A Modelica library and Scenarios for Thermal and Electric Solar Energy and Storage for Cities and Buildings

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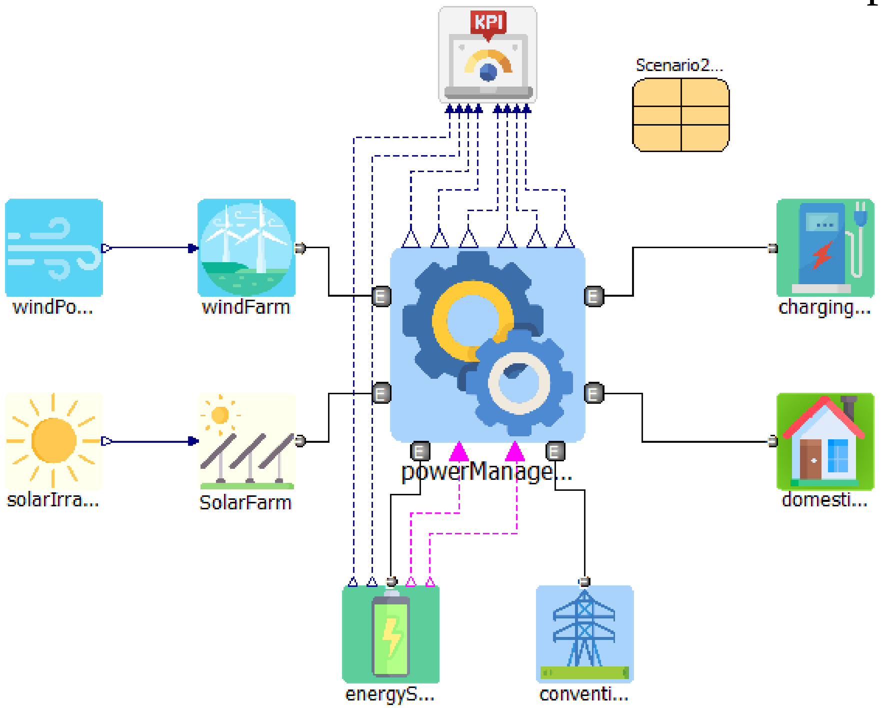
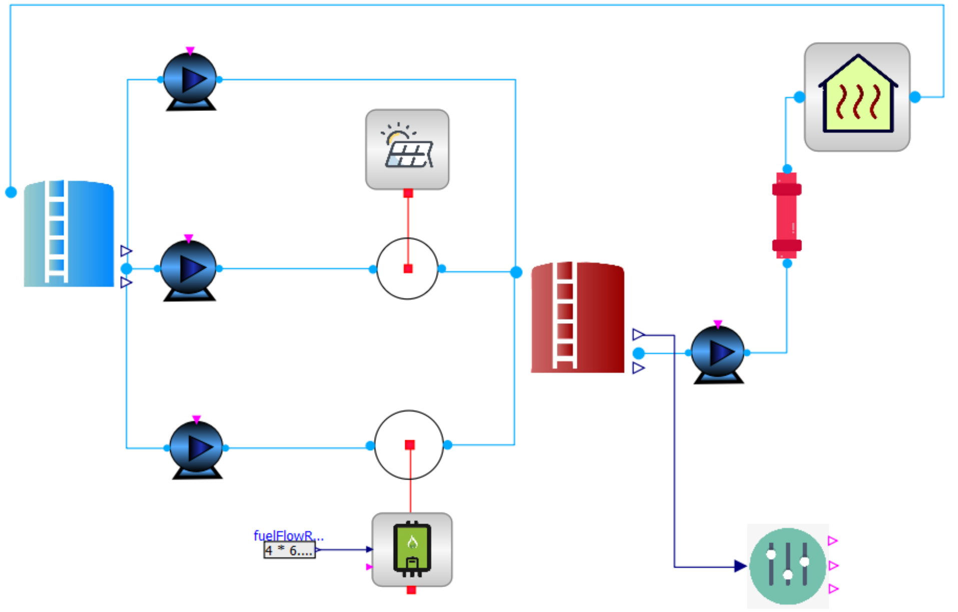
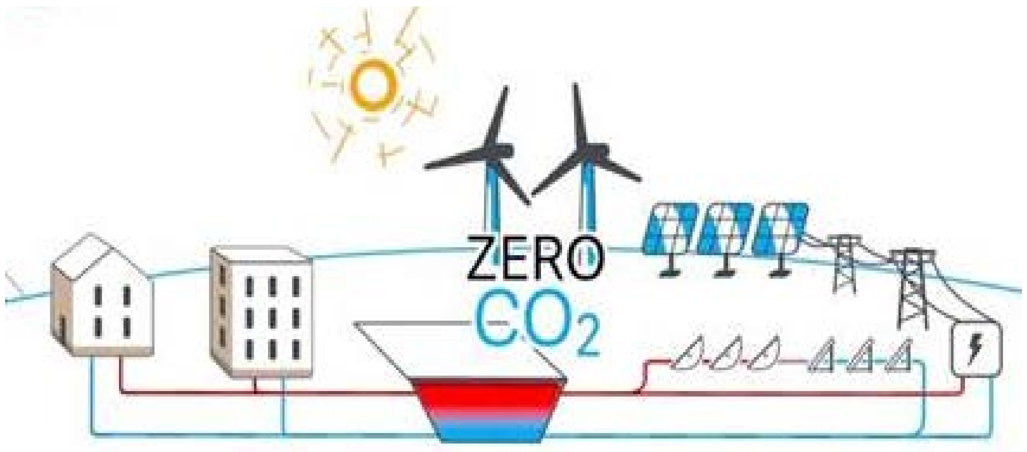
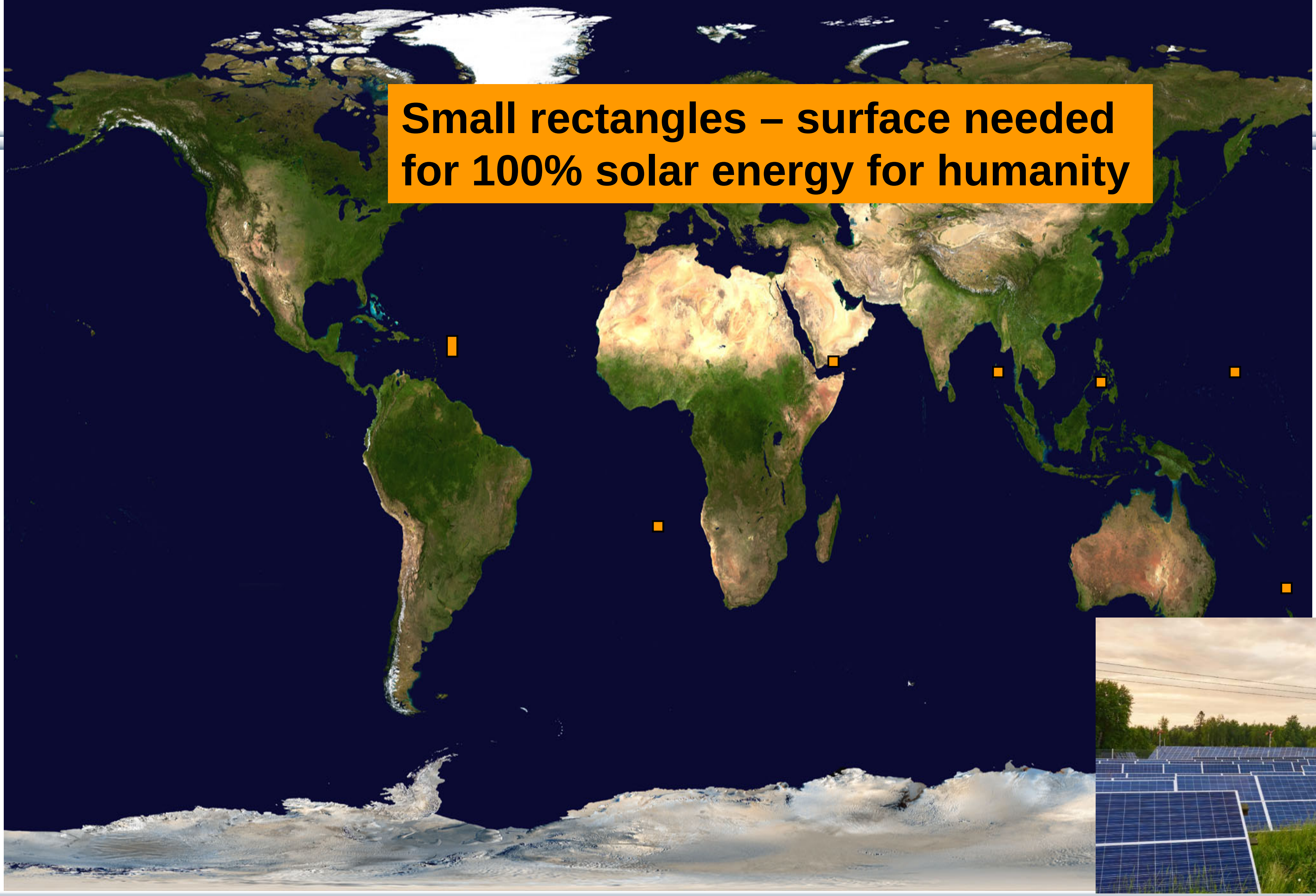




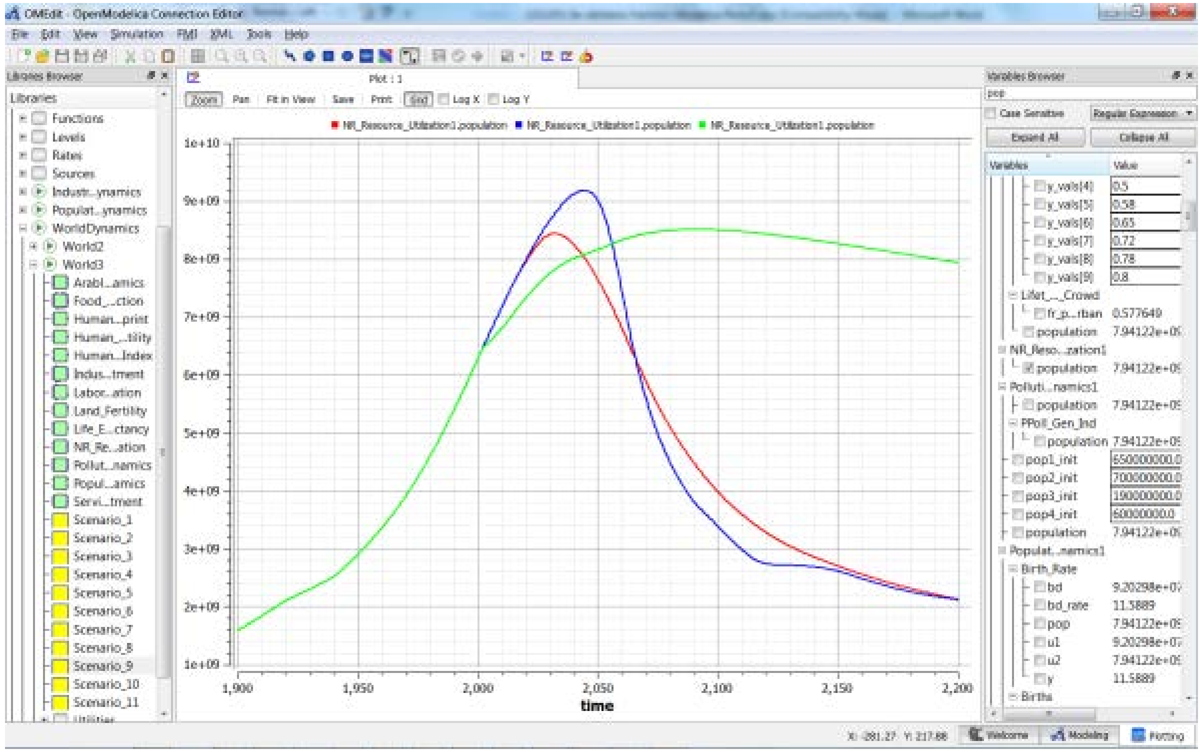
Goals for the Thermal and Electric Energy Library and Scenarios

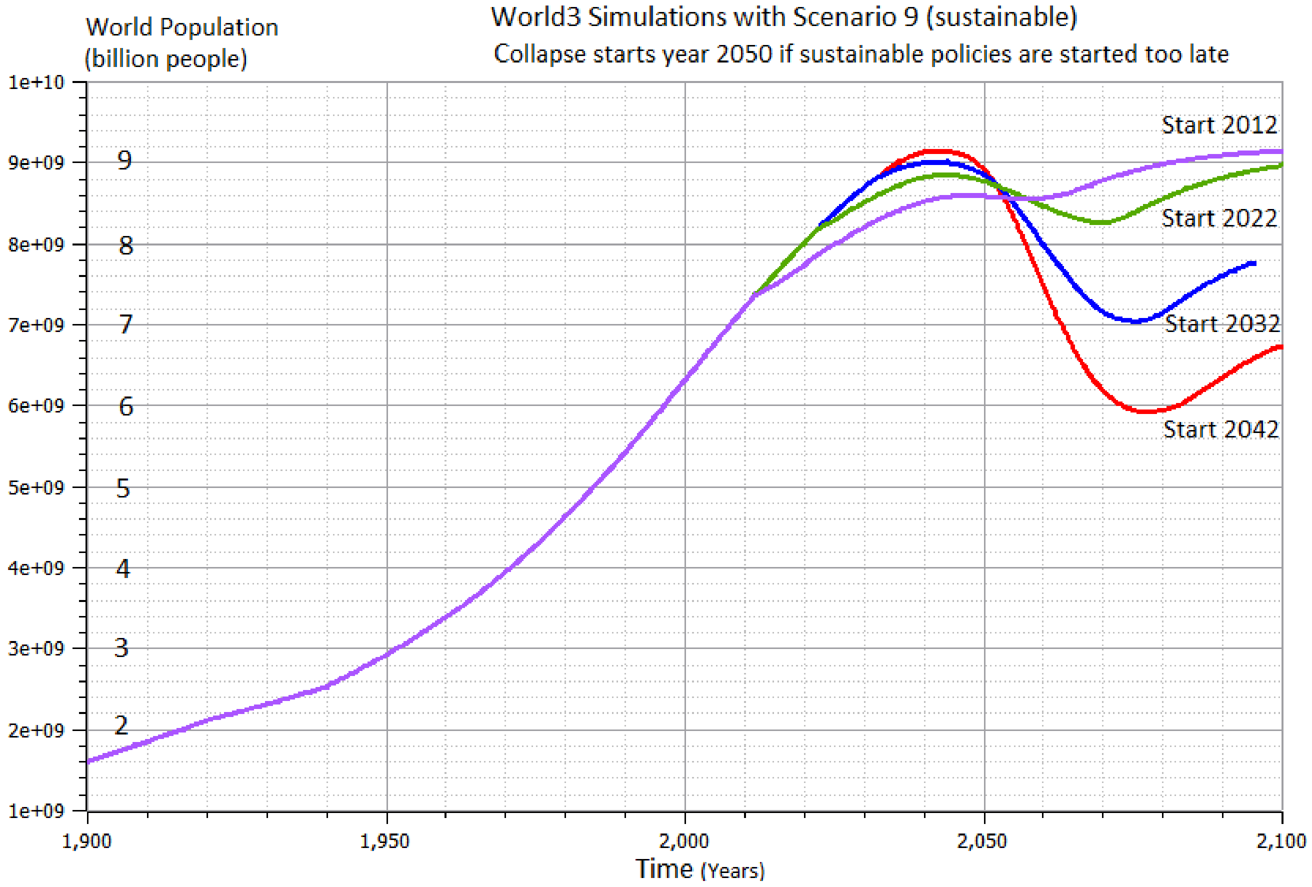
- Develop an **easy-to-understand low-to-medium** complexity library
- Easily **extensible** to include more model details
- Both **electric** and **thermal** solar energy
- Including a simple **wind** energy model
- Thermal and electric energy **storage**
- Electric vehicle charging models
- Simple **controller** models




Small rectangles – surface needed for 100% solar energy for humanity

World3 Simulations with Different Start Years for Sustainable Policies – Collapse if starting too late





Left. System Dynamics World3 simulation with OpenModelica. World population. (ref Meadows et al)

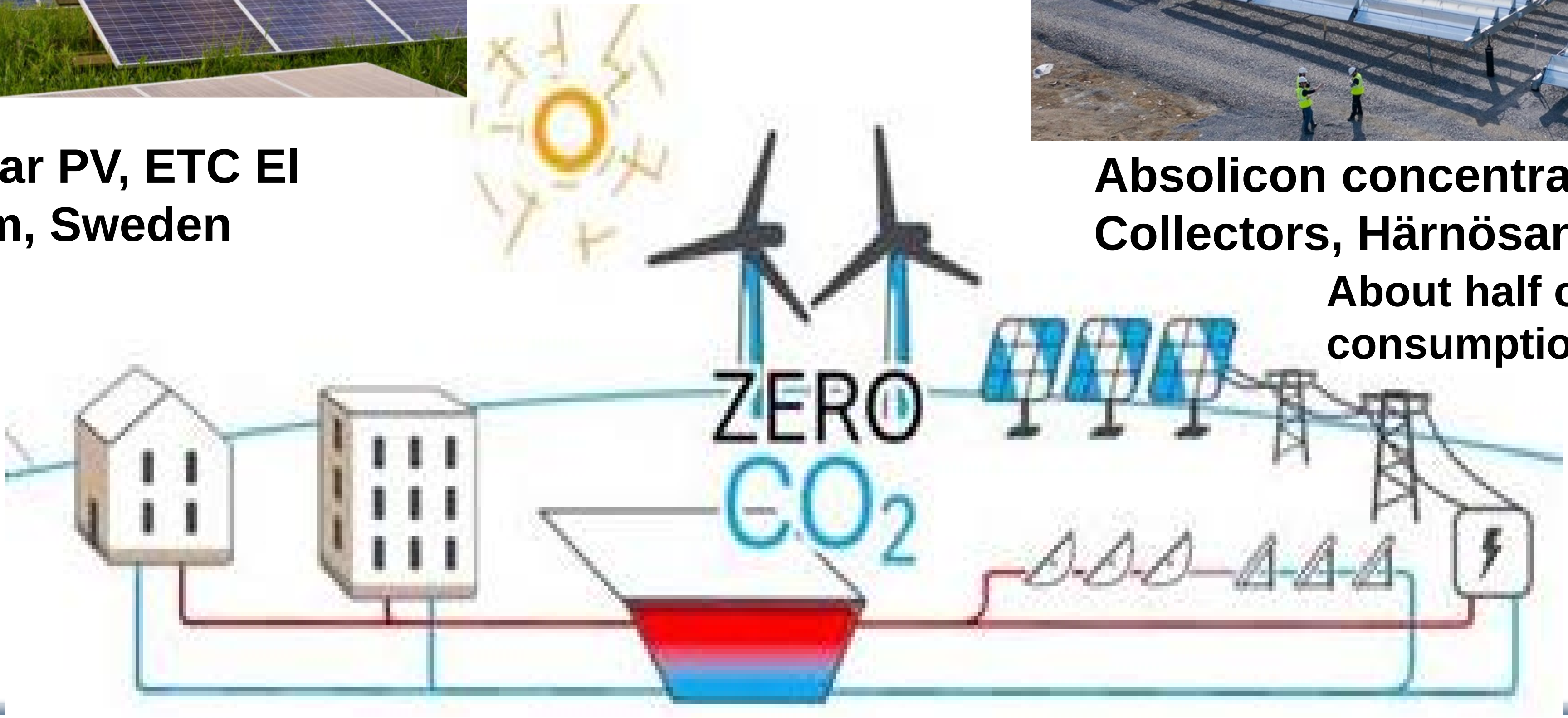
- 2 collapse scenarios (close to current developments)
- 1 sustainable scenario (green).

Sustainable Renewable Energy System
Solar Electric PV, Solar Thermal, Wind, and Storage

Electric solar PV, ETC El Katrineholm, Sweden

Absolicon concentrated solar thermal Collectors, Härnösand, Sweden

About half of global energy consumption is thermal energy



Large-scale Annual Storage of Solar Thermal Energy from Summer to Winter – Danish city Dronninglund

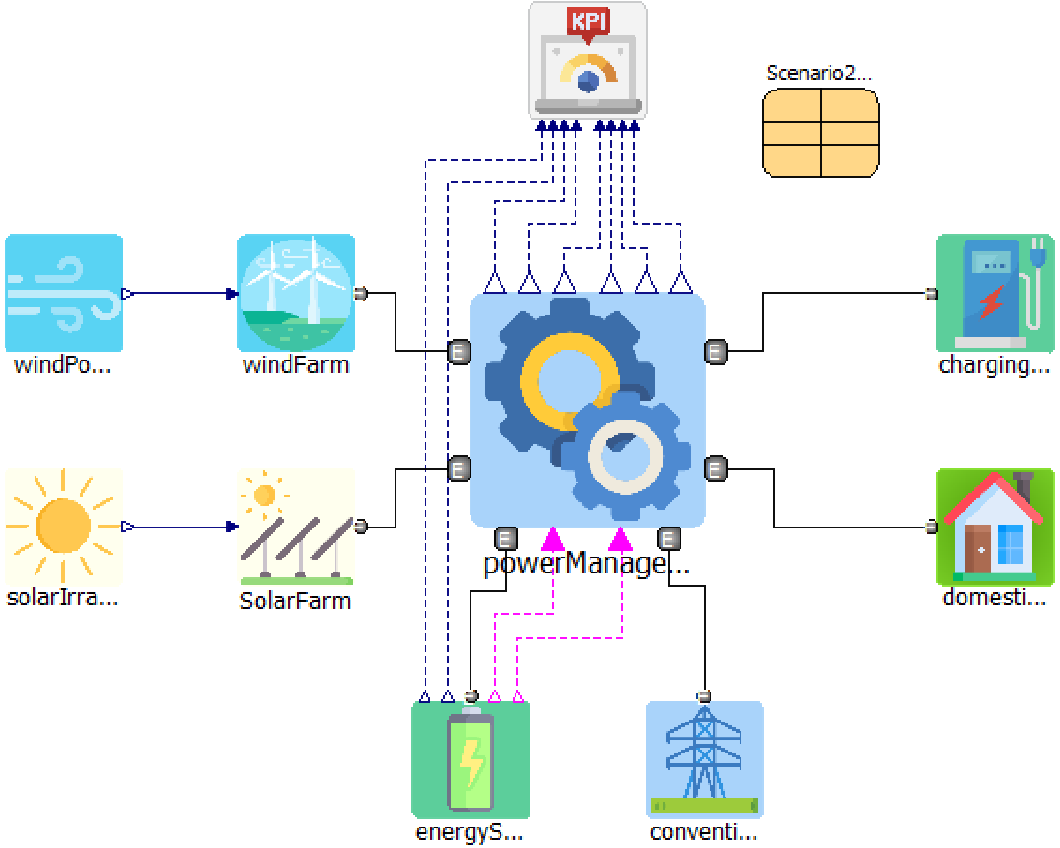
Field with 26 MW (37 500 m2) Thermal solar collectors

Heat storage 60 000 m3 hot water with insulating cover

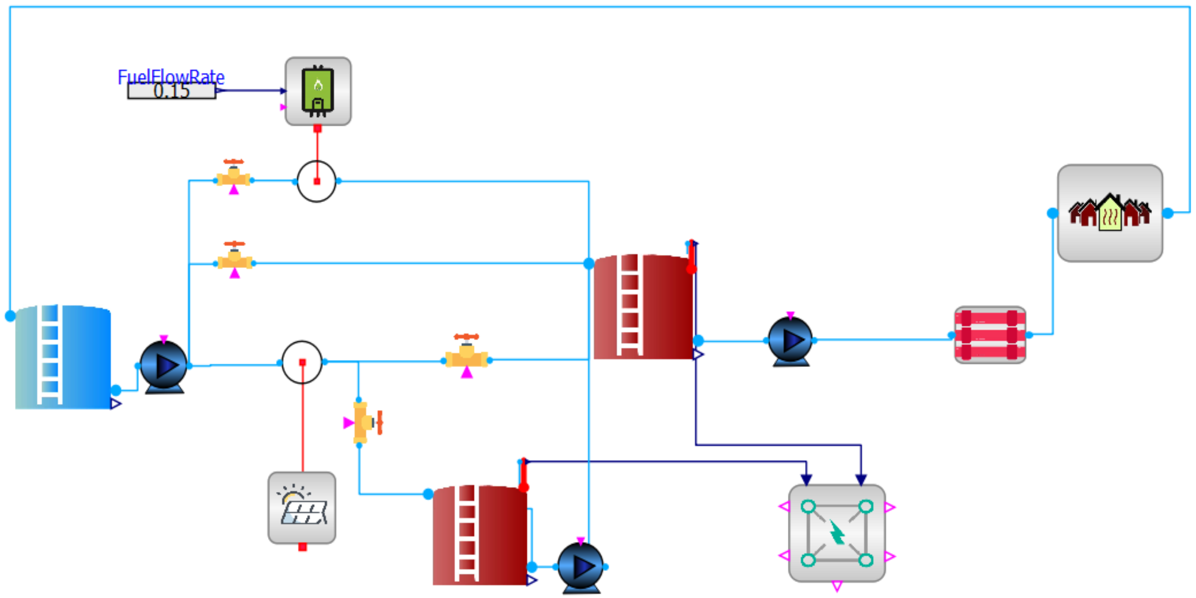
The Danish city Dronninglund 2013 built a solar collector field and a seasonal storage that together covers 50% of the citys heat needs

Modelica Library Thermal and Electric Solar Energy
Two small example models

Electric grid model, group of houses
Solar PV, wind power, car charging, etc.

