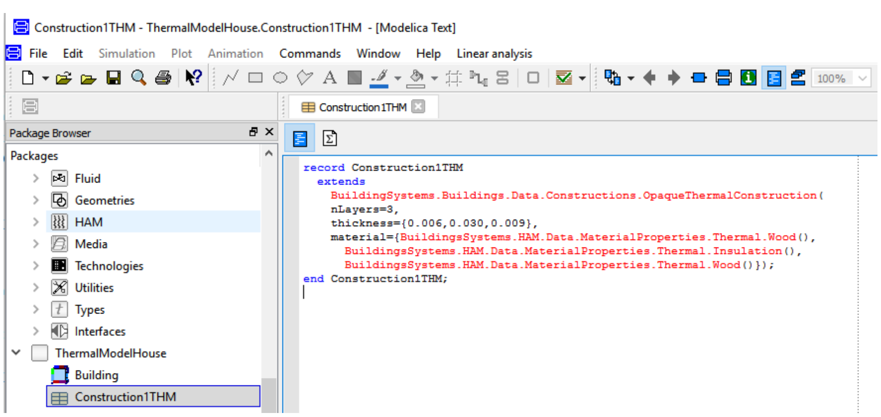


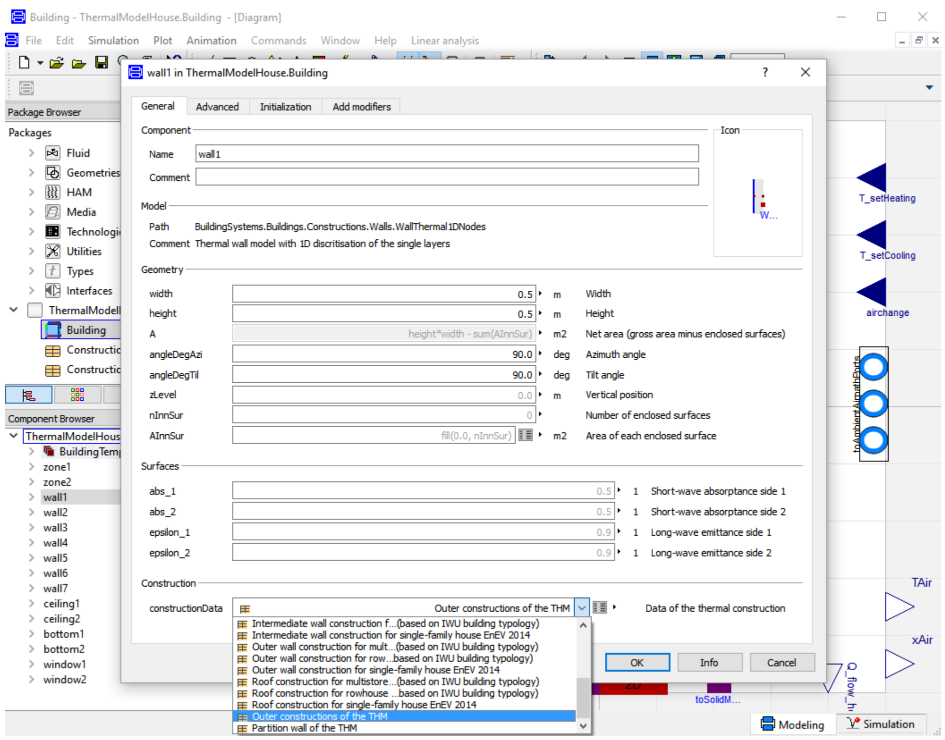
Figure 3.9: *Adapted record type of the first construction*

```
record Construction1THM
  "Outer constructions of the THM"
  extends BuildingSystems.Buildings.Data.Constructions.OpaqueThermalConstruction(
```

```
    nLayers=3,
    thickness={0.006,0.030,0.009},
    material={BuildingSystems.HAM.Data.MaterialProperties.Thermal.Wood(),
    BuildingSystems.HAM.Data.MaterialProperties.Thermal.Insulation(),
    BuildingSystems.HAM.Data.MaterialProperties.Thermal.Wood()});
end Construction1THM;
```

- Assignment of an construction type

  Now you can assign this common construction type to all the opaque construction elements by inserting component references using the component parameter dialog of Dymola:



  The generated code, for example for *wall1* shall look now like:

```
BuildingSystems.Buildings.Constructions.Walls.WallThermal1DNodes wall1(
  redeclare Construction1THM constructionData,
  width=0.5,
  height=0.5,
  angleDegAzi=90.0,
  angleDegTil=90.0);
```

- Create in the same manner for the partition wall a second *construction2THM*, which only consists in one layer of wood with a thickness of 0.009 m and assign it afterwards to *wall7*.