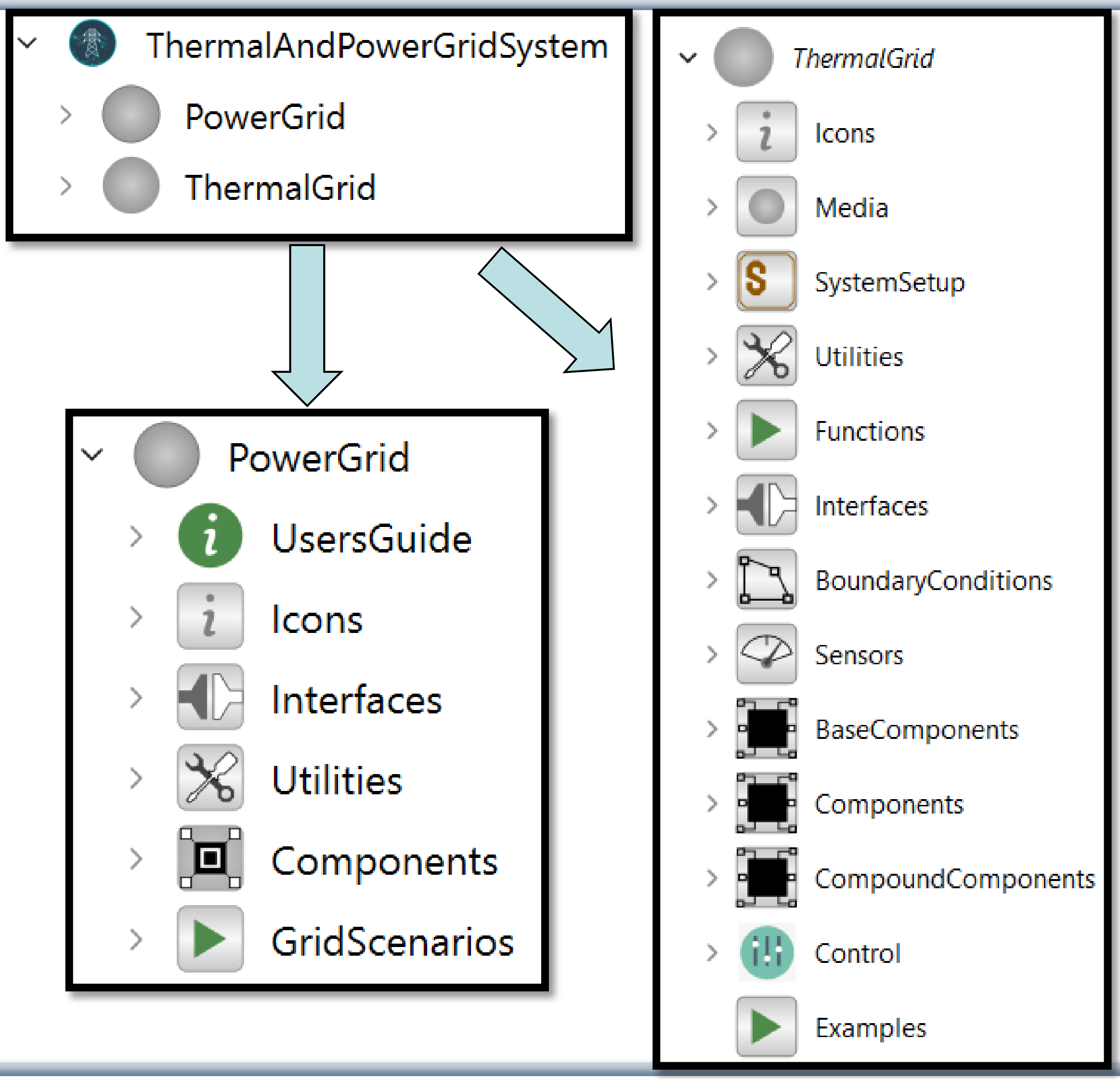


Part of **solar thermal model with storage**
For **small residential** community



Library Overview –
Two parts: Electric Power Grid and Thermal Grid

- The Library contains two main packages, *Power Grid* and *Thermal Grid*. These may be used to simulate interconnected networks of electric as well as district heating systems from generation, distribution to consumption.
- The complexity of the sub-models are low-medium and examples of annual simulations are focussed on.



Simulation of the Library Examples

- **Electric Grid:**

  - Four predefined scenarios are available under "GridScenarios".
  - Parameters may be varied by double clicking on the "*SystemParameters*" record.

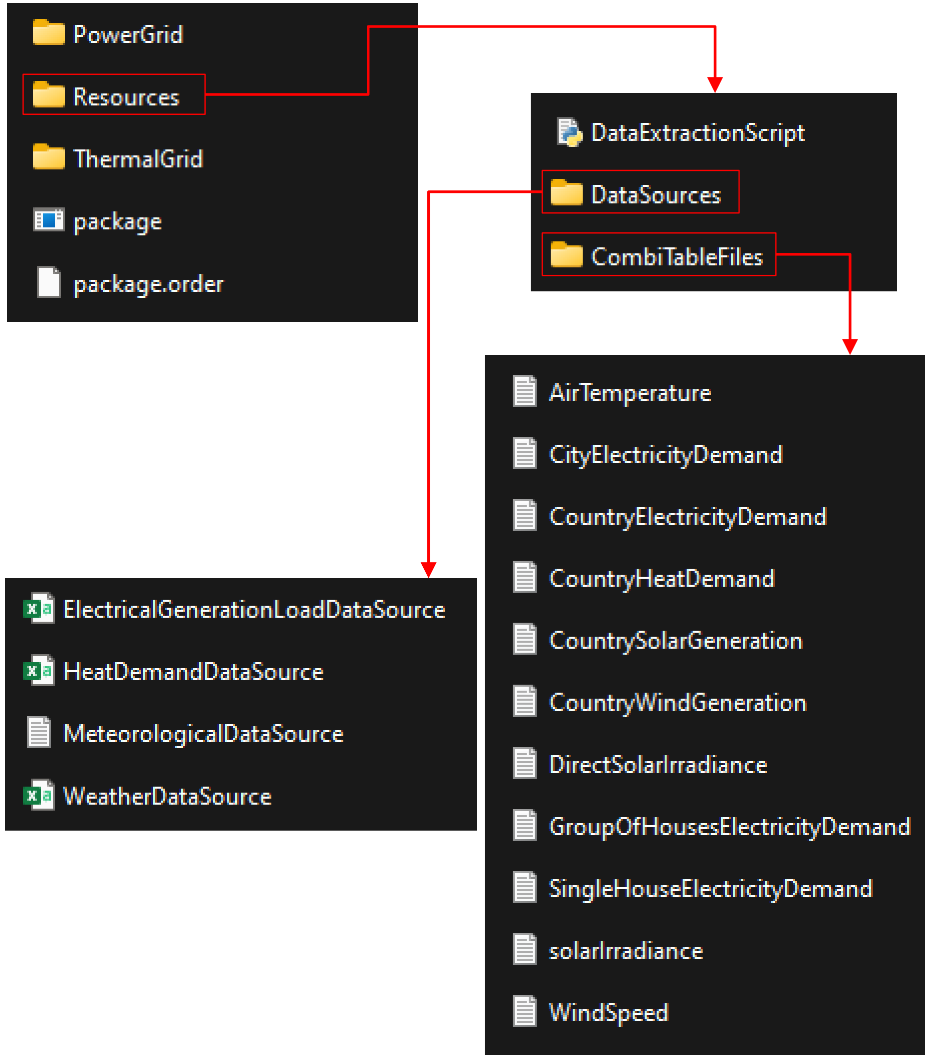
- **Thermal Grid:**

  - *Simulation Scenarios* and other examples under Test Examples.

  - Each scenario has three models. The scenario and the control are decoupled into two models. A third model connects the scenario and its control. This is the model which is to be simulated.

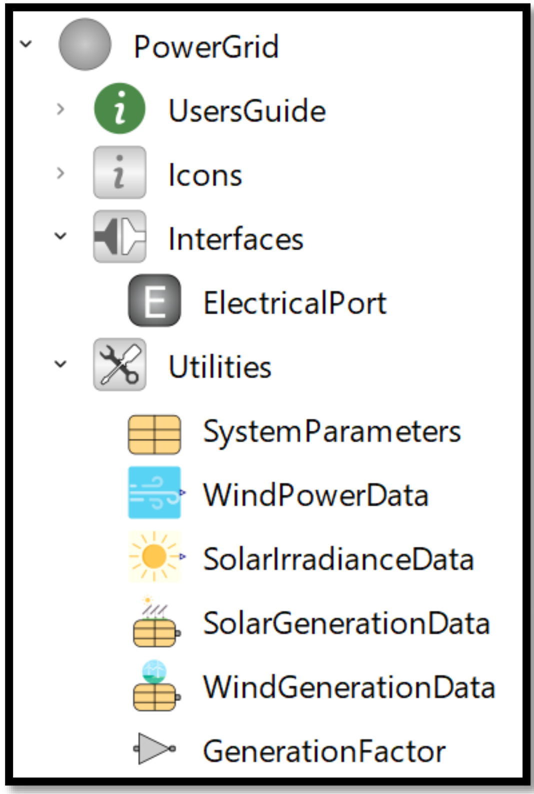
  - The parameters for each scenario may be changed by double clicking on individual components.

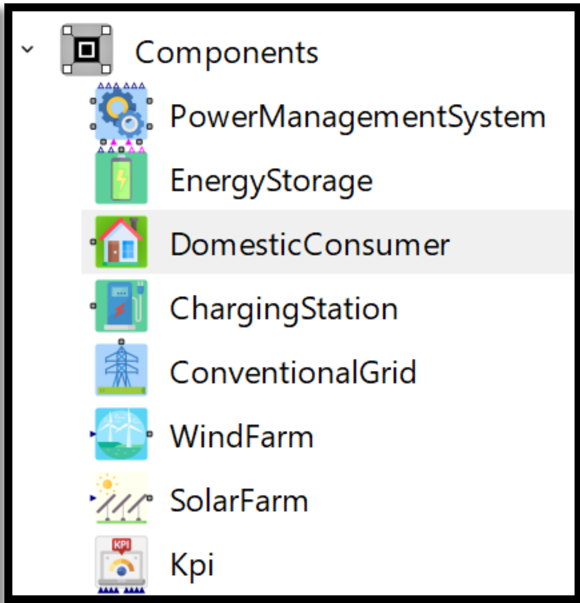
  - To input different hourly solar data, run the python file *"DataExtractionScript.py"* under Resources folder of the main package. This will generate the corresponding combi-table *.txt* file in the "CombiTableFiles" folder, all the data source files are kept in the "DataSources" folder.

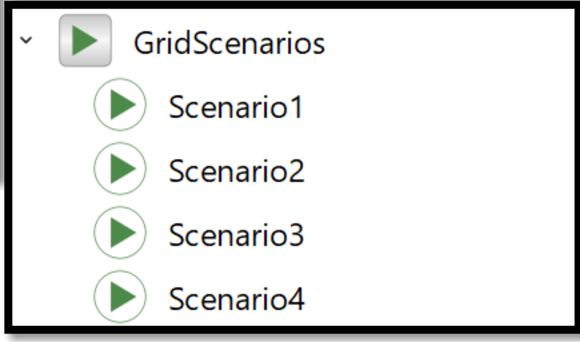


Electric Power Grid Sub library

- **Interfaces:** This sub package contains the port used in the library.
  - Electrical Port
- **Utilities:** This sub package contains the grid parameters and data related modules.
  - System Parameters
  - Wind Power Data
  - Solar Irradiance Data
  - Solar Generation Data
  - Wind Generation Data

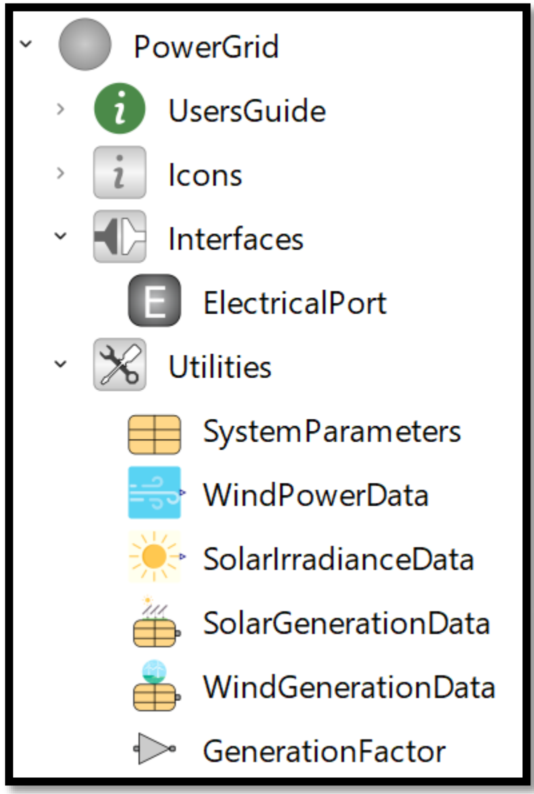


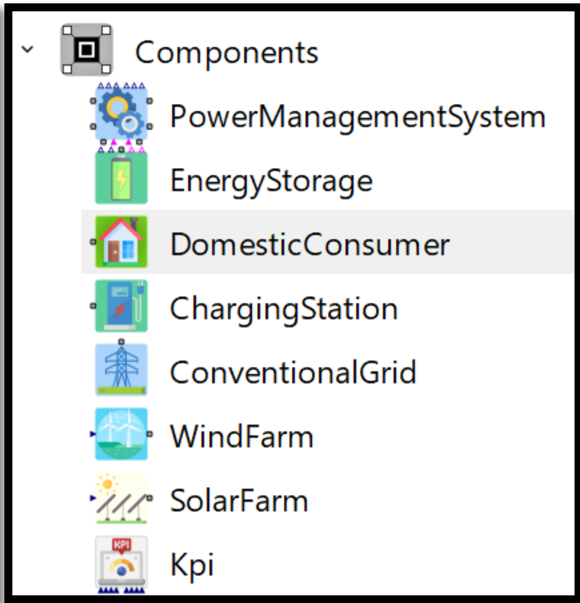


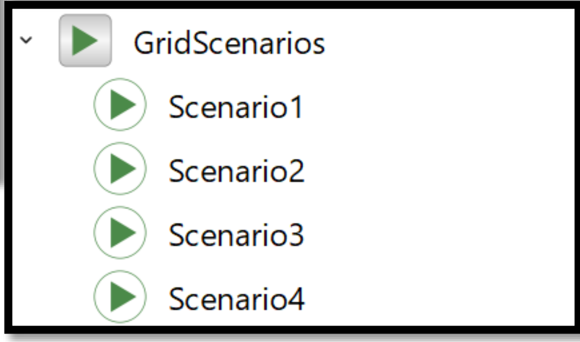


Power Grid Library

- **Components:** This sub package contains the grid component modules
  - Solar Farm
  - Wind Farm
  - Power Management System
  - Energy Storage
  - Conventional Grid
  - Domestic Consumer
  - Charging Station
  - KPI
- **Grid Scenarios:** This sub package contains the library grid scenario examples.
  - Scenario-1 : **Single house** grid scenario
  - Scenario-2 : **Group of houses** grid scenario (~200 Houses)
  - Scenario-3 : **City grid** scenario (~75000 Houses)
  - Scenario-4 : **Country grid** scenario

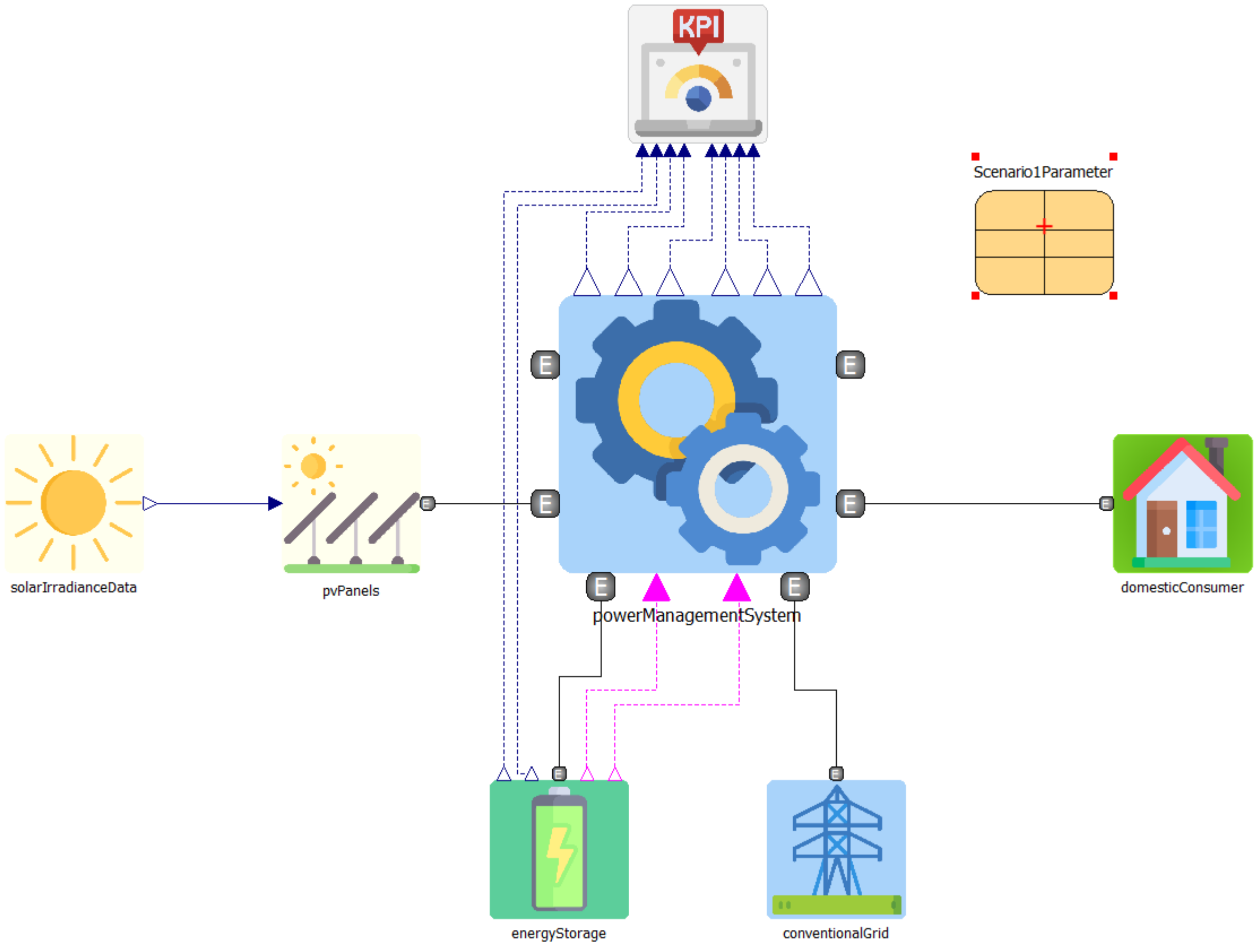






Electric Grid Scenarios: Scenario-1 – Single House

Single House Grid Scenario



Parameters:

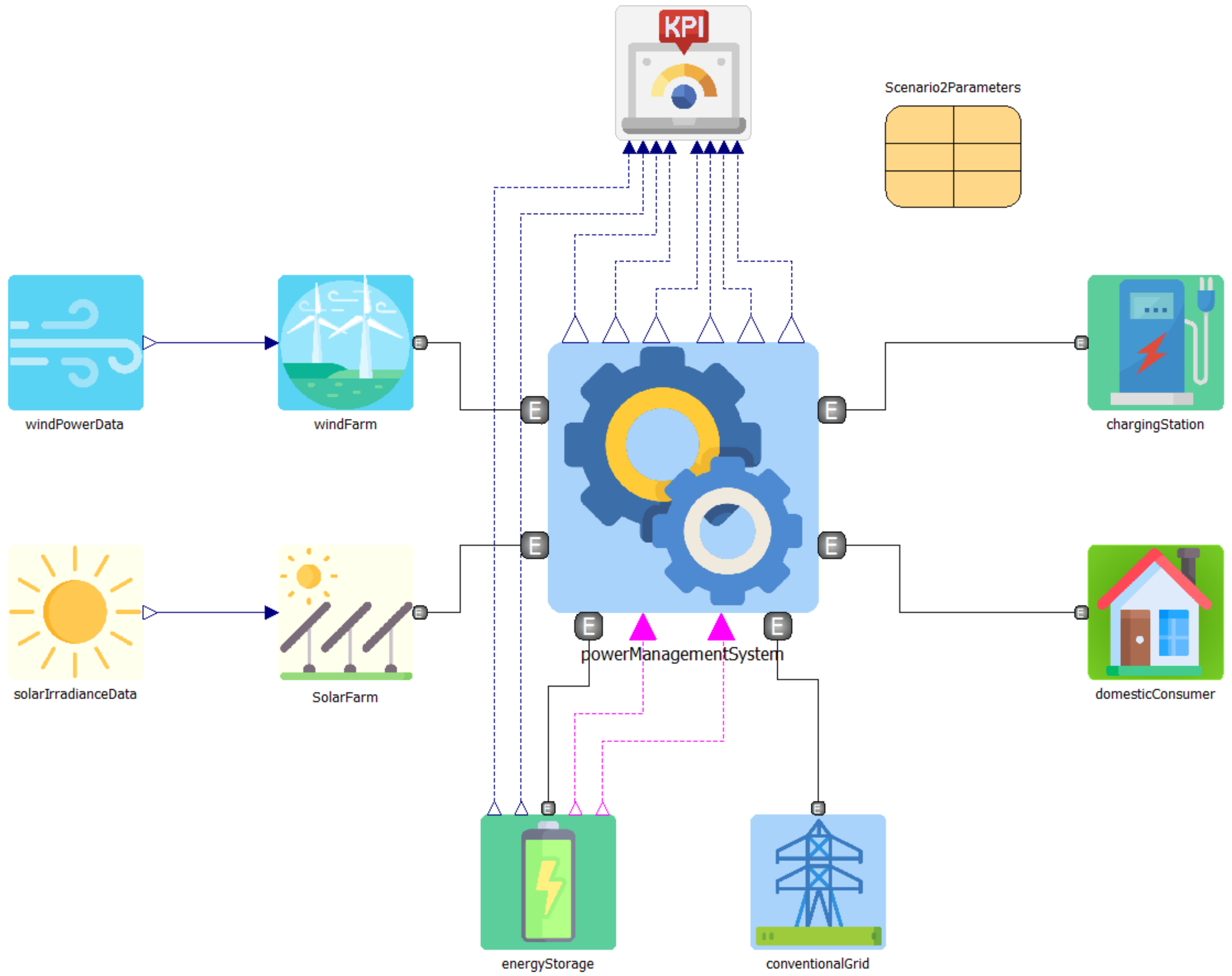
- Number of PV panels : 12
- Surface Area of each panel : 2m^2
- PV generation efficiency : 20%
- Energy storage capacity : 5 kWh
- Energy storage Max power limit : 1 kW
- Domestic Load : Single House

Simulation Results (Annual):

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
3.74 MWh	6.52 MWh	0.67 MWh	9.59 MWh

Electric Grid Scenarios: Scenario-2 – Group of Houses

Group of Houses Grid Scenario (~200 Houses)



Parameters:

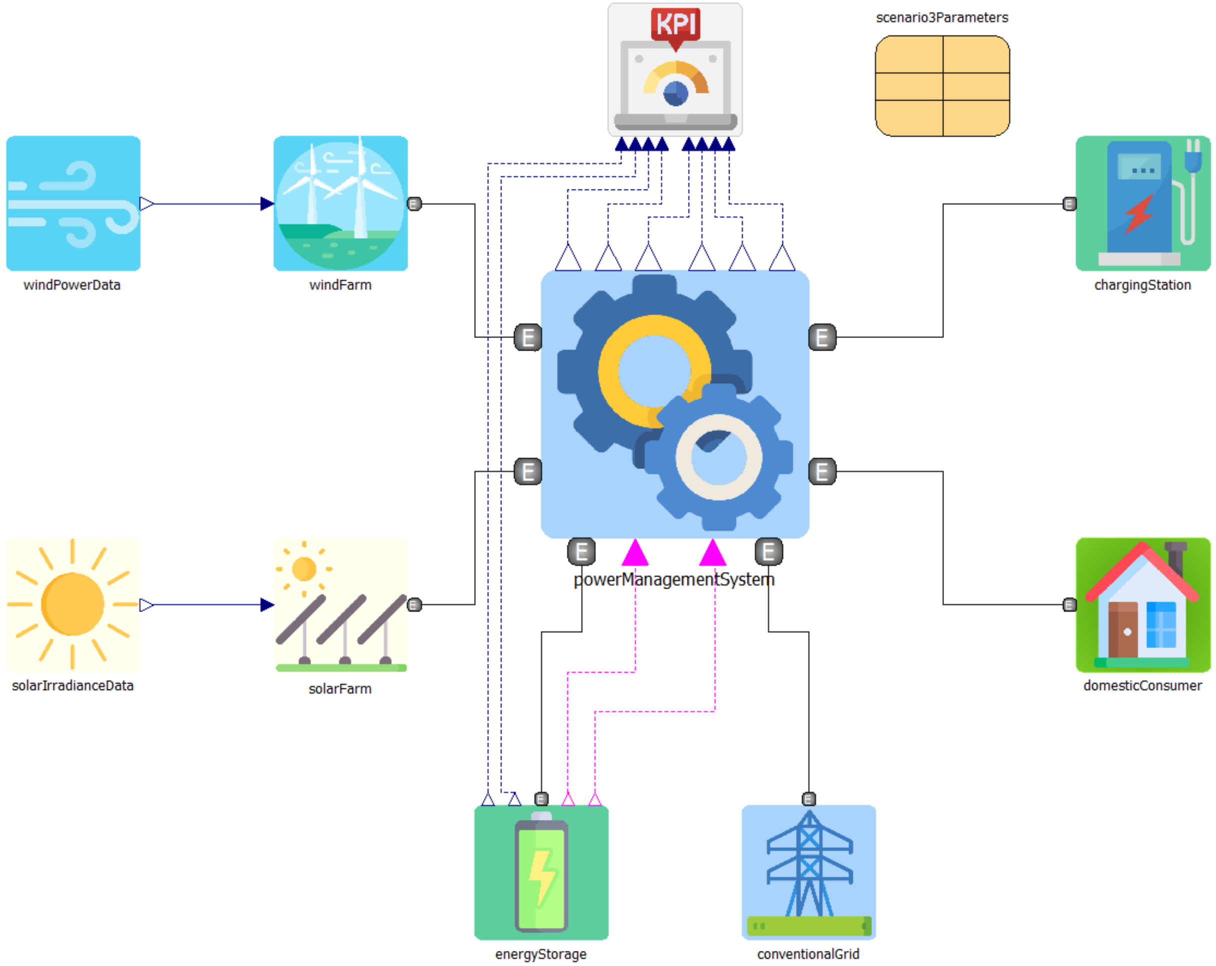
- Number of PV panels : 1000
- Surface Area of each panel : $2m^2$
- PV power generation efficiency : 20%
- Wind turbine rotor radius : 30m
- Number of turbines : 3
- Wind power generation efficiency : 80%
- Wind power generation limit: 2MW
- Energy storage capacity : 5 MWh
- Energy storage Max power limit : 0.5 MW
- Domestic Load : ~200 Houses
- Charging Stations : 4 No.(80 Bikes, 48 Cars)

Simulation Results (Annual):

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
6.98 GWh	1.04 GWh	1.56 GWh	6.46 GWh

Electric Grid Scenarios: Scenario-3 – Medium-sized City

City Grid Scenario (~75000 Houses)



Parameters:

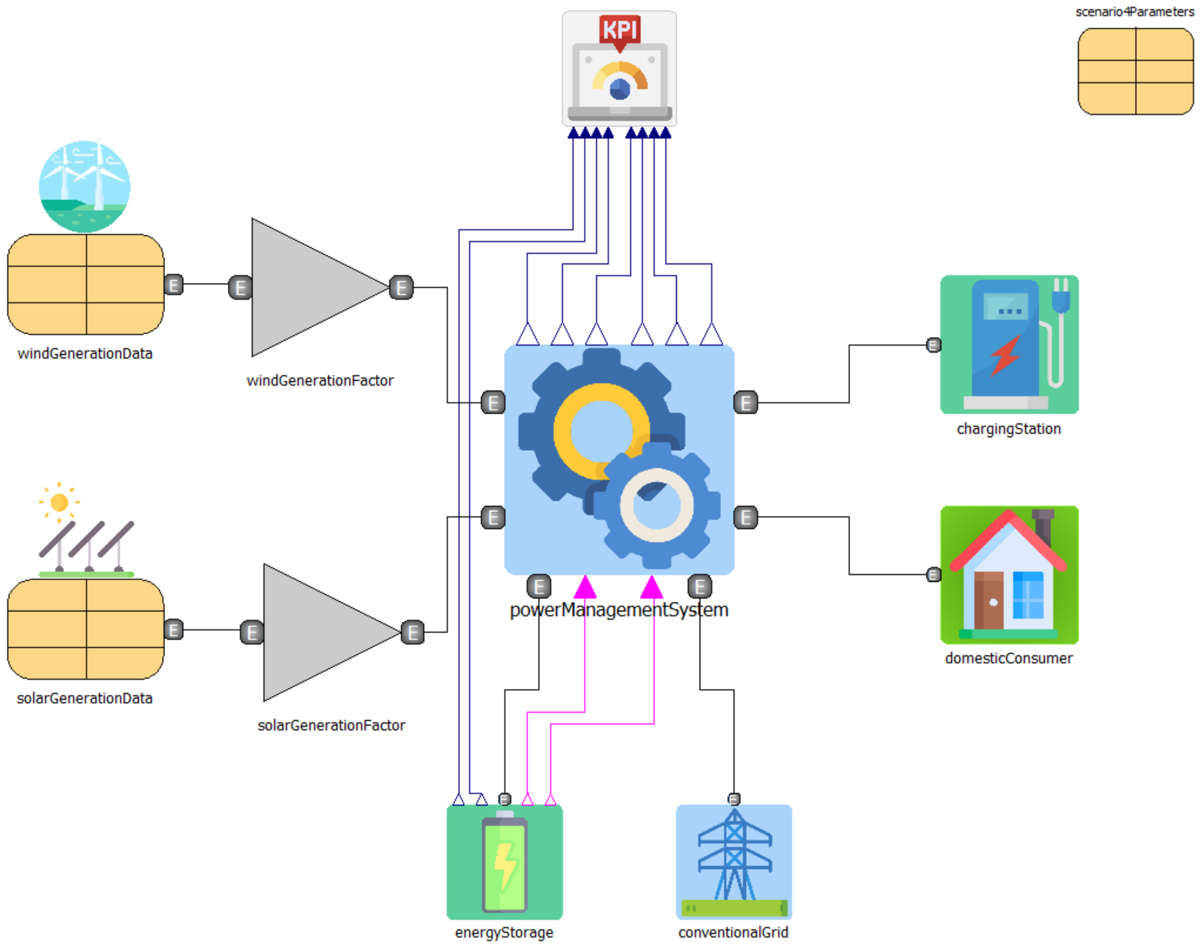
- Number of PV panels : 200000
- Surface Area of each panel : 2m^2
- PV power generation efficiency : 20%
- Wind turbine rotor radius : 30m
- Number of turbines : 600
- Wind power generation efficiency : 80%
- Wind power generation limit: 350MW
- Energy storage capacity : 900 MWh
- Energy storage Max power limit : 50 MW
- Domestic Load : ~75000 Houses
- Charging Stations : 200 No.(4000 Bikes, 2400 Cars)

Simulation Results (Annual):

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
1332.96 GWh	85.23 GWh	567.27 GWh	850.21 GWh

Electric Grid Scenarios: Scenario-4 – Whole Country (Actual)

Country grid Scenario (Netherland, Year: 2016)



Parameters:

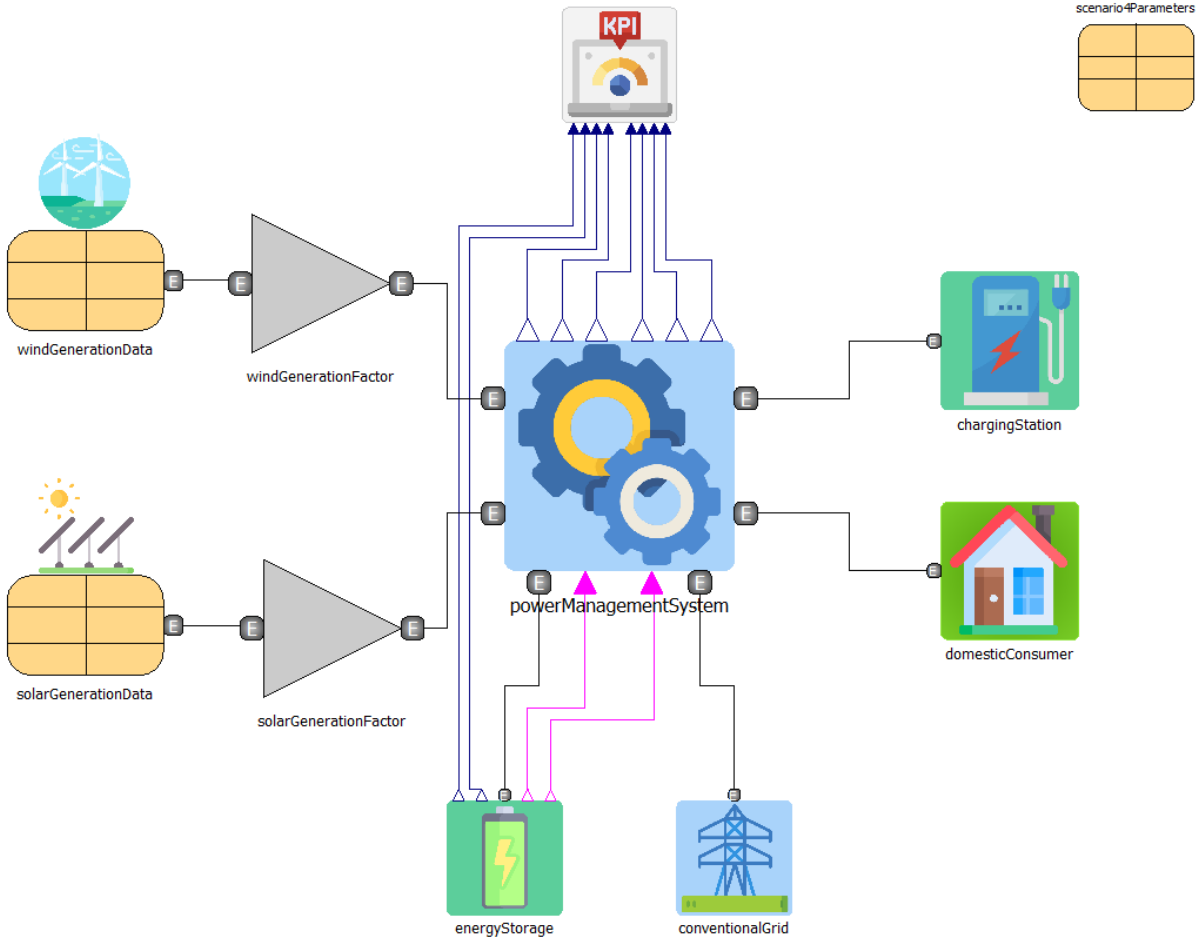
- Solar Generation : Country solar generation power
- Wind Generation : Country wind generation power
- Solar generation factor: 1
- Wind generation factor: 1
- Energy storage capacity : 500 MWh
- Energy storage Max power limit : 500 MW
- Domestic Load : Country demand power
- Charging Stations : 20000 No.(400000 Bikes, 240000 Cars)

Simulation Results (Annual):

Total Renewable Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid & Storage	Total Energy Demand
8.9 TWh	130.57 TWh	0 TWh	139.47 TWh

Electric Grid Scenarios: Scenario-4 – Whole Country (Projected)

Country grid Scenario (Netherland, Year: 2016)



Parameters:

- Solar Generation : Country solar generation power
- Wind Generation : Country wind generation power
- Solar generation factor: 10
- Wind generation factor: 10
- Energy storage capacity : 500 MWh
- Energy storage Max power limit : 500 MW
- Domestic Load : Country demand power
- Charging Stations : 20000 No.(400000 Bikes, 240000 Cars)

Simulation Results (Annual):

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
89 TWh	61.3 TWh	10.8 TWh	139.5 TWh

Interface: Electrical Port

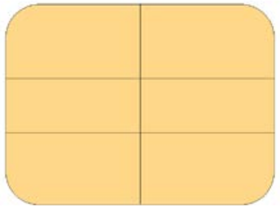
- Grid power transfer connector called as *“Electrical Port”*.
- The port has two variables,
  - *“Power”* a flow variable
  - *“Voltage”* a potential variable (dummy variable)
- Power flowing inward to the port is considered as positive
- Power flowing outward to the port is considered as negative

Utility: System Parameters

- A record file containing all the parameters required for each library component
- This record file can be dragged on to each library example and corresponding component parameter values can be entered.
- The parameters in this record is shown in the following figure.
- Additionally, it also contains the data file links corresponding to the wind speed profile, solar radiation profile data, solar generation data, wind generation data and domestic demand profile data.

Parameters	
Air density	Energy storage capacity
Wind speed data file	Max allowable charge %
Turbine rotor radius	Min allowable charge %
Turbine generation efficiency	T&D efficiency
Number of turbines	Voltage
Wind farm rated power	Energy storage rated power
PV panel tilt angle	EV car charging capacity
Solar irradiance data file	EV bike charging capacity
PV generation efficiency	EV car charging rated power
PV panel surface area	EV bike charging rated power
Number of PV panels	Max number of cars per station
Solar generation data file	Max number of bikes per station
Solar generation factor	Number of charging stations
Wind generation data file	EV car charging duration
Wind generation factor	EV bike charging duration

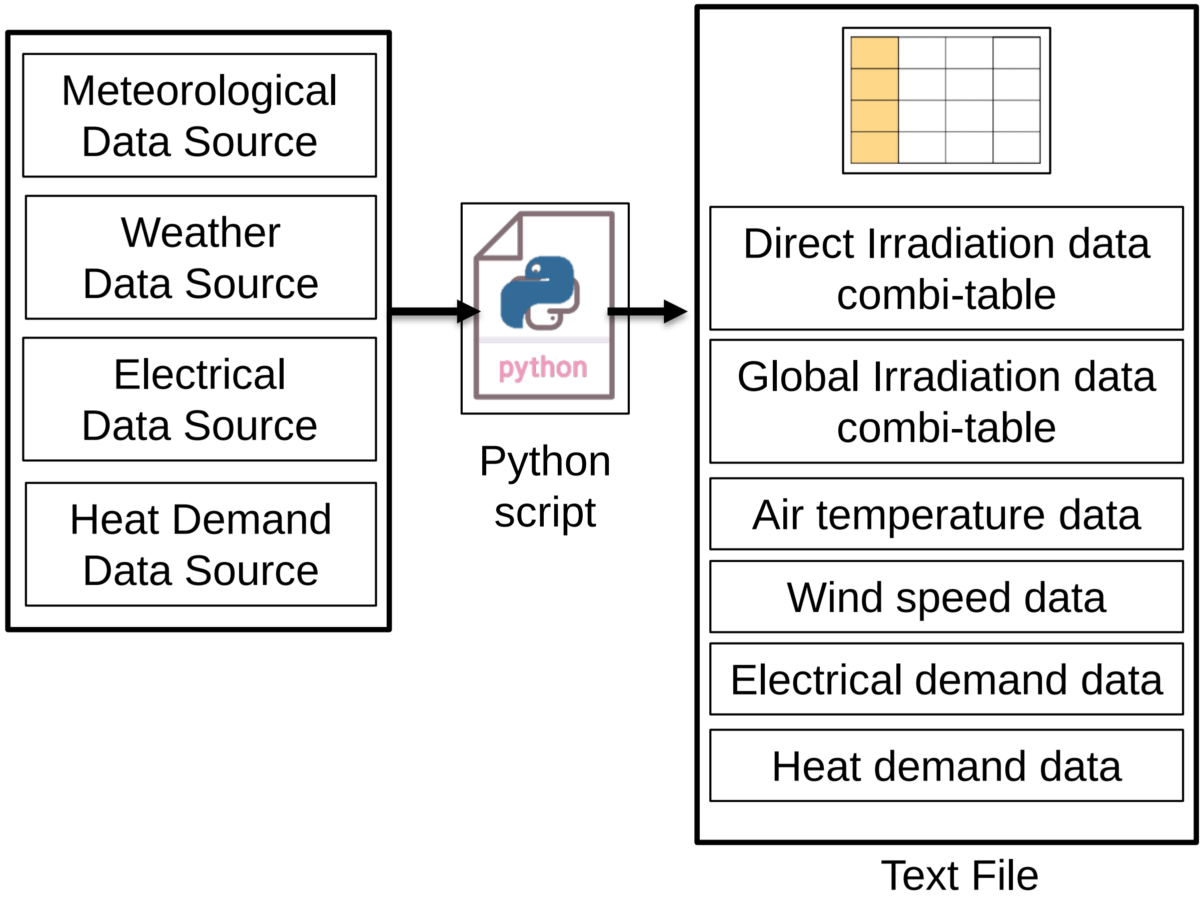
System Parameter



Graphical representation

Utility: Data extraction

- The data is extracted from the annual hourly data source file using an python script.
- The data sources are,
  - Meteorological radiation data (2007 - Sweden, Norrköping)
  - Weather data (2013 - Netherland)
  - Electrical solar generation, wind generation and demand power data (2016 – Netherland)
  - Heat demand data (2013 – Netherland)
- The output file of the python script are the individual text files in the combi-table format.
- In the corresponding model these text files are imported as combi-tables.
- The location (Country) and the year for data extraction can be changed in the python script.

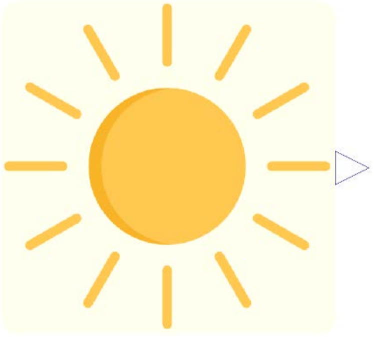


Utility: Solar Irradiance Data

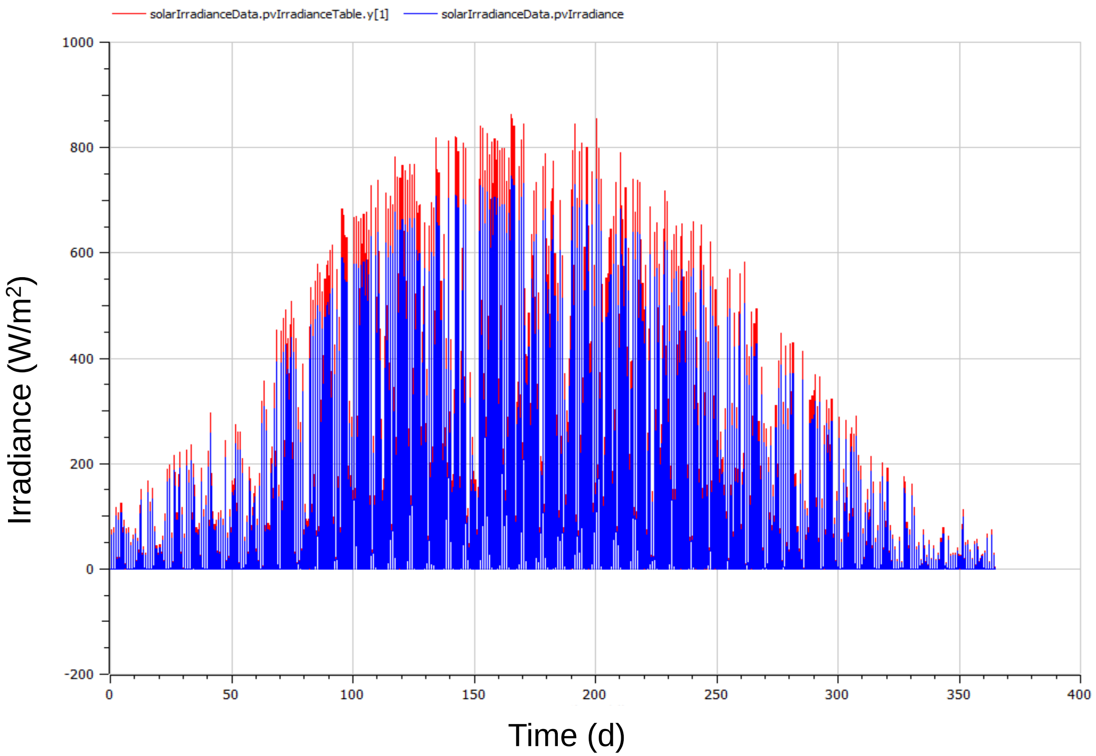
- The annual hourly solar irradiance data is converted to the irradiance on the panel using the combi-table and tilt angle of the PV panel.
- Input
  - o Hourly horizontal surface irradiance data
- Parameters
  - o PV panel tilt angle
- Output
  - o Solar irradiance on the PV panel
- Equation

$$E_{module} = E_e * \cos\left(\frac{\pi * \beta}{180}\right)$$

E_e (W/m^2) - Horizontal surface data
E_{module} (W/m^2) - Solar irradiance on the PV panel
β (deg) - PV panel tilt angle



Graphical representation



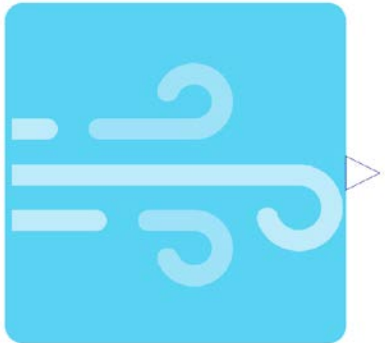
The example plot shows the module irradiance for an PV panel with tilt angle = 30deg.

Utility: Wind speed Data

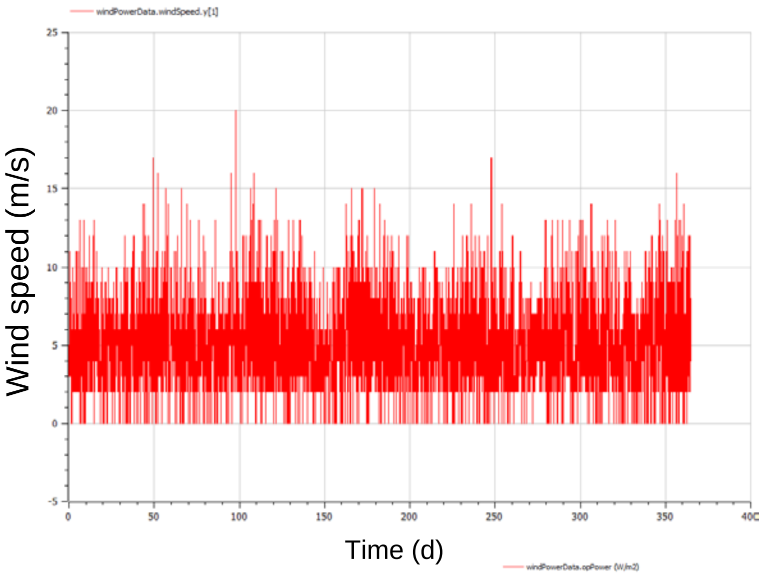
- Wind speed data is converted to wind power per unit area of the turbine rotor area.
- Input
  - o Hourly wind speed data
- Parameter
  - o Air density
- Output
  - o Wind power per unit area
- Equation

$$P_{wa} = \frac{1}{2} * \rho * v^3$$

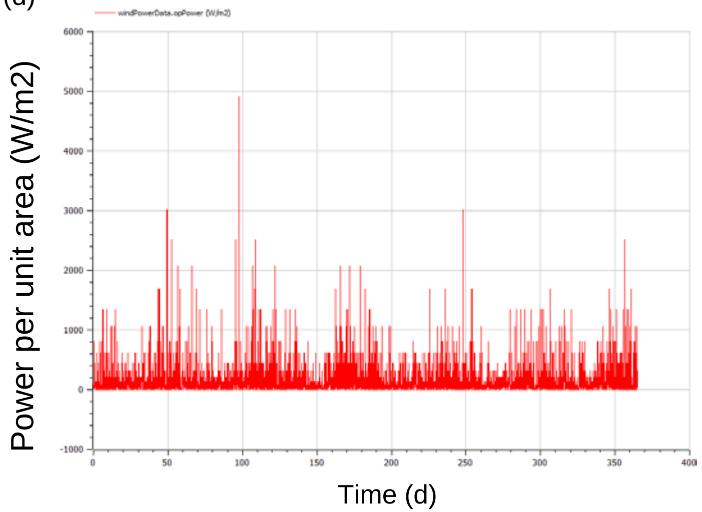
P_{wa} (W/m^2) – Wind power per unit area
v (m/s) – Wind speed
ρ (kg/m^3) - PV panel tilt angle



Graphical representation



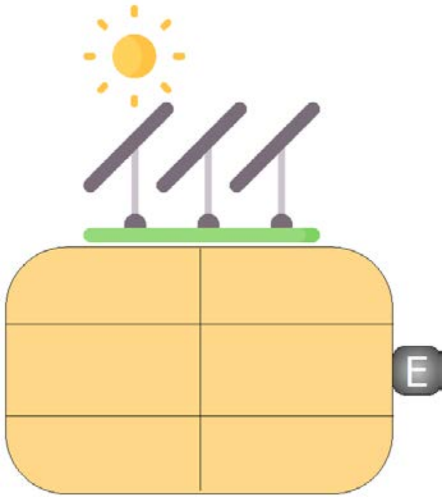
Sample wind speed data



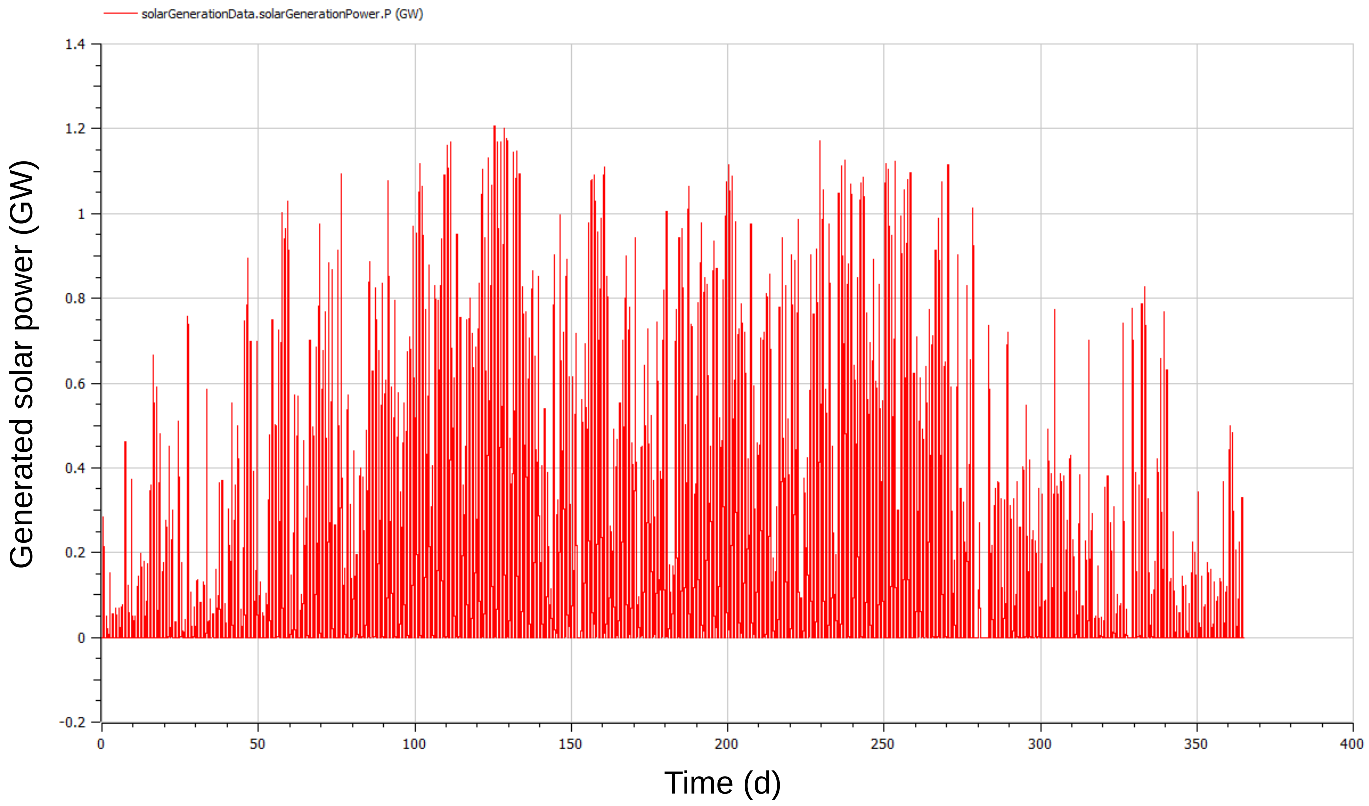
Wind power data

Utility: Solar Generation Data

- The annual hourly solar generated power data for a country is imported using the combi-table.
- Input
  - o Country solar generation data
- Output
  - o Solar generation power