3.3 Configure the system model and set its boundary conditions

1. Create a new model with the name *SystemModel* and insert it into the package *ThermalModelHouse*.

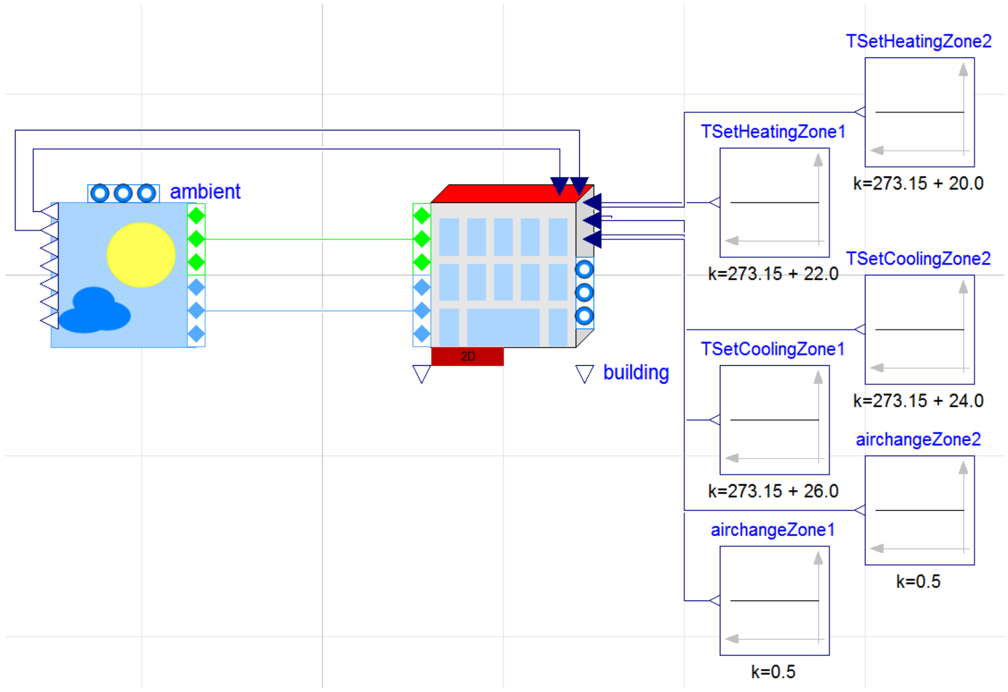


Figure 3.10: *System model of the THM*

2. Instantiate the previous defined building model within the system model and rename it to *building*.

3. Instantiate an ambient model *BuildingSystems.Buildings.Ambient* within the system model and set the climate data (parameter weatherDataFile) to *WeatherDataFile_USA_SanFrancisco*.

4. Assign the parameter *nSurfaces* of the ambient model to the number of surfaces of the building, which are in contact with the building environment:

```
nSurfaces={building.nSurfacesAmbient}
```

5. Connect the ambient model and the building model regarding to their blue interfaces (boundary conditions of the facade surfaces to the air) and their green interfaces (boundary conditions of the facade surfaces to the solar irradiation and other enclosing surfaces)

6. Connect the output variable *ambient.TAirRef* and the input variable *building.TAirAmb* (ambient temperature at a reference height of 10 m) and also *ambient.xAirRef* and *building.xAirAmb* (ambient absolute moisture).

7. Add six constant sources of the type *Modelica.Blocks.Sources.Constant* for the definition of the set temperatures for heating and cooling as well as the air change for both thermal zones:

```
..
Modelica.Blocks.Sources.Constant TSetHeatingZone1(k=273.15 + 22.0);
Modelica.Blocks.Sources.Constant TSetCoolingZone2(k=273.15 + 20.0);
Modelica.Blocks.Sources.Constant TSetHeatingZone1(k=273.15 + 26.0);
Modelica.Blocks.Sources.Constant TSetCoolingZone2(k=273.15 + 24.0);
Modelica.Blocks.Sources.Constant airchangeZone1(k=0.5);
Modelica.Blocks.Sources.Constant airchangeZone2(k=0.5);
```

and connect them to the input signals of the building model.