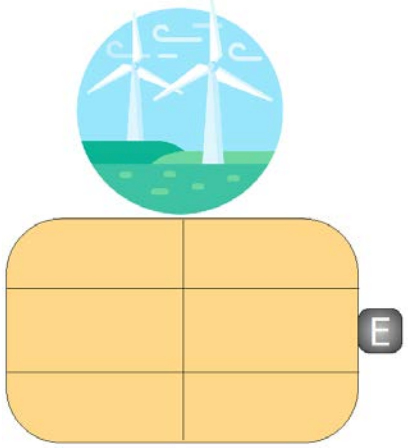


Graphical representation

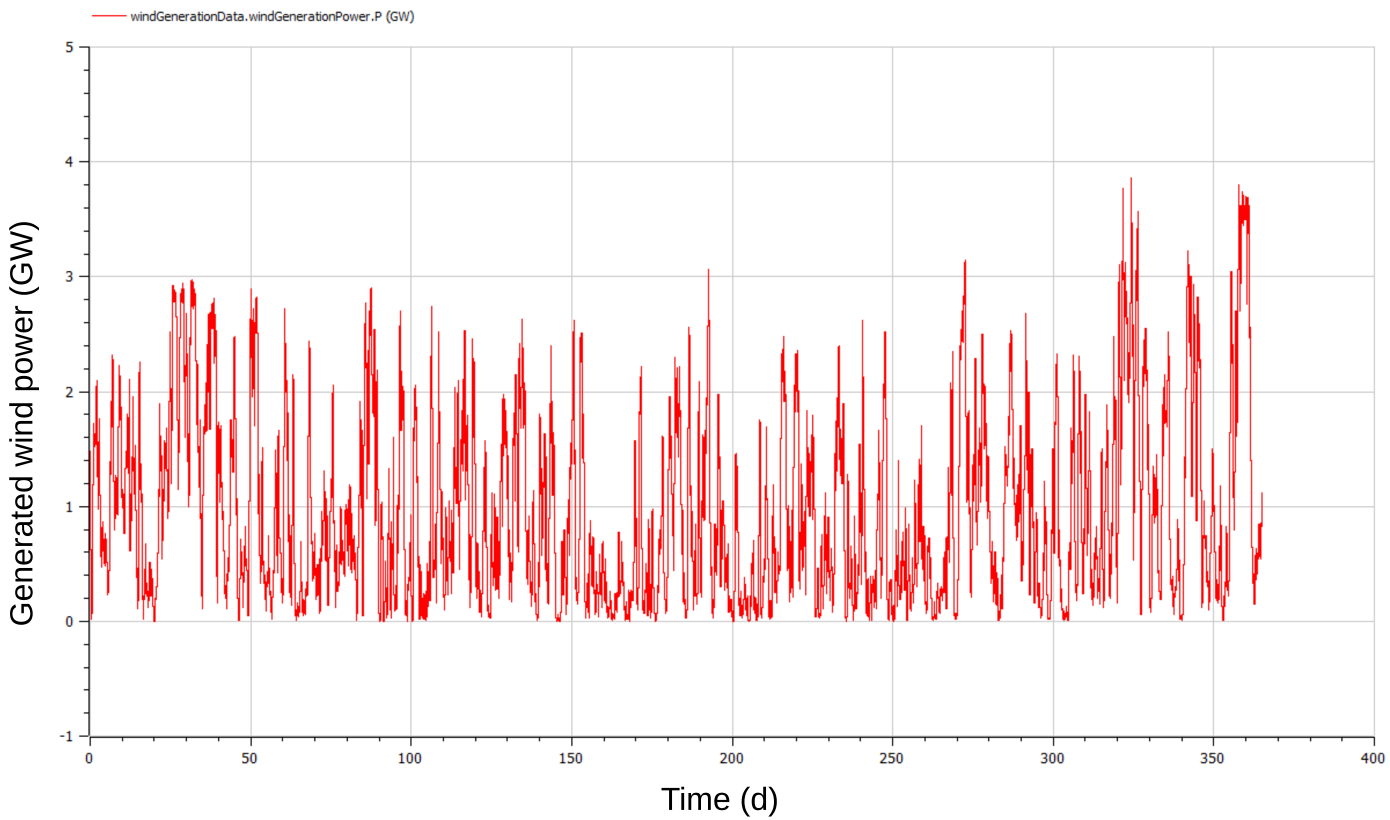


Utility: Wind Generation Data

- The annual hourly wind generated power data for a country is imported using the combi-table.
- Input
  - o Country wind generation data
- Output
  - o Wind generation power

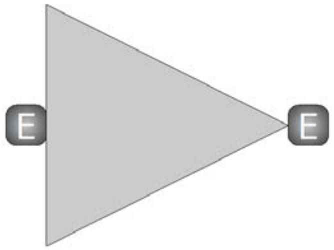


Graphical representation



Utility: (Solar/ Wind) Generation Factor

- The generation factor is to enable carrying out sensitivity studies on (decreasing or increasing) the generation capability of renewable power – Solar/ wind.
- The default value is 1 for both solar and wind indicating the generation capability on 2016.
- To study the impact of increasing / decreasing renewable power this factor can be changed from 0 to some large number.
- Input
  - Actual solar/ wind generation power (2016)
- Parameter
  - Factor
- Output
  - Projected solar/ wind generation power

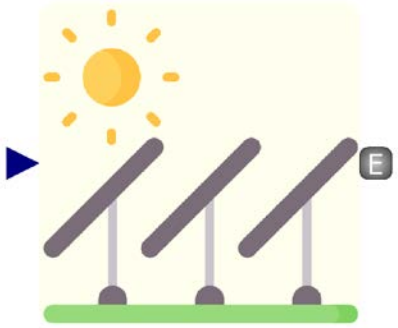


Graphical representation

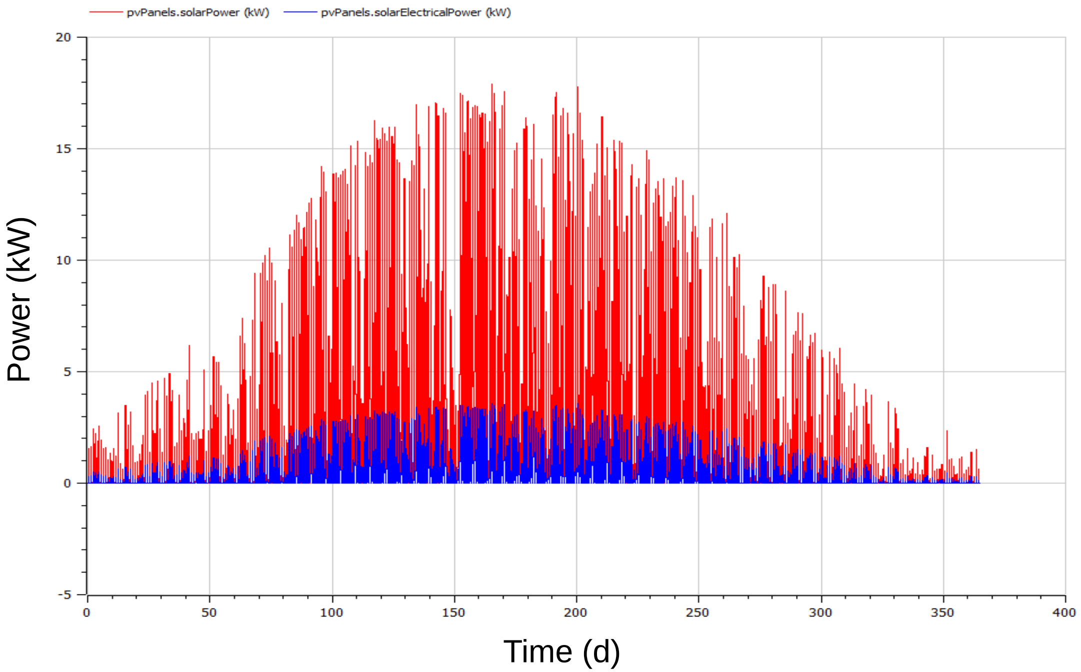
Components: Solar Farm of Electric PV Panels

- This model consists of number of solar PV panels in a solar farm.
- Solar power is converted to electrical power
- Input
  - o Irradiance on the PV panels
- Parameters
  - o Surface area of each PV panel
  - o Number of PV panels in the farm
  - o Generation efficiency
- Output
  - o Generated electrical power
- Equation

$$P_S = \eta_{se} * E_{module} * A_p * n_p$$



Graphical representation



P_S (W) – Solar generated electrical power
E_{module} (W/m^2) - Solar irradiance on the PV panel
A_p (m^2) – Surface area of the PV panel
n_p – Number of PV panels in the farm
ρ (kg/m^3) - PV panel tilt angle
η_{se} – Solar electric power generation efficiency

The example plot shows the solar power and the corresponding electrical power generated for n=12 panels of 2m2 surface area with an efficiency of 20%.

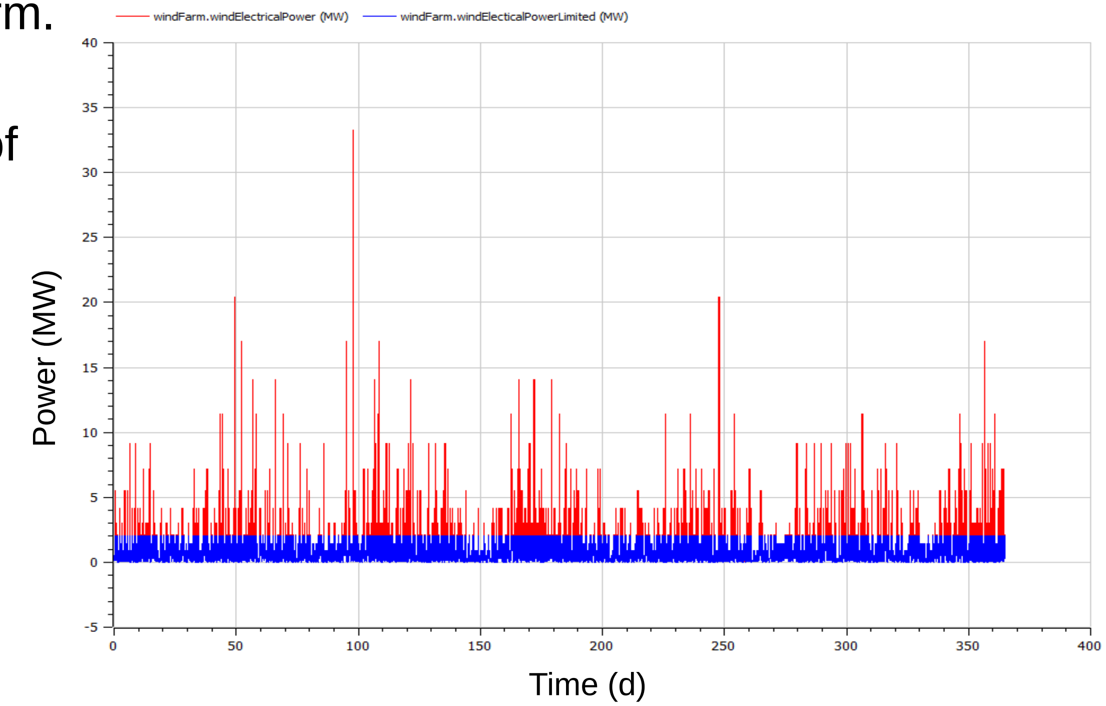
Components: Wind farm

- This model consists of number of wind turbines in a wind farm.
- Wind power is converted to electrical power, The generated electrical power has limiter which signifies the rated power of the turbine farm.
- Input
  - o Wind power per unit area
- Parameters
  - o Rotor radius of the turbines
  - o Number of turbines in the farm
  - o Generation efficiency
- Output
  - o Generated electrical power
- Equation

$$A_t = \pi * {R_r}^2$$

$$P_w = \eta_{we} * P_{wa} * A_t * n_w$$

Graphical representation



P_w (W) – Wind generated electrical power
P_{wa} (W/m²) – Wind power per unit area
A_t (m²) – Turbine rotor swept area
n_w – Number of wind turbines in the farm
R_r (m) – Turbine rotor radius
η_w – Wind electric power generation efficiency

The example plot shows the wind electrical power for n=3 turbines of 30m rotor radius with an efficiency of 80% and rated power of 2MW.

Assumption:
The radius of each turbines in the farm is assumed to be same.

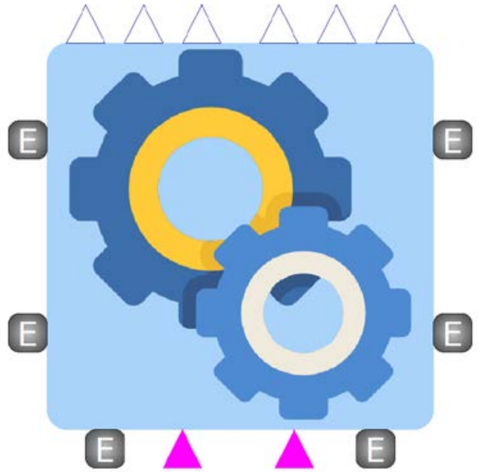
MODELICA

Components: Power Management System

- This model consists of the control algorithm to manage the grid. The control algorithm is designed such that the demand is always met.
- Input
  - o Generated electrical powers
  - o Demand powers (domestic demand & Charging station)
  - o Can charge, can discharge flags from energy storage
- Parameters
  - o Energy storage power supply limit
  - o Number of turbines in the farm
  - o Transmission & distribution efficiency
- Output
  - o Stored power
  - o Power from or to conventional grid (infinite source& sink)
- Equation

$$P_{ag} = \eta_{tnd} * (P_{g1} + P_{g2})$$

$$P_{td} = \eta_{tnd} * (P_{d1} + P_{d2})$$



Graphical representation

P_{ag} (W) – Available generated electrical power
P_{g1} (W) – Solar generated electrical power
P_{g2} (W) – Wind generated electrical power
P_{td} (W) – Total demand electrical power
P_{d1} (W) – Domestic demand electrical power
P_{d2} (W) – Charging station demand electrical power
η_{tnd} – Transmission & distribution efficiency

Components: Power Management System

- **Control Algorithm Flow chart**

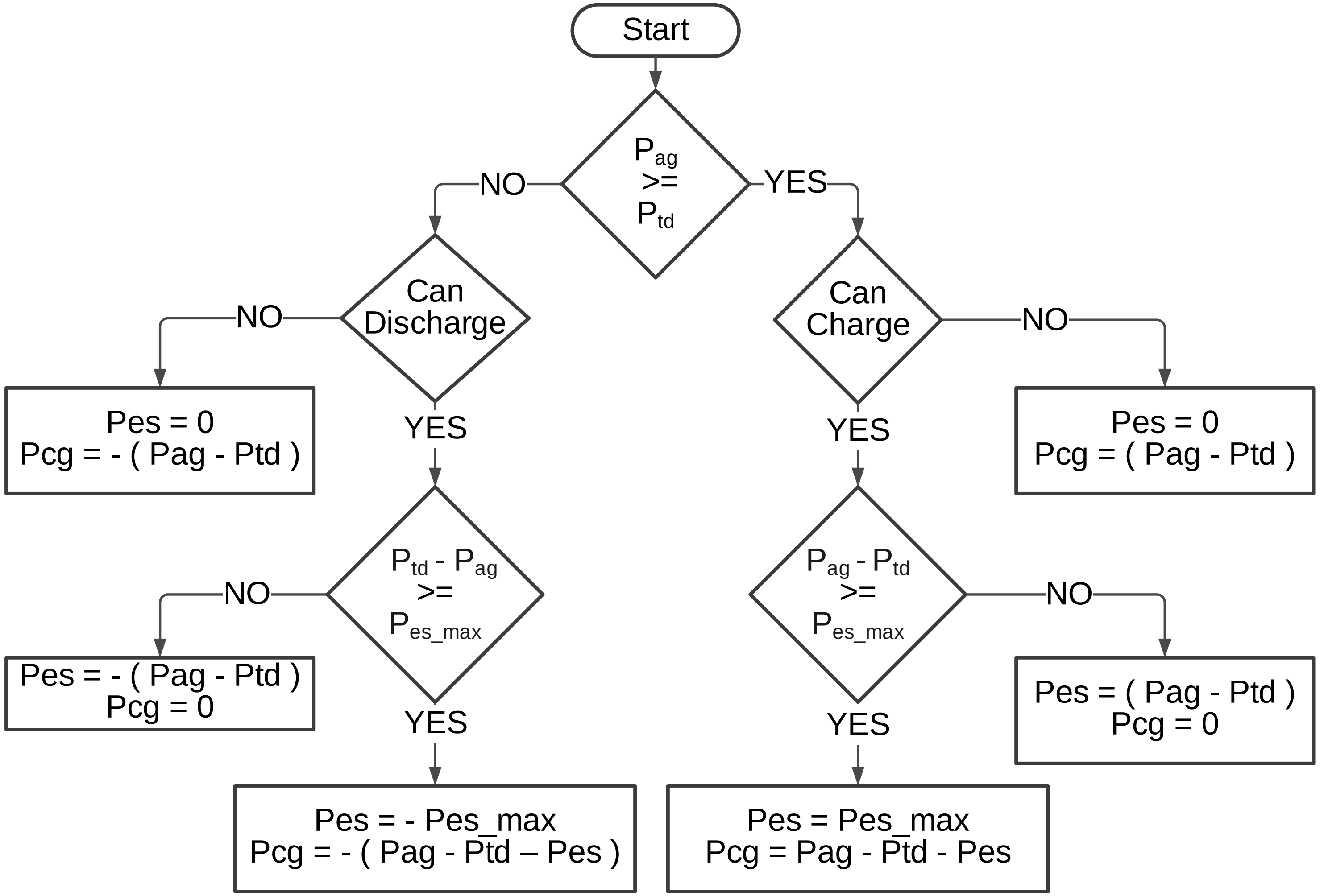
P_{ag} – Available **Generated power**

P_{td} – Total **demand power**

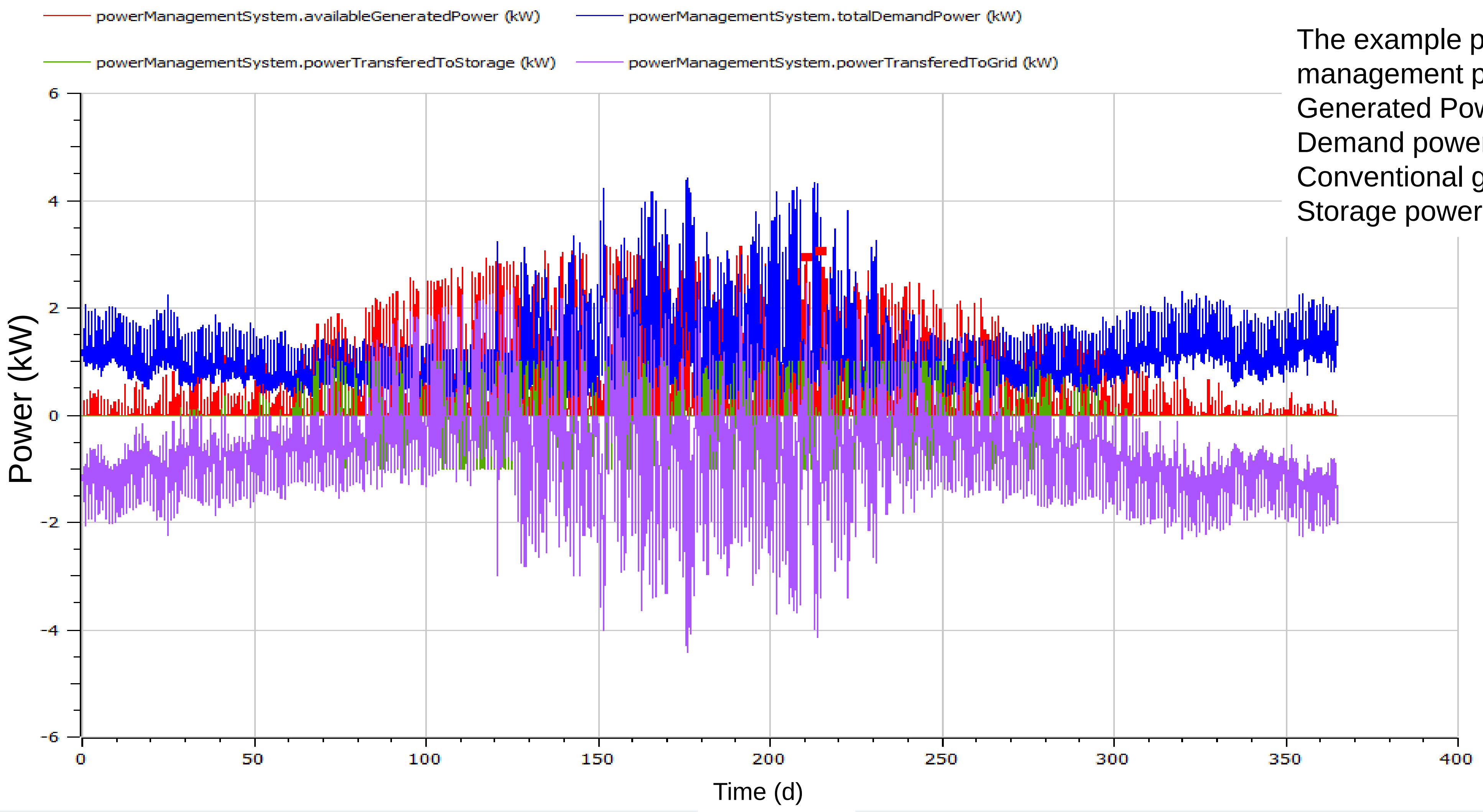
P_{es} – Power transferred to **energy storage**

P_{cg} – Power transferred to **conventional grid**

P_{es_max} – **Energy storage** power supply limit



Components: Power Management System



The example plot shows the solar power management plot for **single house grid**,
Generated Power (Red)
Demand power (Blue)
Conventional grid power (Purple)
Storage power (Green)

Components: Electric Energy Storage

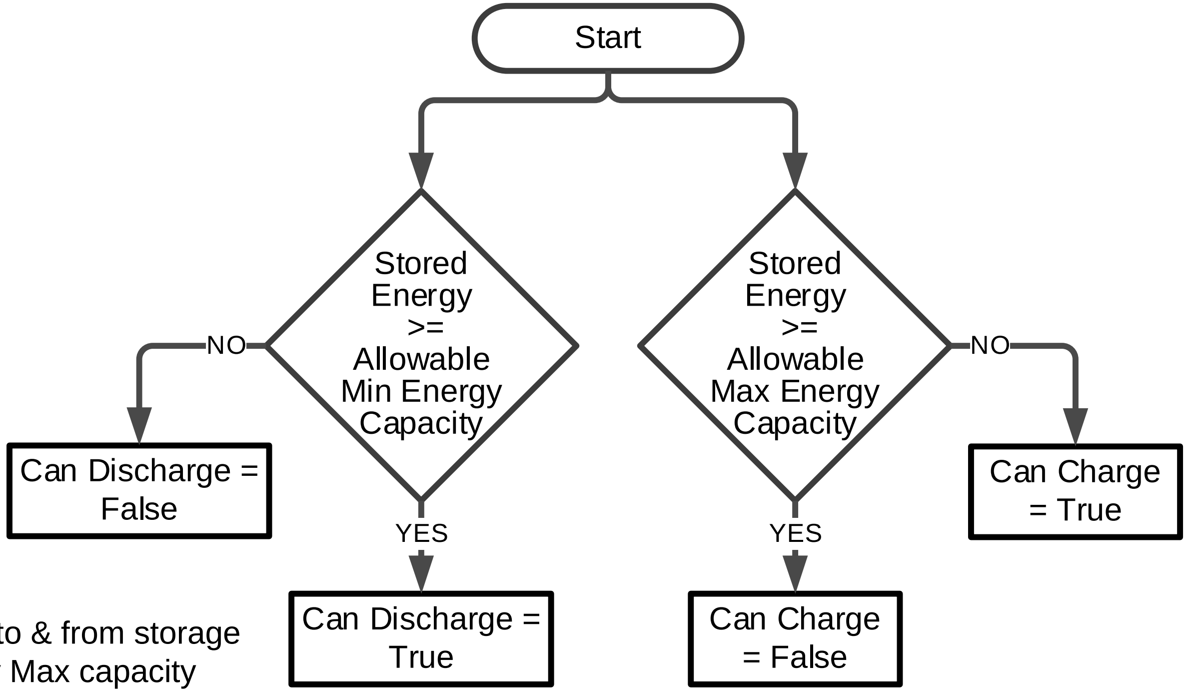
- The energy storage model is used to store excess power which will be at the instance when generation is greater than the demand.
- The charging & discharging control algorithm is shown in the following flowchart.
- Input
  - o Power from grid
- Parameters
  - o Storage capacity
  - o Min allowable charge %
  - o Max allowable charge %
- Output
  - o Stored energy
  - o Boolean Flags : can charge, can discharge
- Equation

$$E_{es} = \int P_{es}\, dt \Big/ 3600$$

E_{es} (Wh) – Stored Energy
P_{es} (W) – Power transferred to & from storage
E_{es_cap} (Wh) – Stored Energy Max capacity

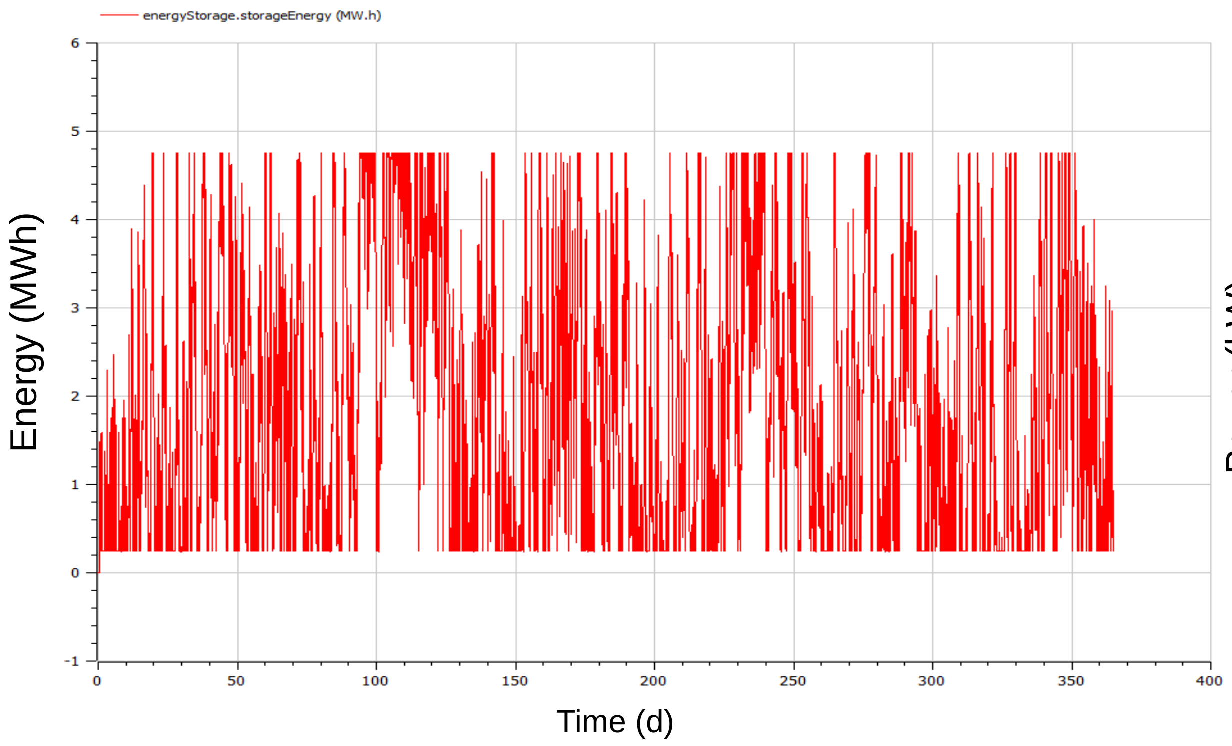
Graphical representation

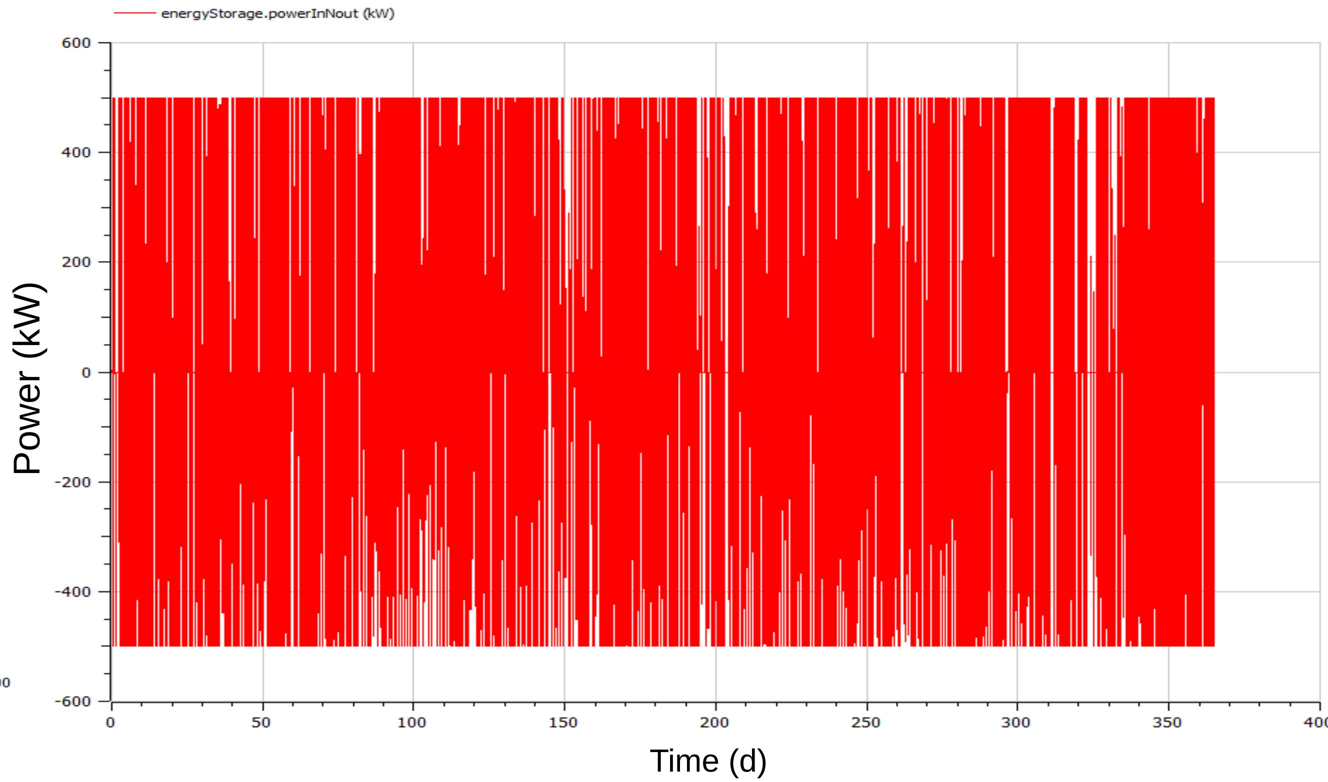
Control Algorithm Flow Chart



MODELICA

Components: Energy Storage



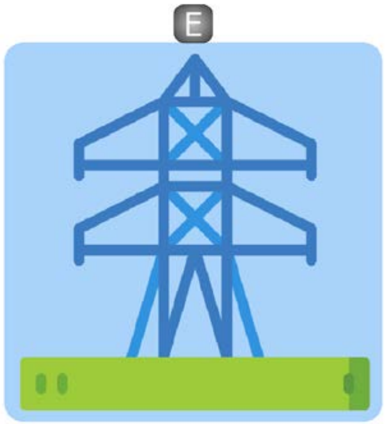


The example plot shows the energy storage energy profile with 5MWh max capacity

The example plot shows the energy storage Power profile with 500kW Power limit

Components: Conventional Electric Grid

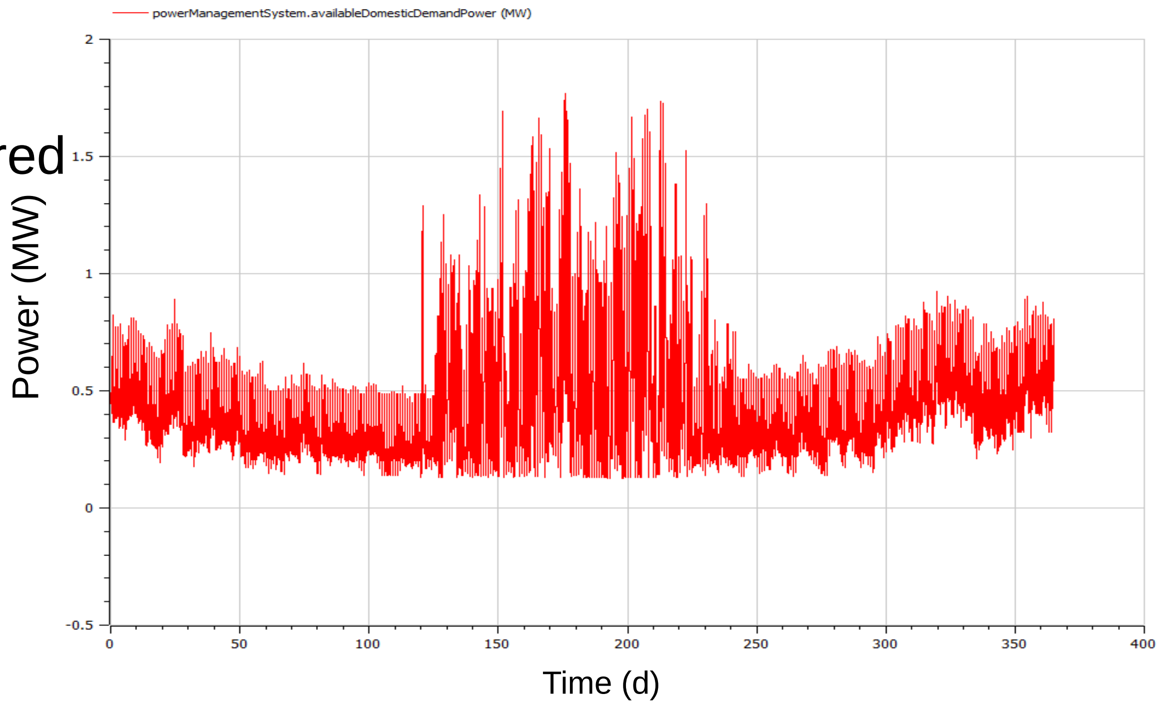
- This model is an infinite source and sink of power
- Power from the conventional grid will be supplied when the generation power is less than demand and energy storage is fully discharged.
- Power to the conventional grid will be supplied when the generation power is more than demand and energy storage is fully charged.
- Input
  - Input power
- Output
  - Output power



Graphical representation

Components: Domestic Consumer

- This model is provides the domestic consumer demand.
- Sample annual hourly demand data profiles are stored in the library resources as an text file. Four different scale sample data are provided for simulating the given four scenarios.
- Using a combi-table the domestic demand data is imported and given to the grid.
- Input
  - o Domestic demand power data
- Output
  - o Demand power

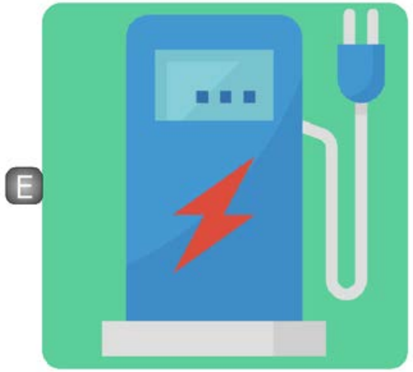


The example plot shows the domestic consumption data for a group of houses (~200 Houses), probably air conditioning in a southern location

Graphical representation

Components: Charging Station

- This model is an simulated (hypothetical) demand data generator for EV charging stations.
- Using random number generator the number of cars & bikes charging in any given station is calculated.
- After the said charging duration the random number generator will give out new number of vehicles per station.
- Parameters
  - Number of charging stations
  - Max number of cars & bikes per station
  - Charging duration for cars & bikes
- Output
  - Total charging station demand power
- Equation

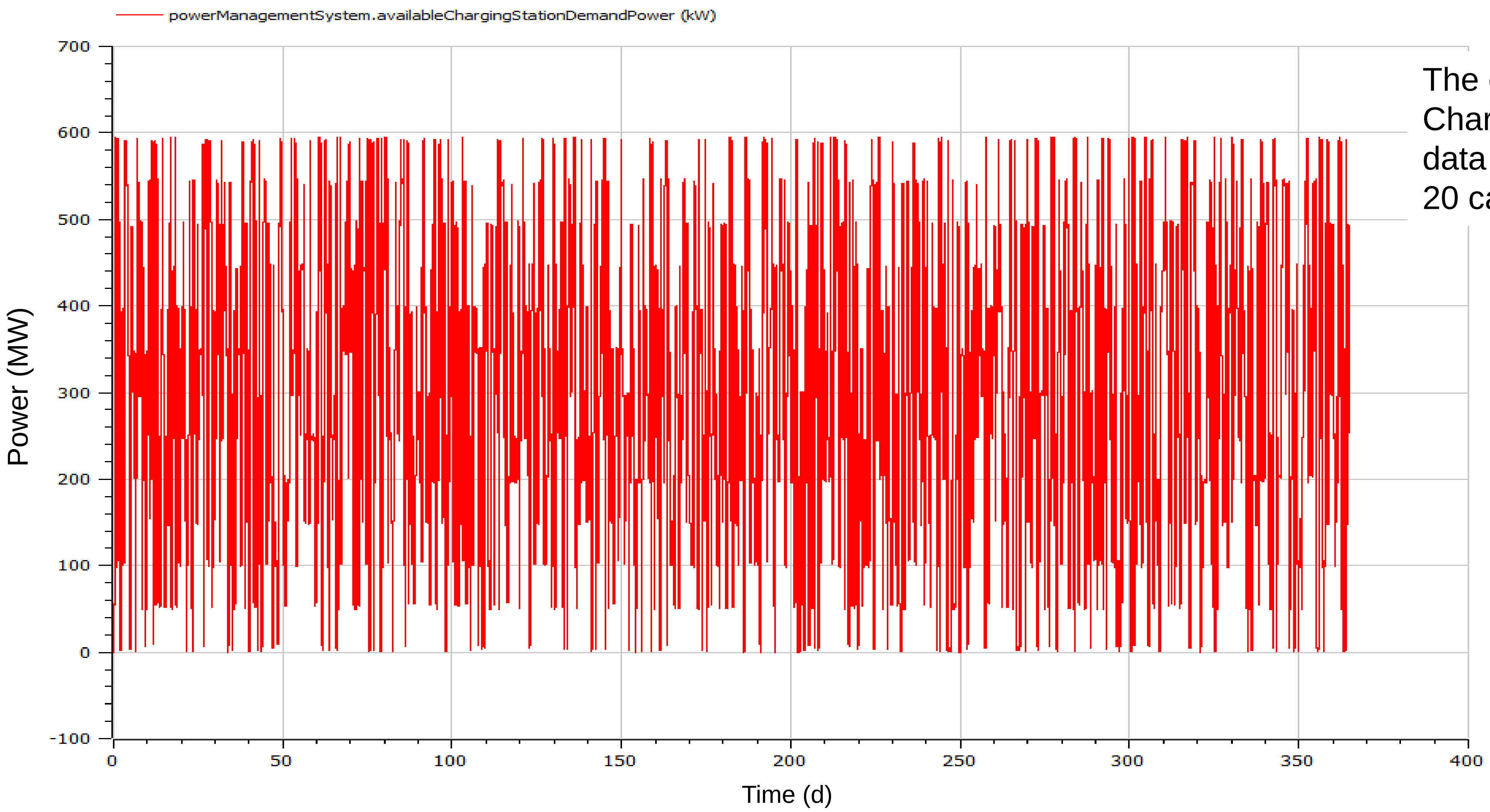


Graphical representation

$$P_{ch} = n_{st} * \left(n_{car} * P_{ch_{car}} + n_{bike} * P_{ch_{bike}} \right)$$

P_{ch} (Wh) – Total charging stations demand power
P_{ch_car} (W) – Charging Power for a car
P_{ch_bike} (W) – Charging Power for a bike
n_{car} & n_{bike} – Number of cars & bikes per station
n_{st} – Number of charging stations

Components: Charging Station



The example plot shows the Charging station consumption data for 4 charging stations (Max 20 cars/station & 12 bikes/station)

Components: Electric KPI (Key Performance Indicator)

- This model is used to highlight the “Key Performance Indicator” of the power grid.
- The KPI parameters are,
  - **Grid power** ratio
  - **Storage power** ratio
  - **Generation power** ratio
  - **Storage effectiveness**
  - **Generation effectiveness**
  - **Solar** generated **energy**
  - **Wind** generated **energy**
  - **Domestic** demand energy
  - **Charging station** energy

Graphical representation

- Equations

$$E_w = \int P_w \, dt \Big/ 3600$$

$$E_{dd} = \int P_{dd} \, dt \Big/ 3600$$

$$E_s = \int P_s \, dt \Big/ 3600$$

$$E_{ch} = \int P_{ch} \, dt \Big/ 3600$$

P_w (W) – Wind generated electrical power
P_S (W) – Solar generated electrical power
P_{dd} (W) – domestic demand electrical power
P_{ch} (Wh) – Total charging stations demand power
E_w (W) – Wind generated energy
E_S (W) – Solar generated energy
E_{dd} (W) – domestic demand energy
E_{ch} (Wh) – Total charging stations demand energy

Components: KPI (Key Performance Indicator)

- Equations,

$$Generation\ Effectiveness = \frac{Total\ Demand\ Power\ - Available\ Generated\ Power}{Total\ Demand\ Power}$$

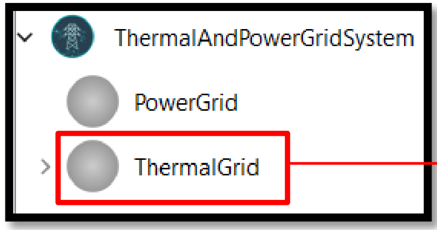
$$Grid\ Power\ Ratio = \frac{Power\ Supplied\ from\ Grid}{Total\ Demand\ Power}$$

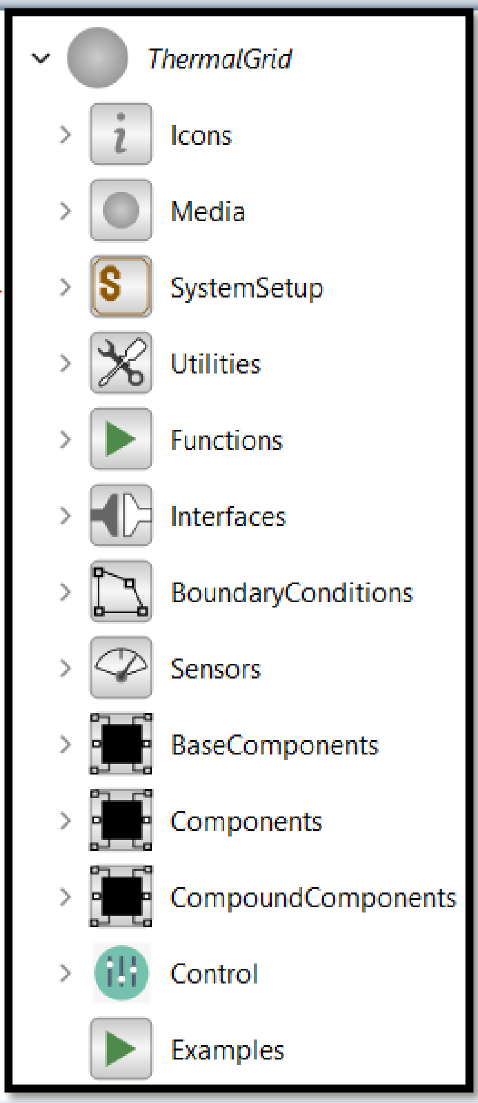
$$Generation\ Power\ Ratio = \frac{Available\ Generated\ Power}{Total\ Demand\ Power}$$

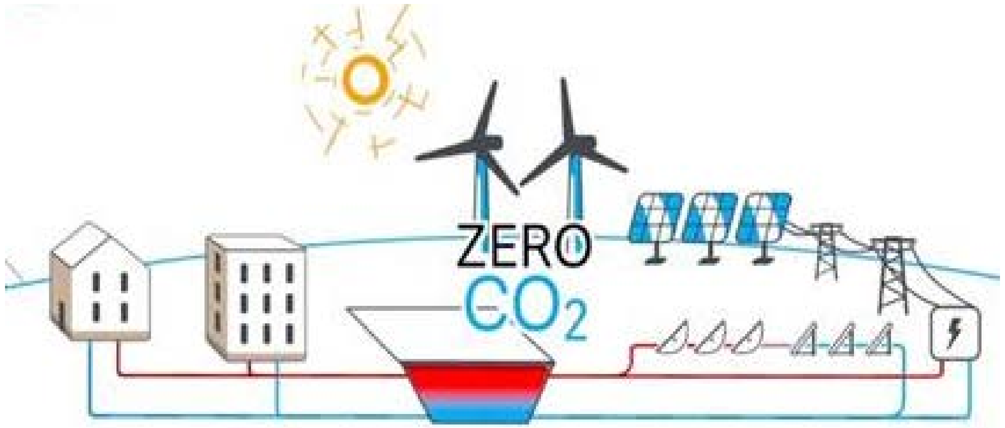
$$Storage\ Power\ Ratio = \frac{Power\ Supplied\ from\ Storage}{Total\ Demand\ Power}$$

$$Storage\ Effectiveness = \frac{Average\ Storage\ Energy}{Storage\ Capacity}$$

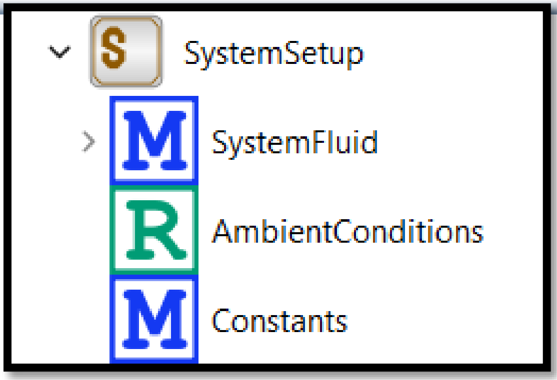
Library Overview – Thermal Sub library







Library Overview – Thermal Sub library



System Fluid

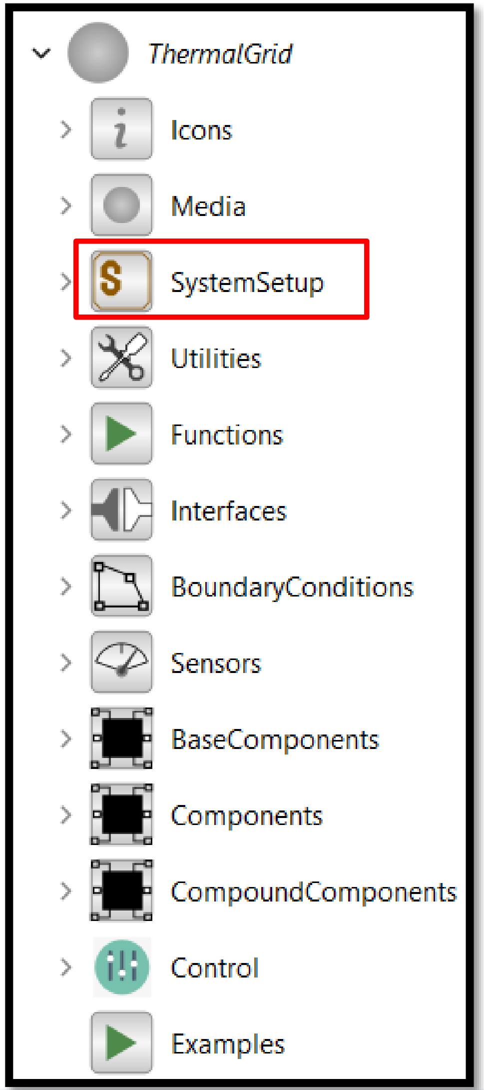
Specific medium models that can be directly utilized from Standard Modelica Library can be defined here. The flexibility of replacing the medium is provided.

Ambient Conditions

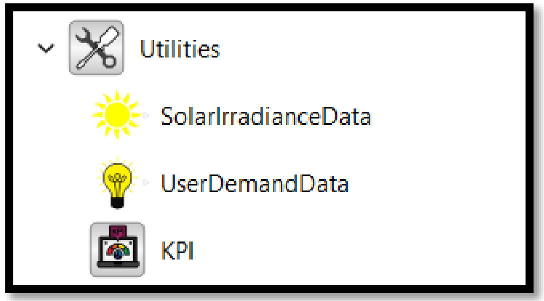
Ambient Conditions such as ambient temperature and pressure conditions assumed for each scenario is declared as a record. The objects are then defined as inner/outer to have singular access to ambient conditions of all sub-models of a scenario.

Constants

Various constants used in the system can be defined in this model.



Library Overview Thermal Sub library



Utilities

Solar Irradiation Data

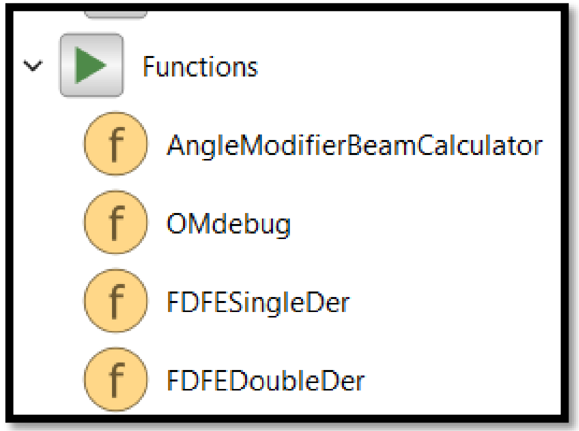
The model uses a combi-table of hourly Irradiance Data. This data is used as input for SolarCSP model.

User Demand Data

The model uses a combi-table of hourly Irradiance Data. This data is used as input for SpaceHeating model.