Caused by this definition of the set temperatures *zone1* will have a higher temperature level than *zone2* during the simulation experiment.

3.4 Simulate the system model

- Perform a simulation with the system model over 10 days (start time = 0.0 s end time = 60 s/h x 24 h/d * 10 d = 864000 s).

  The following diagrams illustrate selected results of the simulation experiment:

  1. The yearly air temperature for *zone1* and *zone2* and the outside air temperature (1st to 3rd line).
  2. The corresponding ideal heating and cooling load for zone 1 (4th and 5th line).
  3. The corresponding ideal heating and cooling load for zone 2 (6th and 7th line).
  4. The heat flow by heat transmittance through both surfaces of *wall7* between both zones (8th and 9th line).

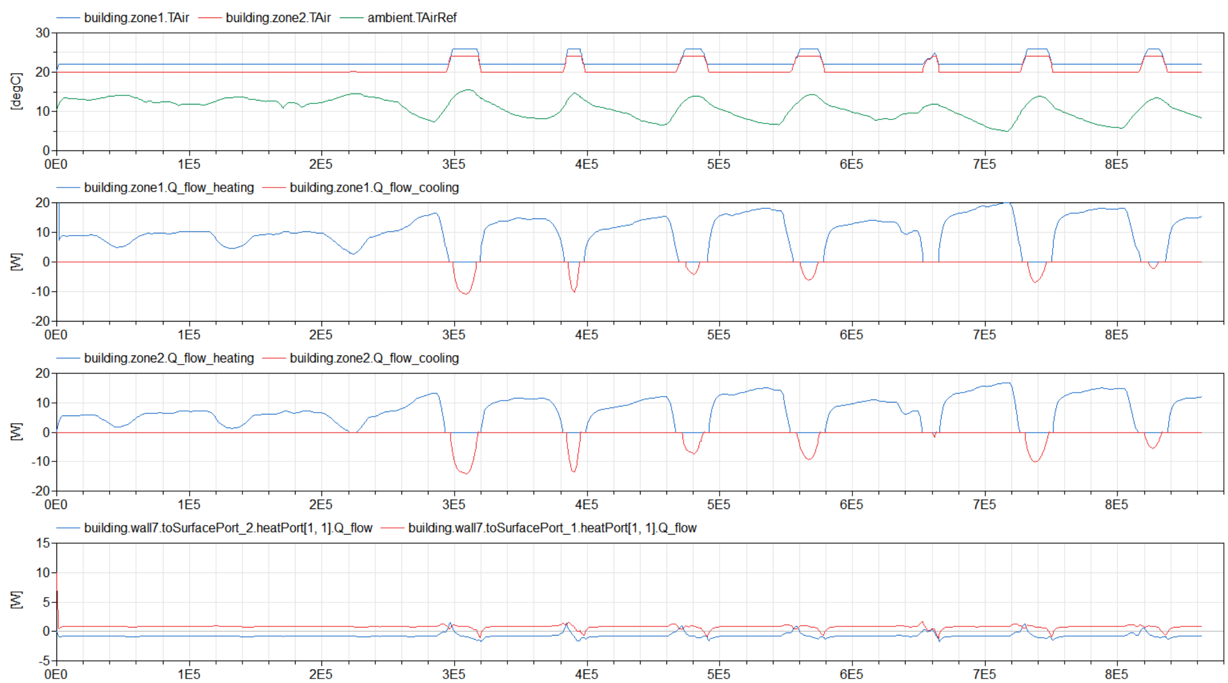


Figure 3.11: *Simulation results of both the THM over 10 days, location San Francisco (USA)*

CHAPTER FOUR

REFERENCES

[1] Christoph Nytsch-Geusen, Jörg Huber, Manuel Ljubijankic, and Jörg Rädler. Modelica buildingsystems - eine modellbibliothek zur simulation komplexer energietechnischer gebäudessysteme. In *BAUSIM 2012*. 2012.

[2] Christoph Nytsch-Geusen, Katharina Mucha, Alexander Inderfurth, and Jörg Rädler. Entwicklung eines räumlich und physikalisch adaptiven energetischen gebäudemodells in modelica. In *BAUSIM 2014*. 2014.