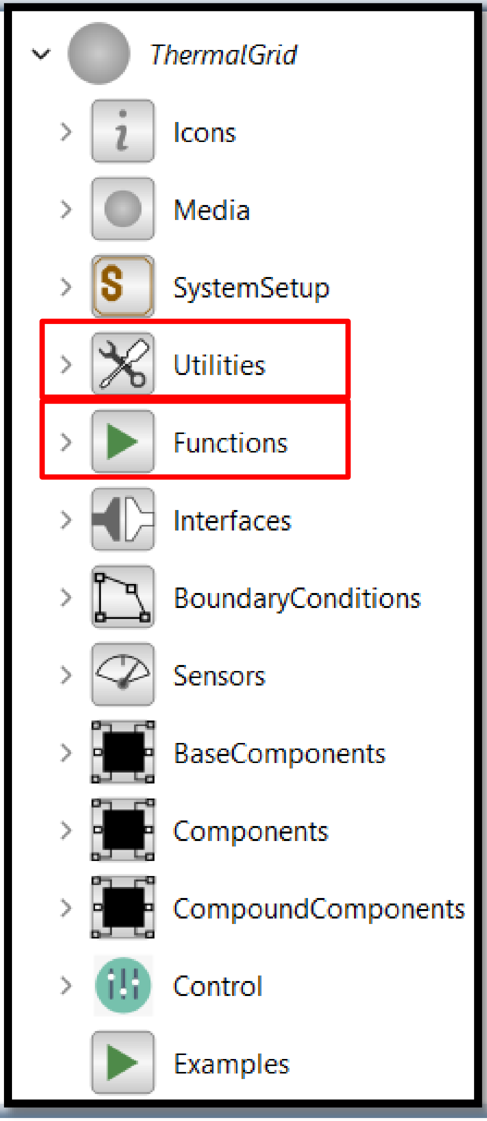
KPI

Calculates Key Performance Indicators.

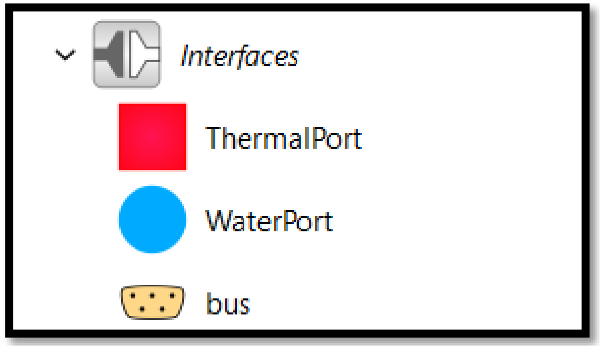


Functions

Functions used for internal debugging, calculating Single derivative and double derivatives.



Library Overview – Thermal Sub library



Thermal Port

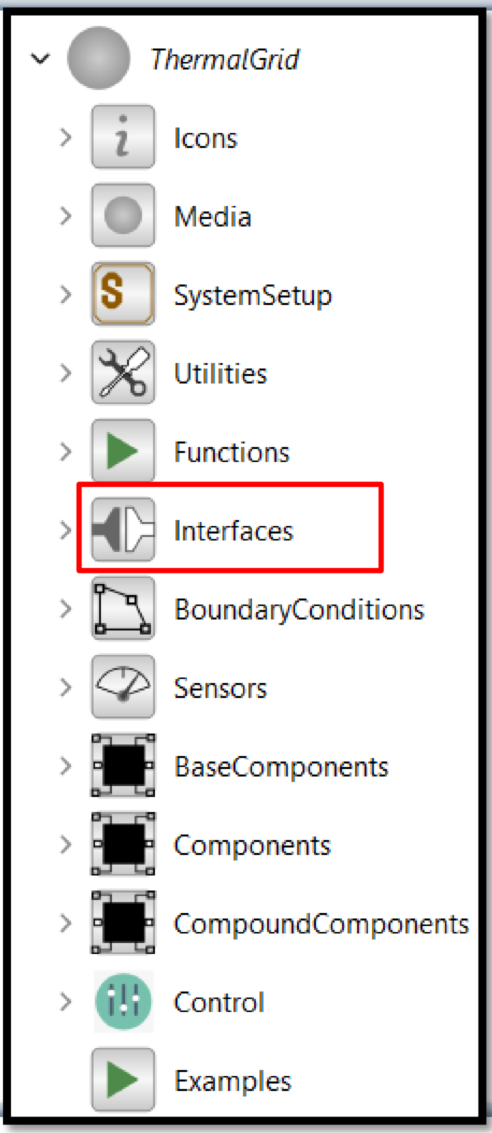
Connector Variables:
Potential Variable: Temperature (K)
Flow Variable : Heat Flow Rate (W)

Water Port (Stream Connector)

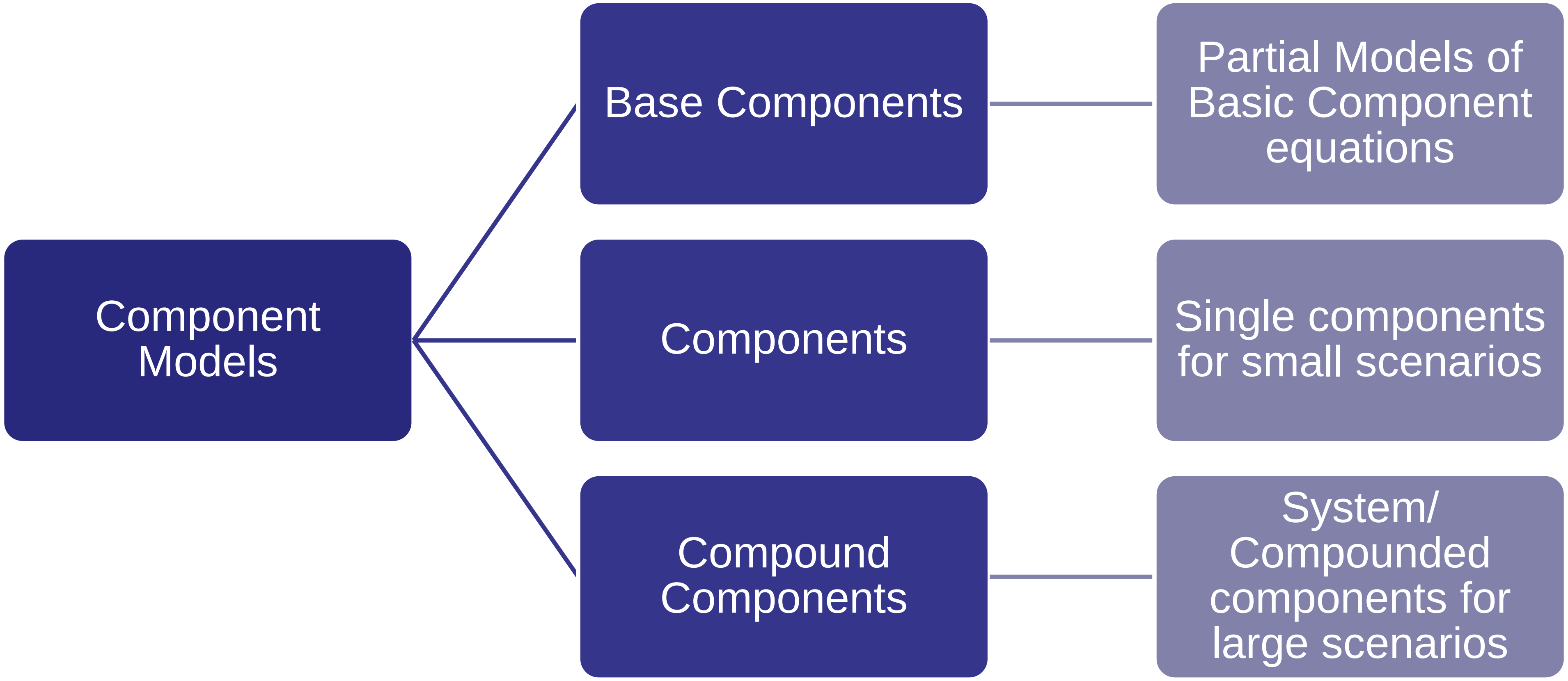
Connector Variables:
Potential Variable: Pressure (Pa)
Flow Variable : Mass Flow Rate (kg/s)
Stream Variable: Specific Enthalpy (W/kg)

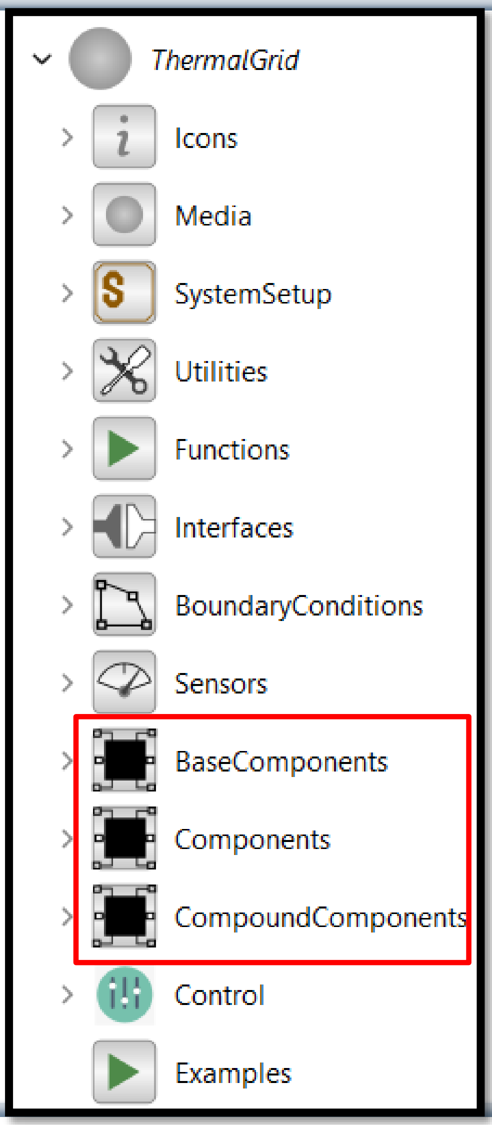
Bus

Expandable Connector used as interface between scenario and Controller.



Library Overview – Thermal Sub library





Component Models - Thermal Energy Generation Models

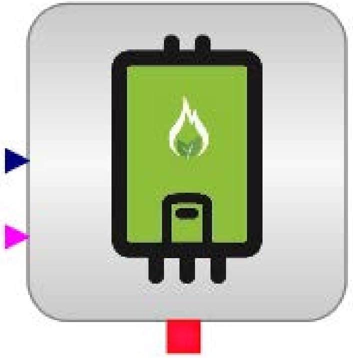
Solar CSP Model

OBJECTIVE: Calculates outlet temperature and total useful energy collected by the receiver taking into account the various energy losses.

INPUT: Hourly Solar Irradiation Data

OUTPUT: Outlet Temperature, Useful Energy

Biomass Boiler Model



OBJECTIVE: Calculates outlet temperature and total useful energy generated by the boiler.

INPUT: Fuel Flow Rate

OUTPUT: Outlet Temperature, Useful Energy

Component Models - Thermal Energy Consumption Models

Domestic Space Heating Consumption Model

OBJECTIVE: Calculates Domestic Space Heating Consumption, return temperature is modeled, for one house.

INPUT: Energy Use Per Person Per Year, Pressure Difference, WaterPort variables

Similar Model for a residential community.
ASSUMPTION: Four residents per house.

INPUT: Number of houses in the community.

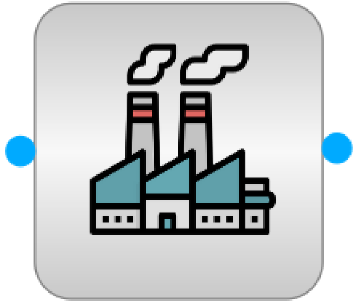
OUTPUT: Return Temperature, WaterPort variables

A third model called SpaceHeating is added to enable the user to provide real data via the UserDemand utility to generate realistic simulations.

MODELICA

Component Models - Energy Consumption Models

Industrial Consumption Model



OBJECTIVE: Energy consumption model for industries, return temperature is modeled for one industry.

INPUT: Energy Use Per Industry Per Year, Pressure Difference, WaterPort Variables

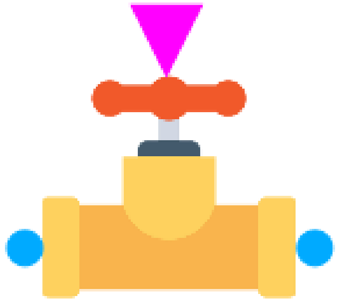
Similar Model for an industrial complex.
ASSUMPTION: Same average energy use for all industries.

INPUT: Number of industries in the complex.

OUTPUT: Return Temperature, WaterPort Variables

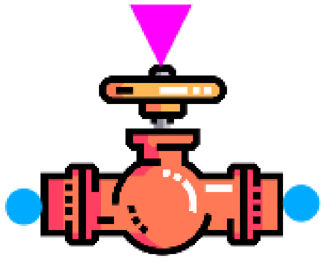
Component Models – Valves

Valve Models



On/Off Valve:
OBJECTIVE: Pressure drop valve model with on-off switch.

INPUT: Control Switch, WaterPort variables



Linear Valve:
Similar Model for linear valve

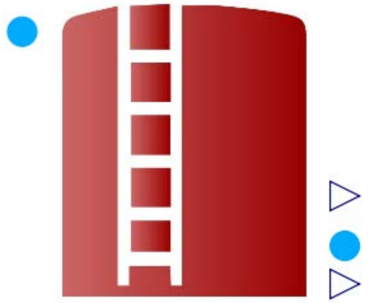
INPUT: Valve Opening

PARAMETERS: Cv value

OUTPUT: Pressure drop across valve, WaterPort variables

Component Models – Thermal Energy Storage Models

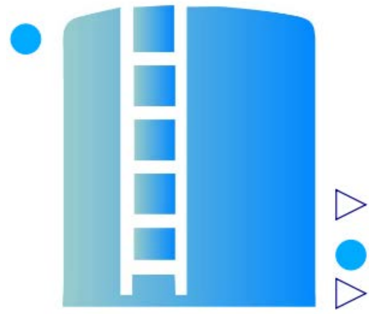
Tank Models



Hot Storage Tank & Cold Storage Tank
OBJECTIVE: Tank open to atmosphere, used for storage of medium (water). The input-output enthalpy change, level of medium in the tank, enthalpy storage, output pressure are modeled.

INPUT: Initial Level, Heat Transfer Coefficient, WaterPort variables

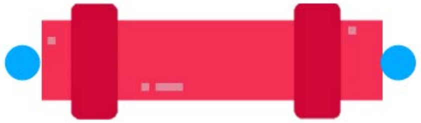
PARAMETERS: Tank Dimensions



OUTPUT: Level of medium, Energy Stored, Energy Loss, WaterPort variables

Component Models – Pipe Models

Pipe Models

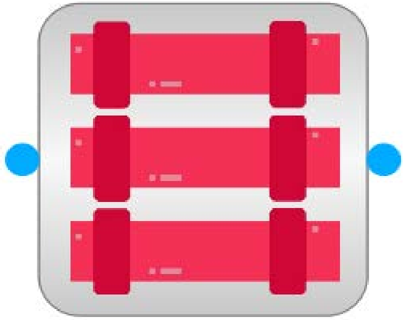


Supply Pipe & Return Pipe

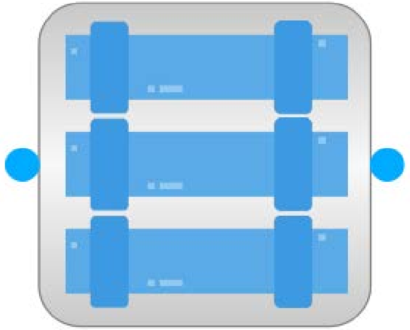
OBJECTIVE: These models calculate the friction coefficient of the pipe/pipeline system, pressure drop across the pipe as well as energy losses.

INPUT: WaterPort variables

PARAMETERS: Dimensions of the pipe



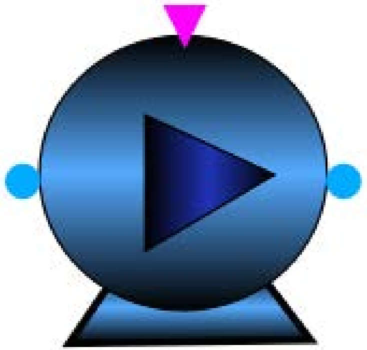
Hot Pipeline System & Cold Pipeline System



OUTPUT: Friction coefficient, Energy Loss, Exit WaterPort variables.

Component Models

Pump Model



OBJECTIVE: To calculate the power consumed by the pump and pressure drop

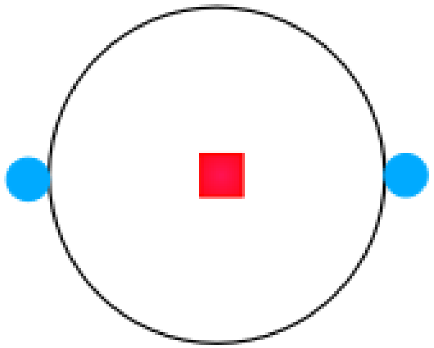
INPUT: WaterPort variables, Control Switch input

PARAMETERS: Pump Efficiency

OUTPUT: Pressure drop, Pump Power, exit WaterPort variables

Component Models

Port Exchange Model

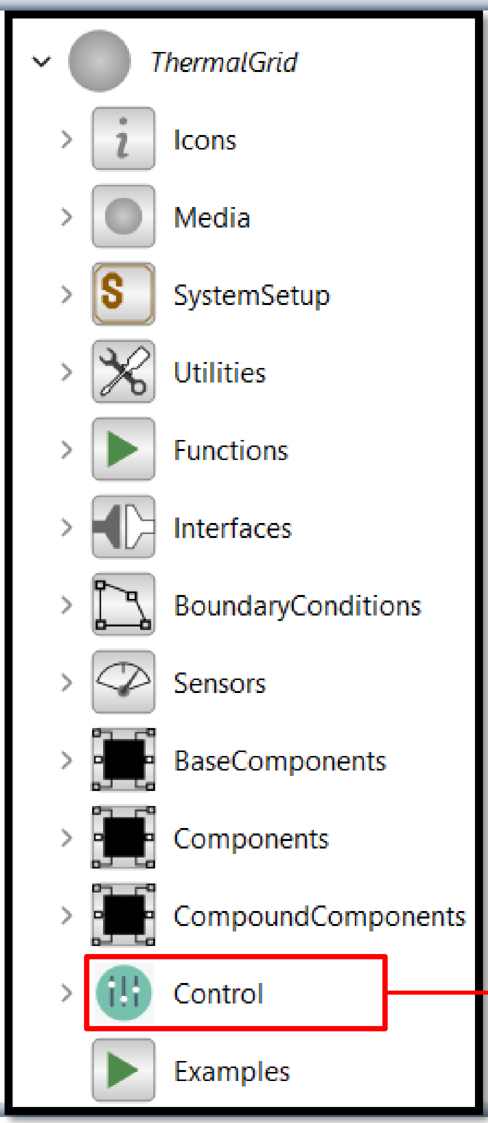


OBJECTIVE: This model is used to carry the information of a heat port onto a water port. It can be considered a simple heat exchanger model.

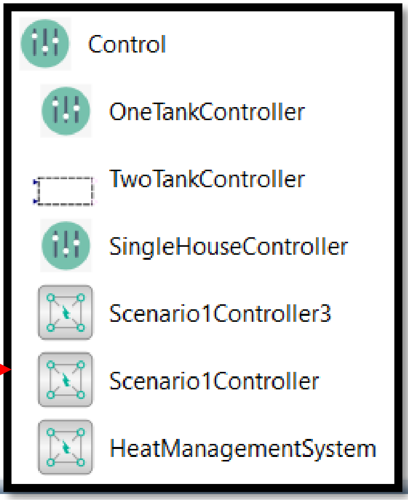
INPUT: HeatPort variables, WaterPort variables

OUTPUT: exit WaterPort variables

Controller Models

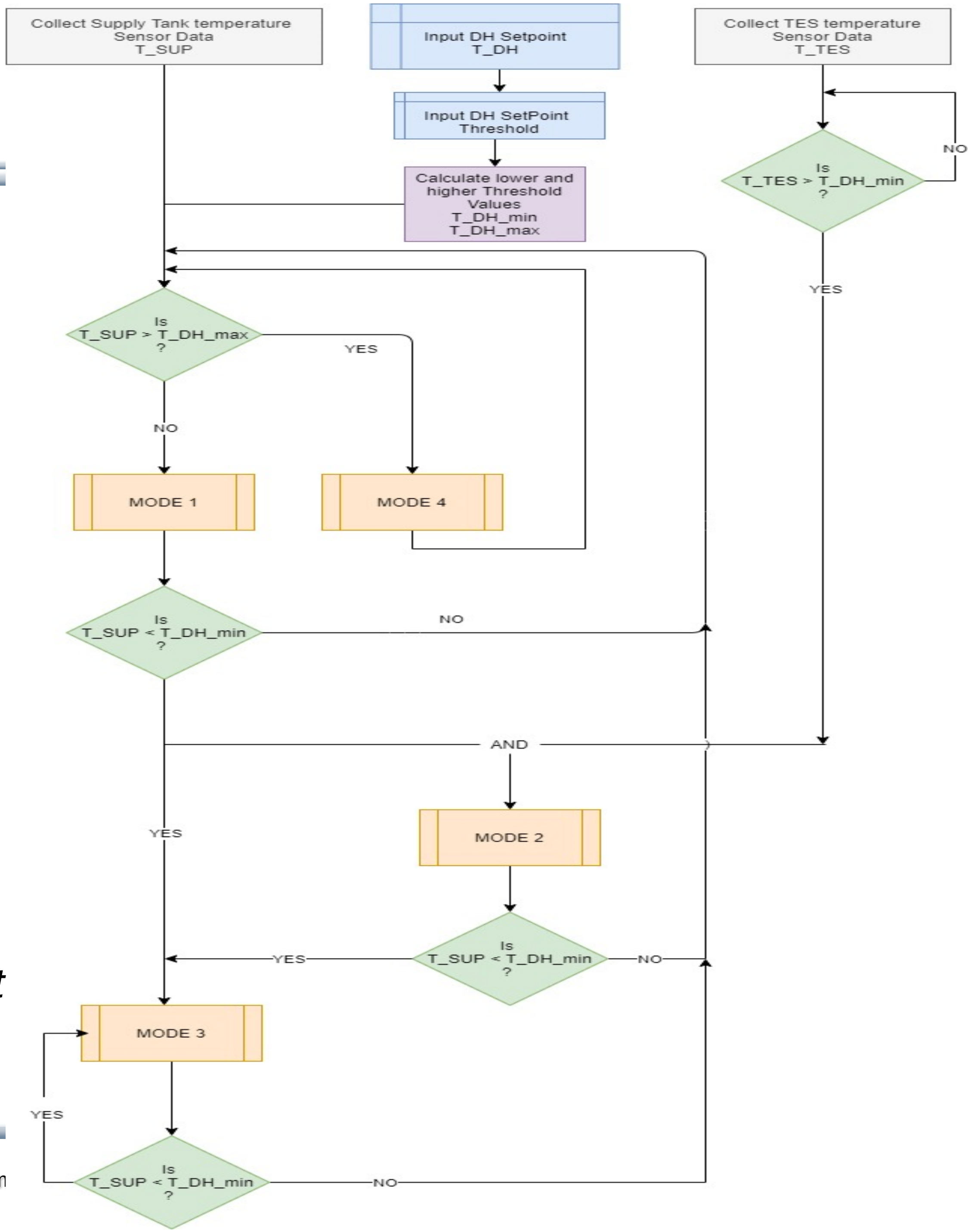


These models are state machine controllers built for specific functions and as central controllers for each scenario.

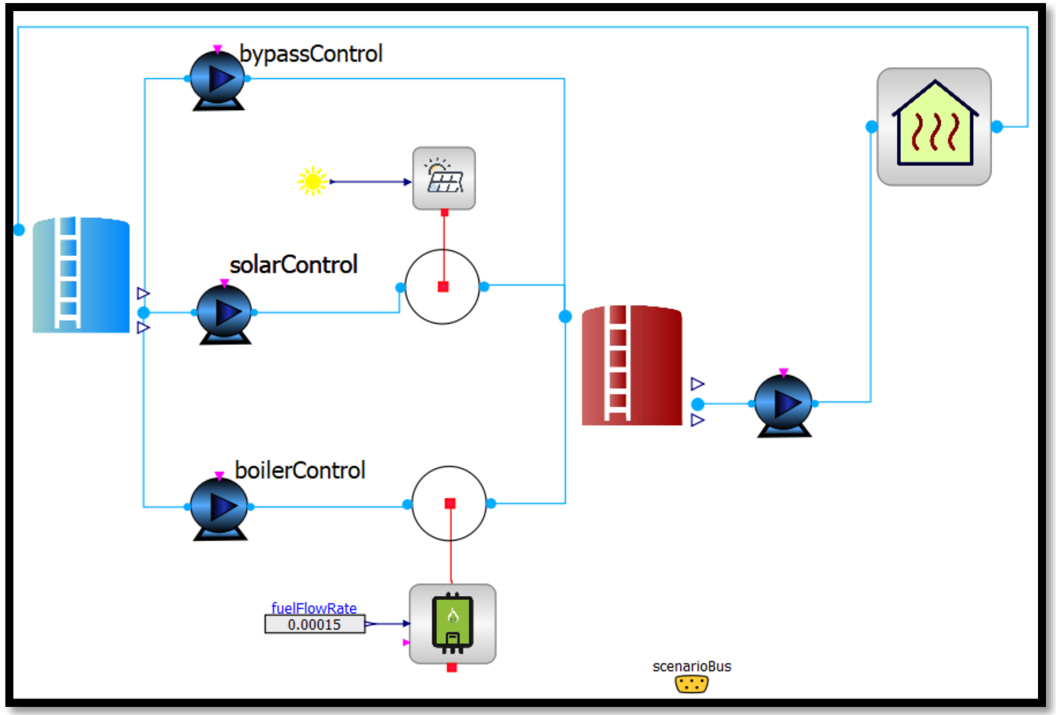


Controller Logic Example:

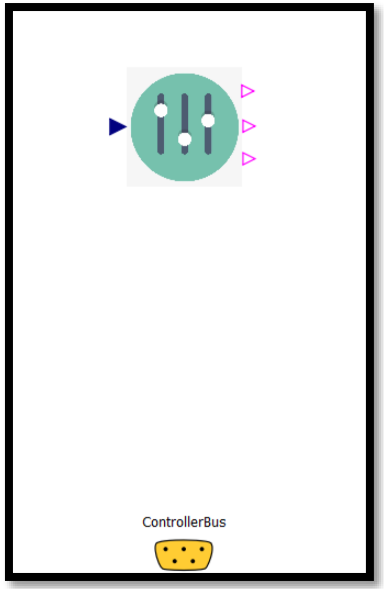
Central Controller Logic used for Scenarios 1,2 and 3 given under *Test Examples* package



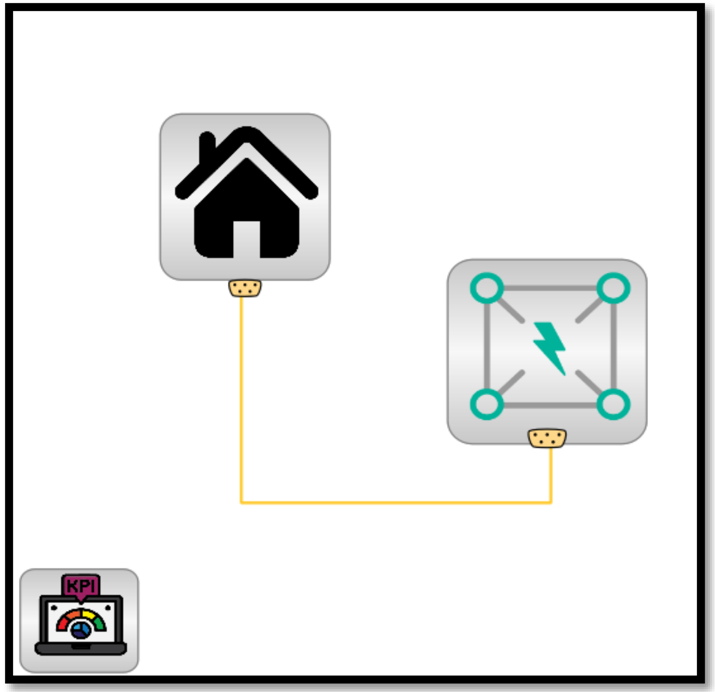
Test Examples – Thermal Scenario 1 – Single House



Single House



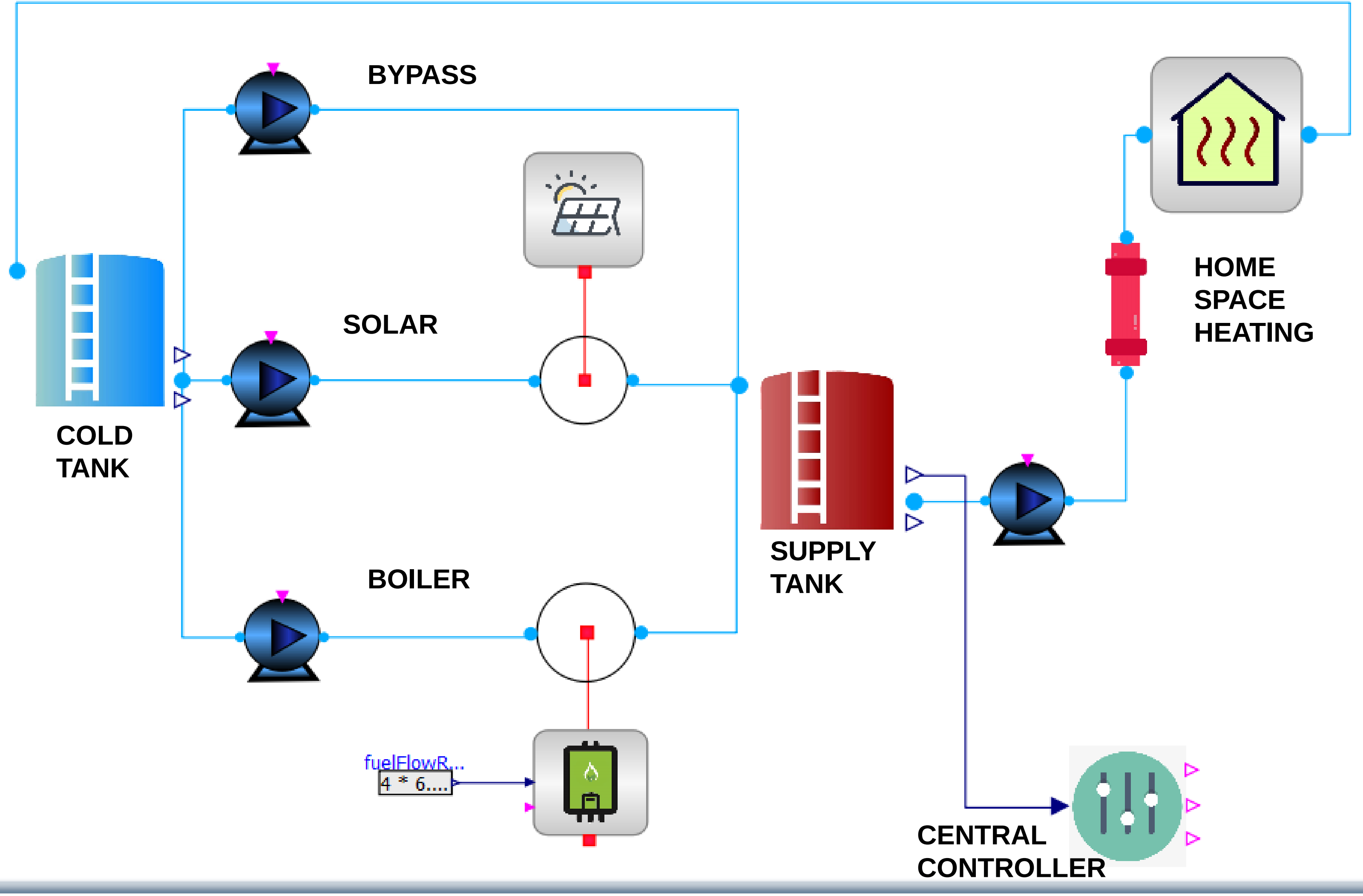
Single House Control



Annual Simulation – Single House

Annual Simulation – Single House

Thermal Scenario 1 – Single House - Results



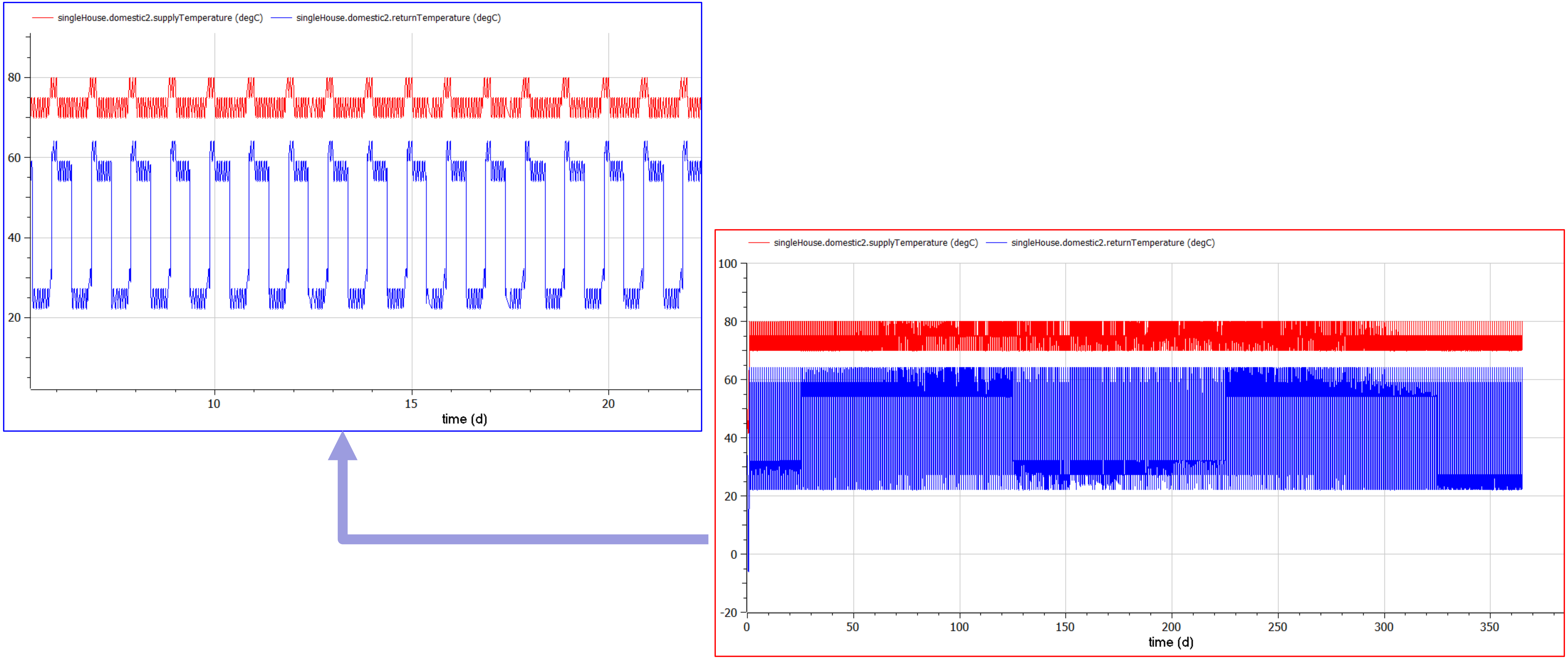
- House of 4 residents
- Heating load of 7000 kWh per year per person

Supply Tank Volume = 20L

Cold Tank Volume = 600L

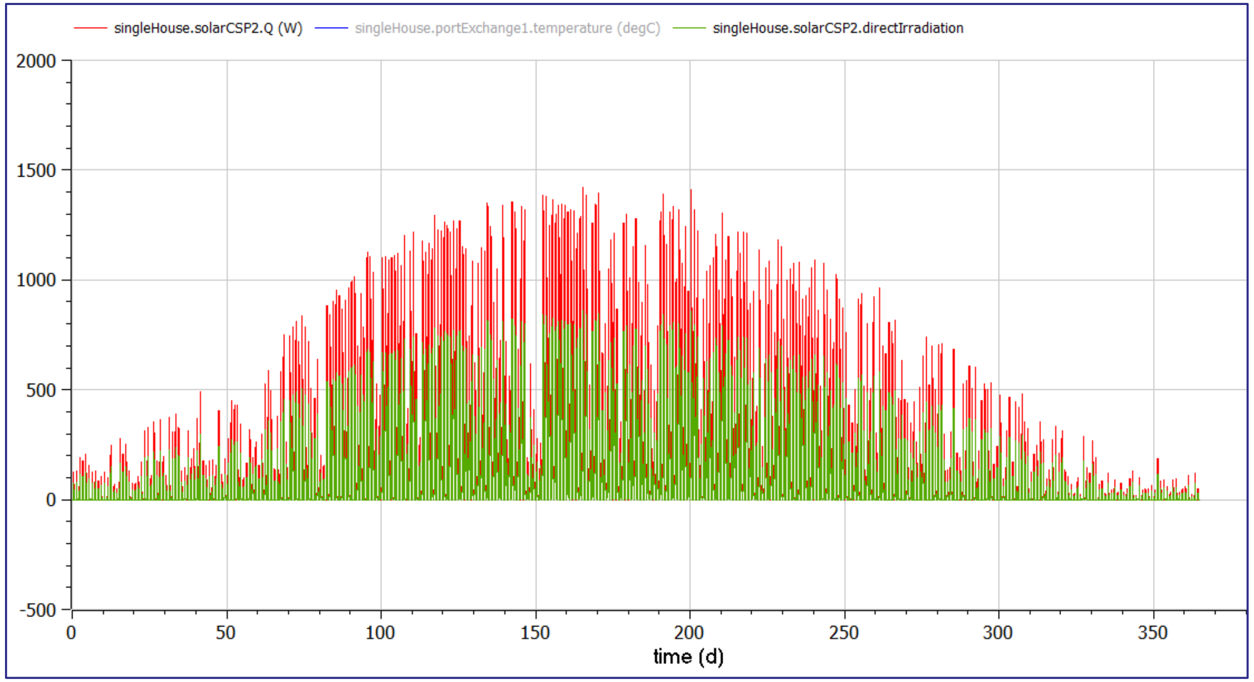
Energy Used per year : 7000 kWh
No. of people per house : 4

Domestic Supply and Return Temperatures



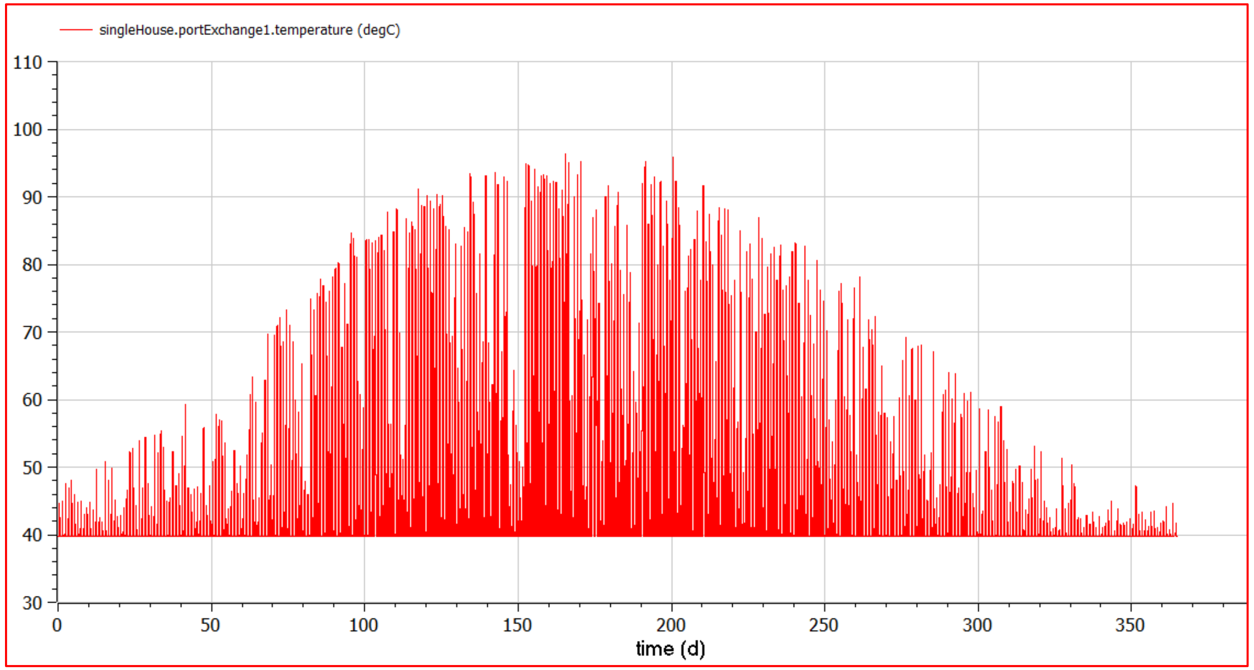
M O D E L I C A

Solar Data



Direct Irradiation Data

Thermal Solar Collector Output Power

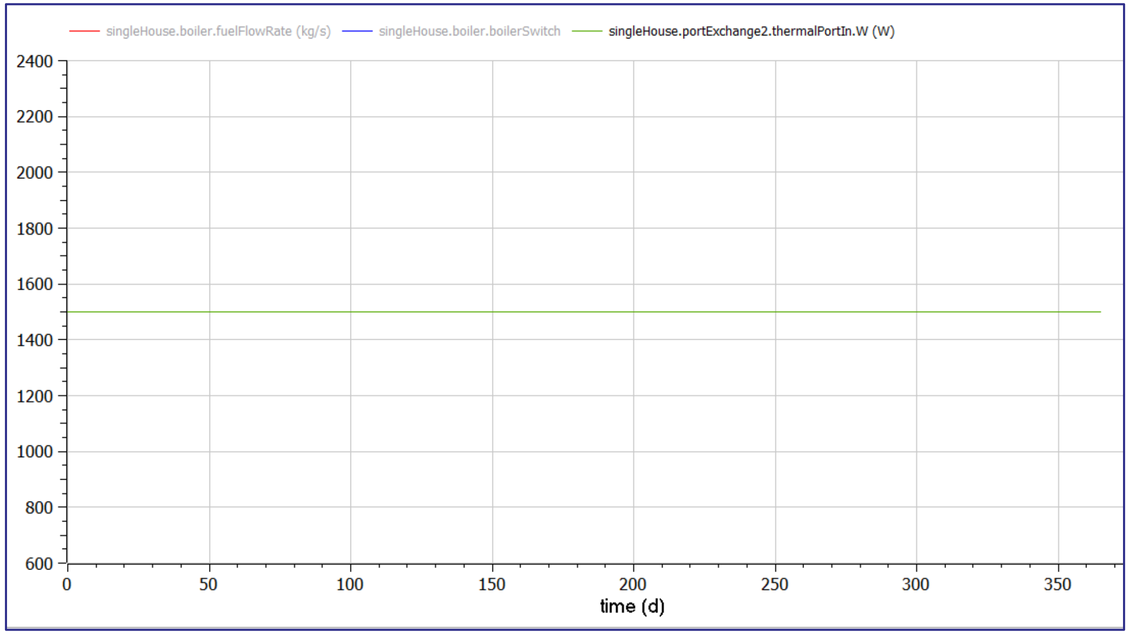


Output Water Temperature

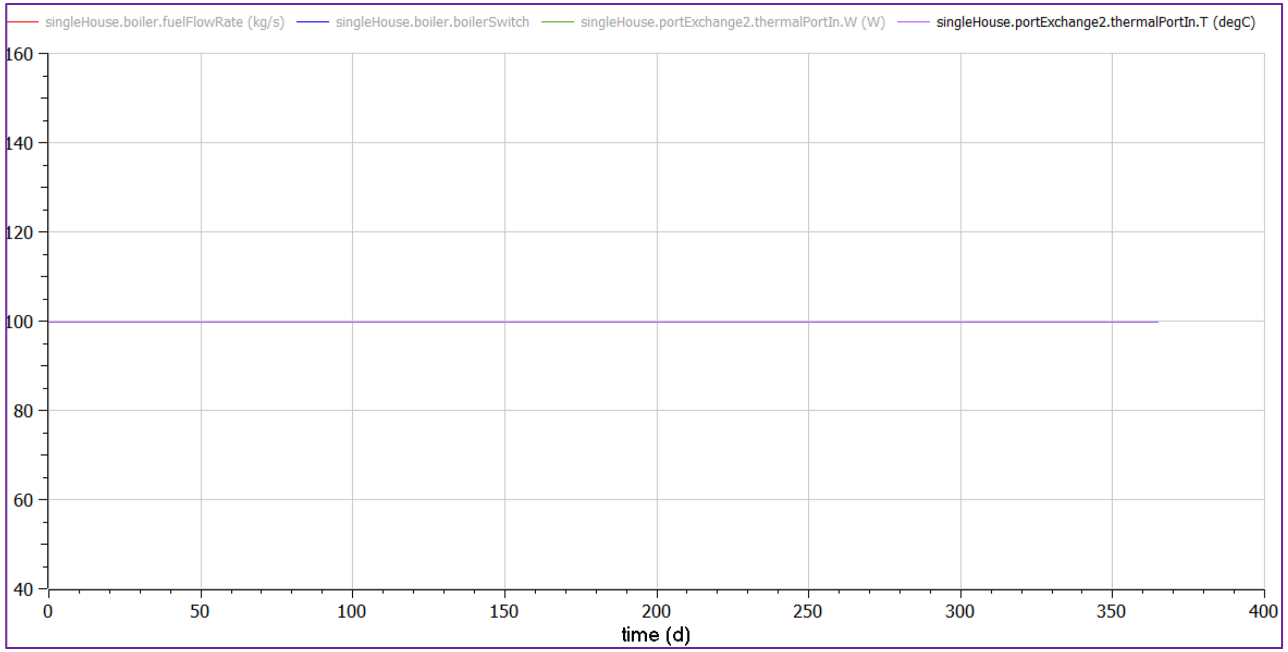
Outlet Temperature

MODELICA

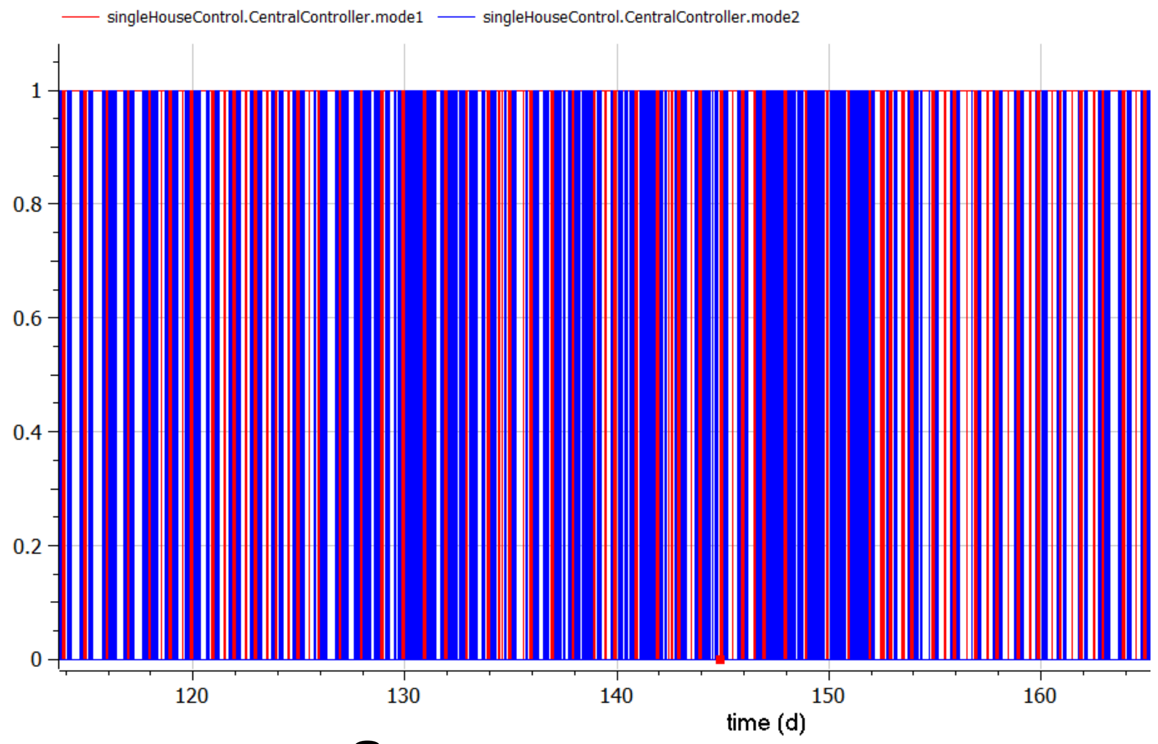
Biomass Boiler



Boiler Water Temperature : 99 ° C
Boiler Power Output : 1500 W



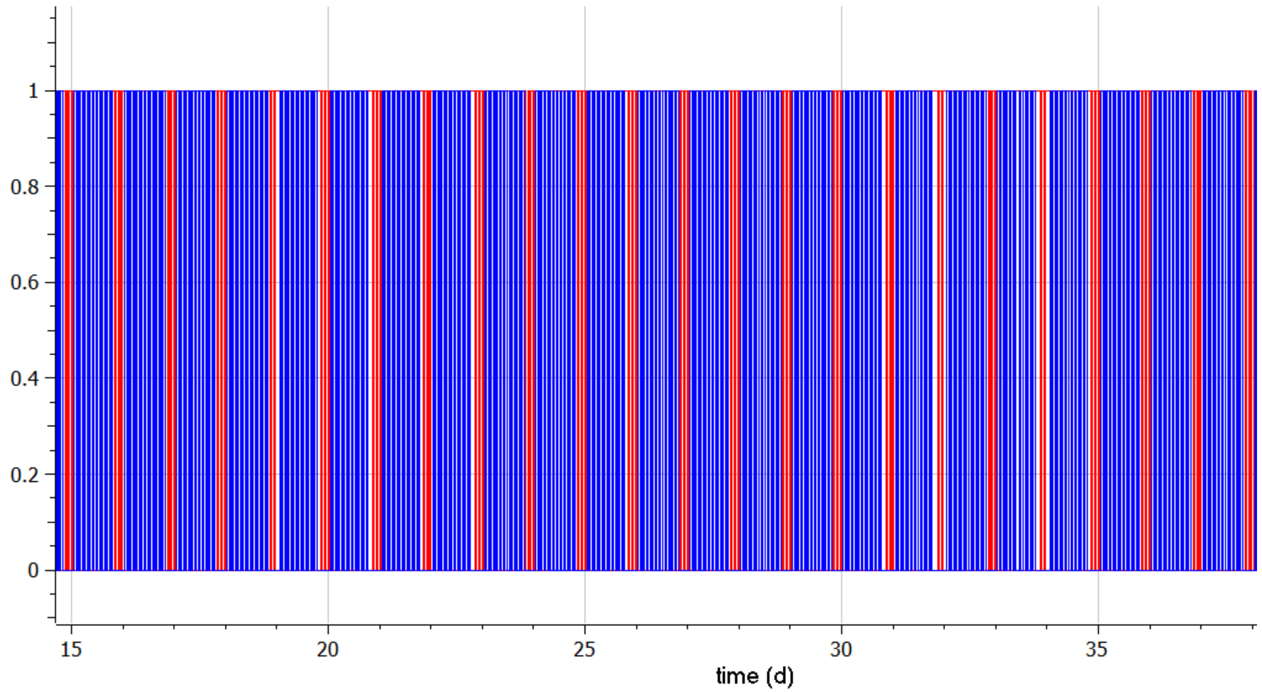
Central Controller Modes



Summer

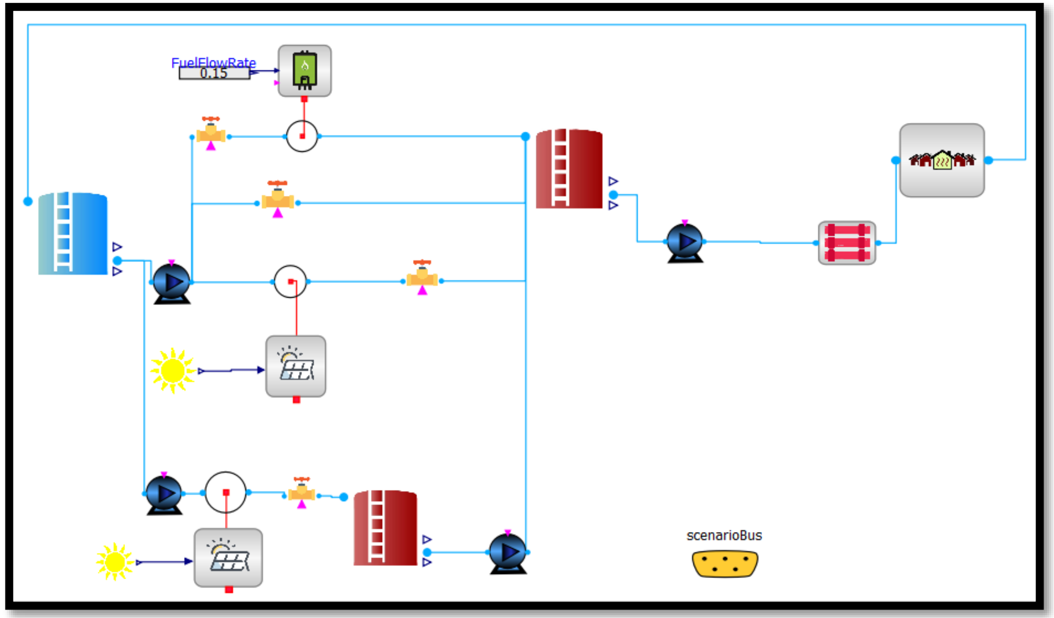
Boiler Mode

Solar Mode

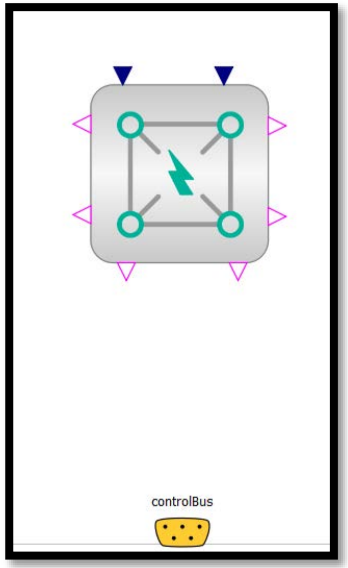


Winter

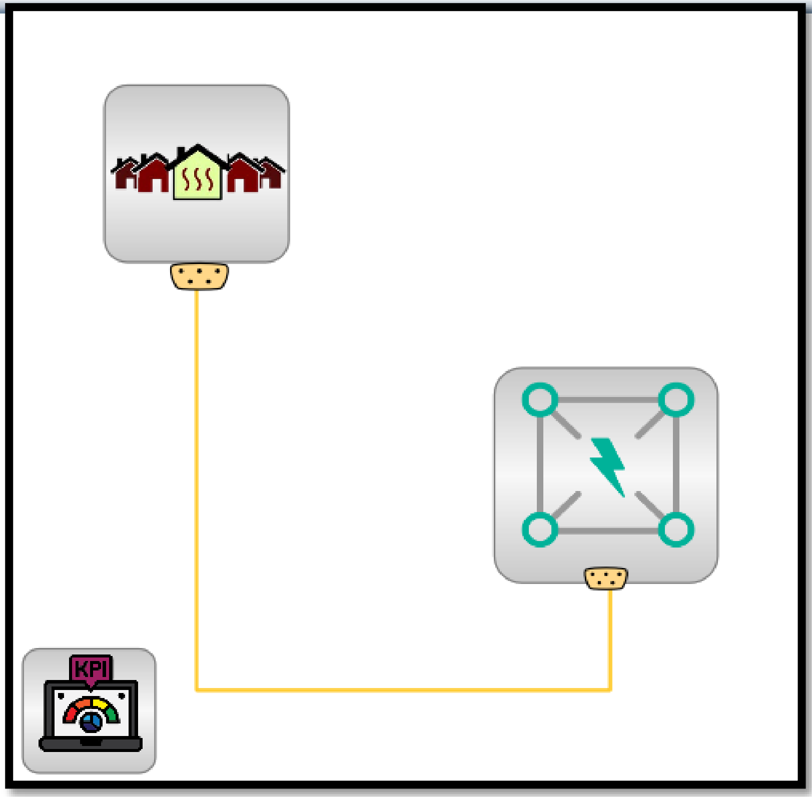
Test Examples – Thermal Scenario 2 (~250 houses)



Small Community



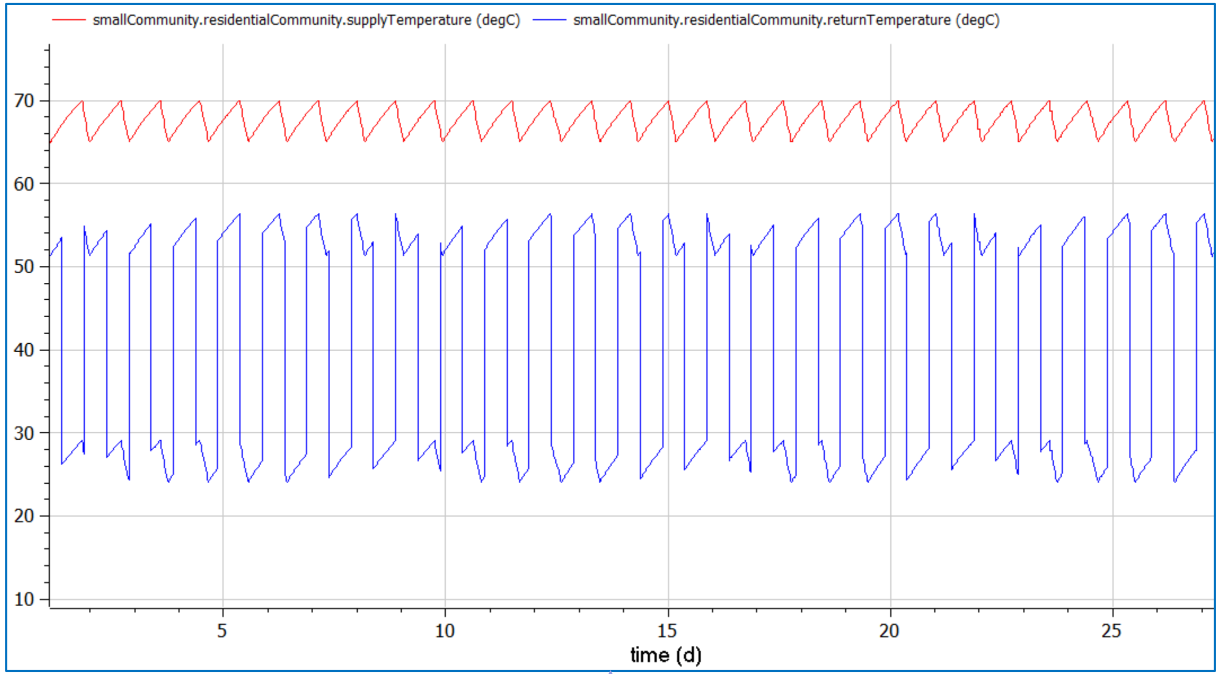
Small Community Control



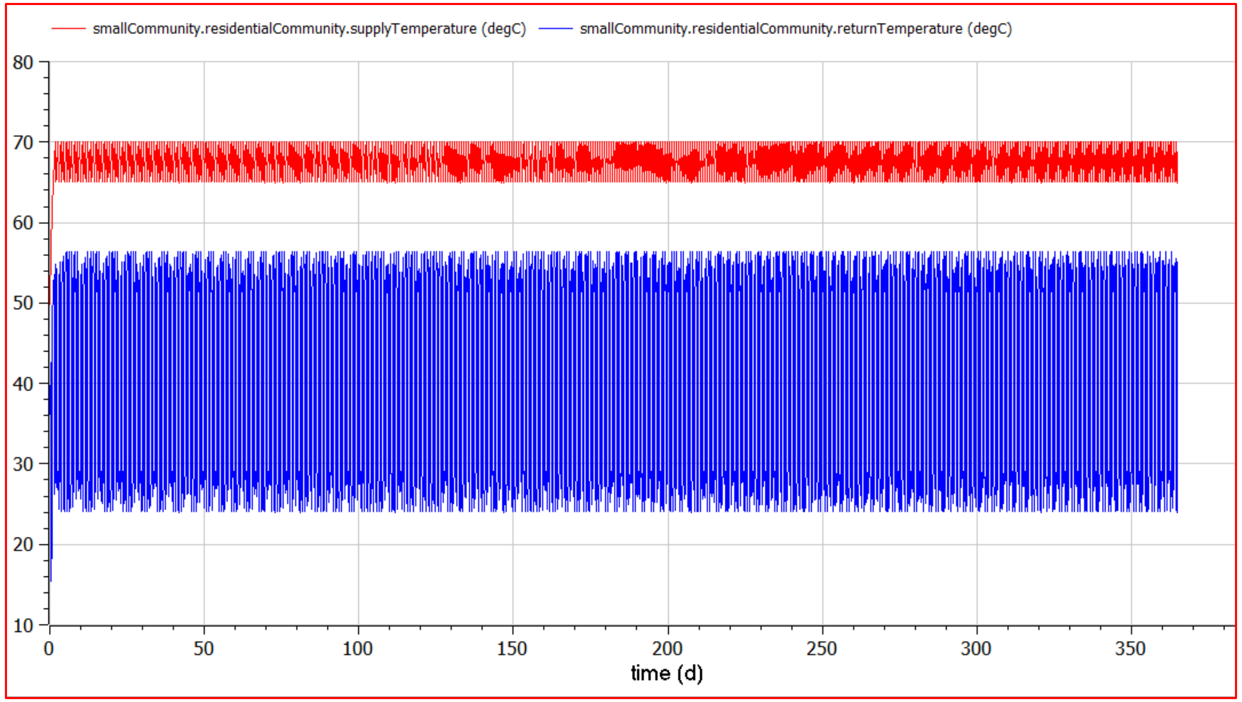
Annual Simulation – Small Community

Annual Simulation – Small Community

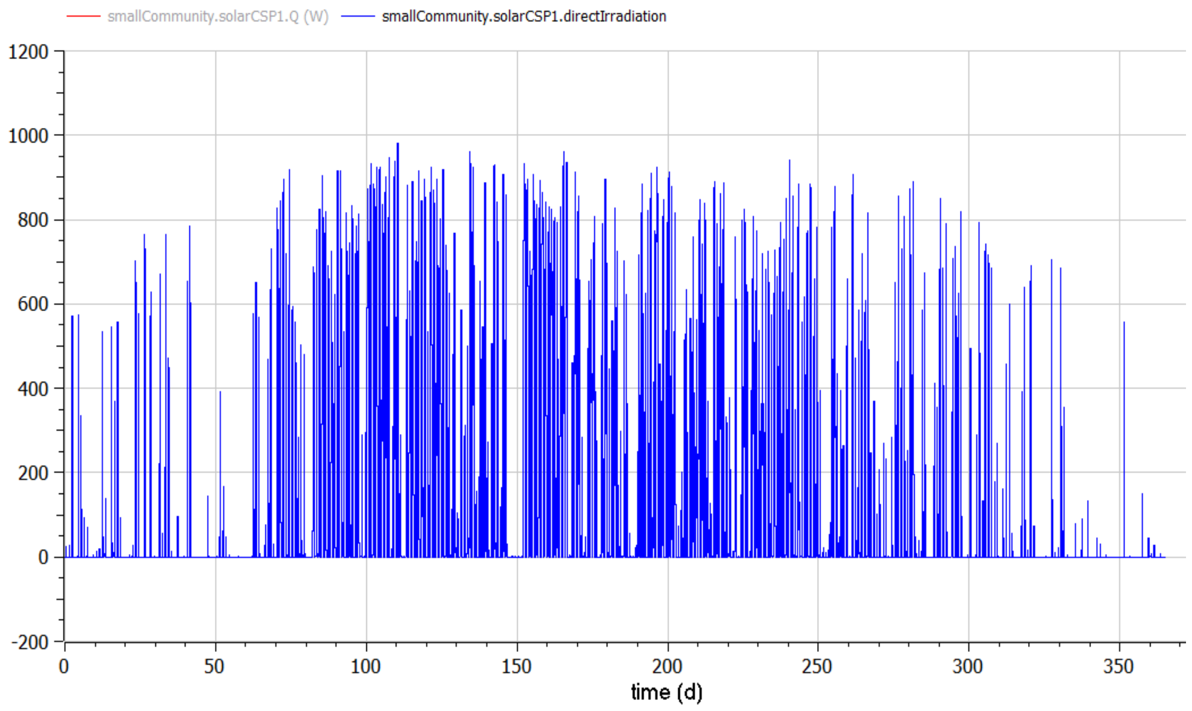
Domestic Supply and Return Temperatures



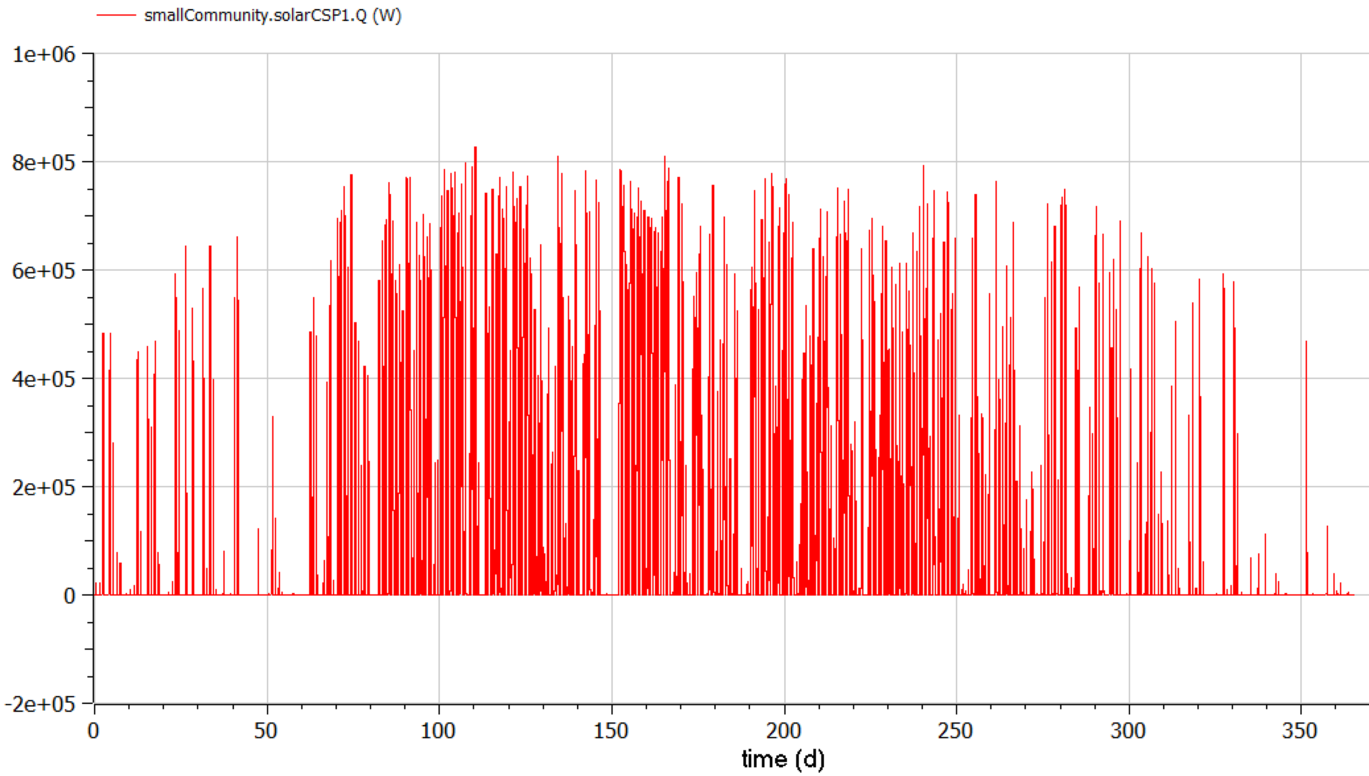
Energy Used per year : 7000 kWh
No. of people per house : 4
No. of houses in the residential community : 250 houses



Solar Data – Solar Thermal



No of collectors	200
Collector Area	5.5 m^2

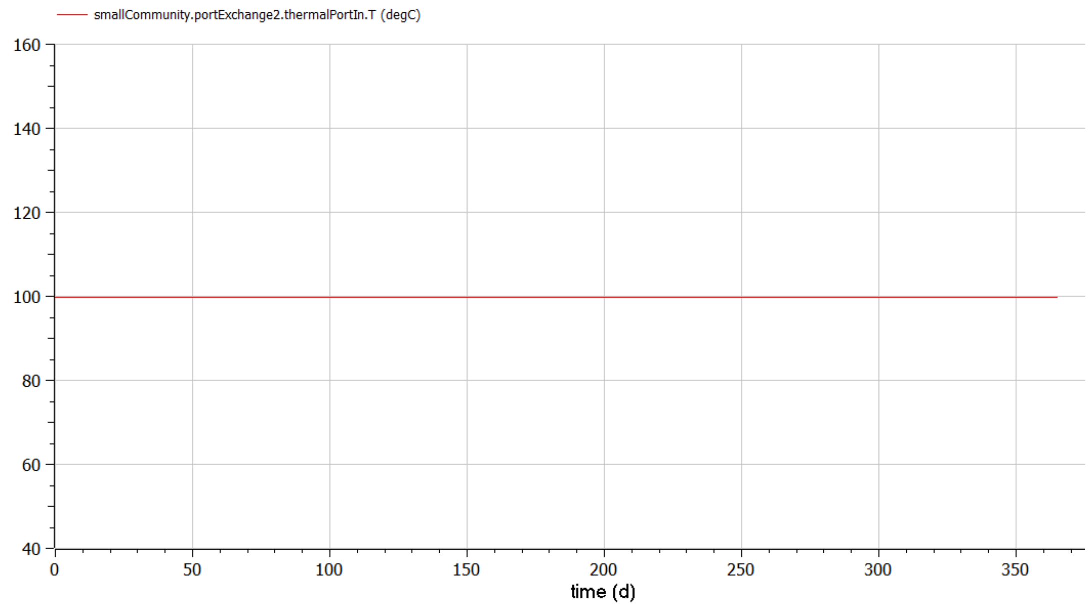


Direct Irradiation Data

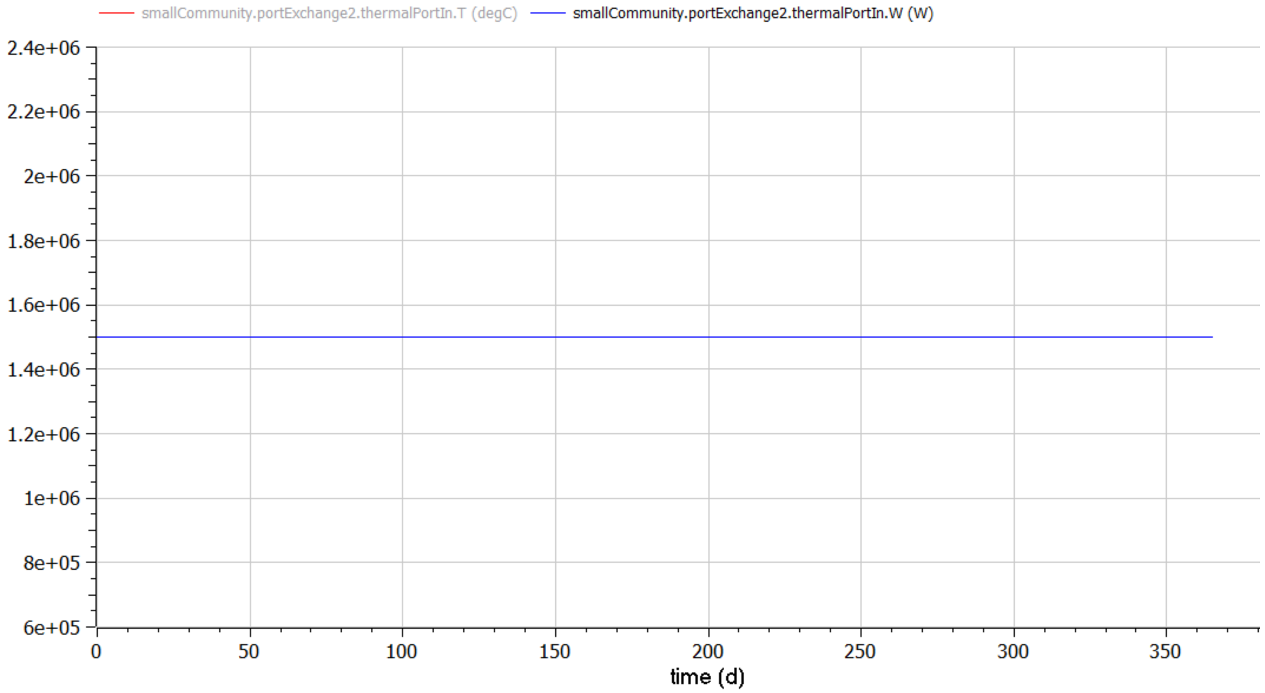
Solar Thermal Collector Output Power

Outlet Temperature

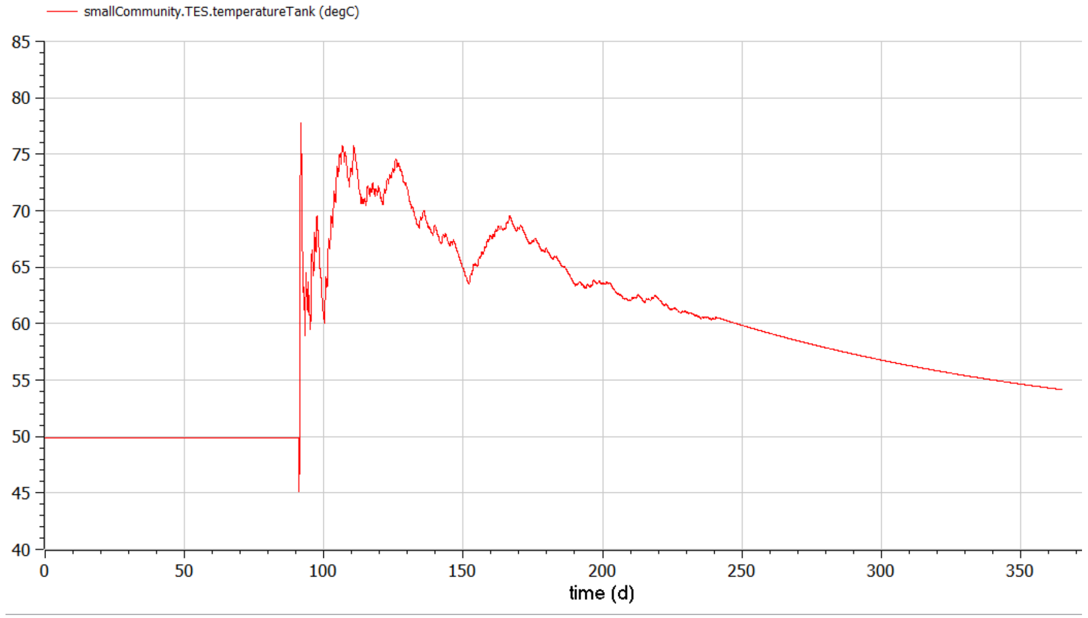
Biomass Boiler



Boiler Water Temperature : 100 ° C
Boiler Power Output : 1500 kW

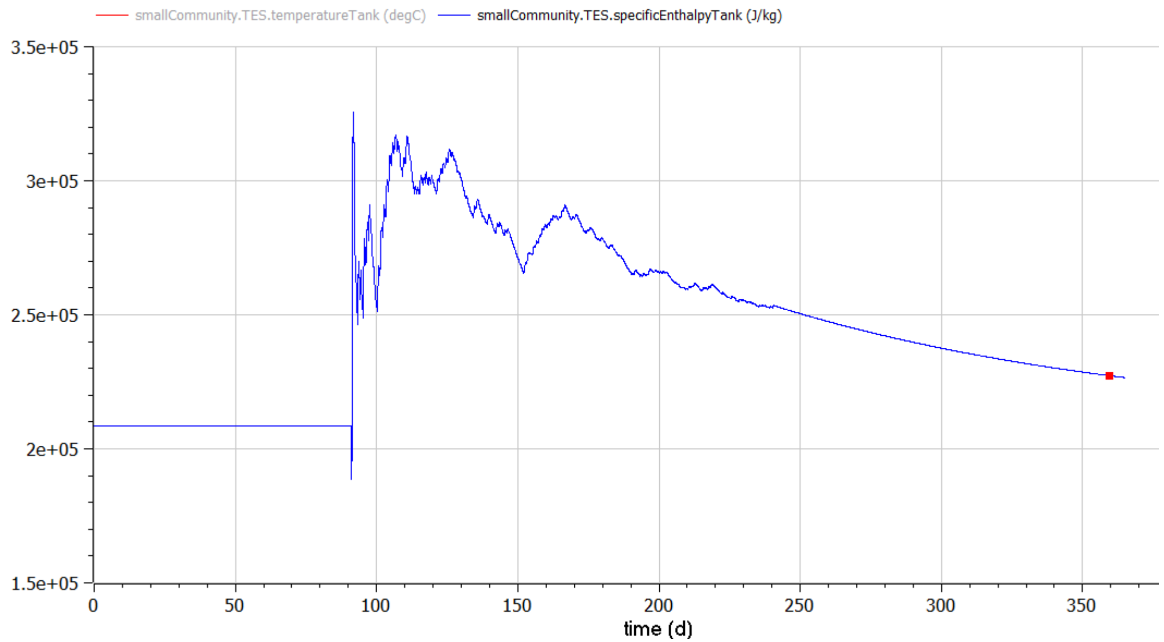


Thermal Energy Storage

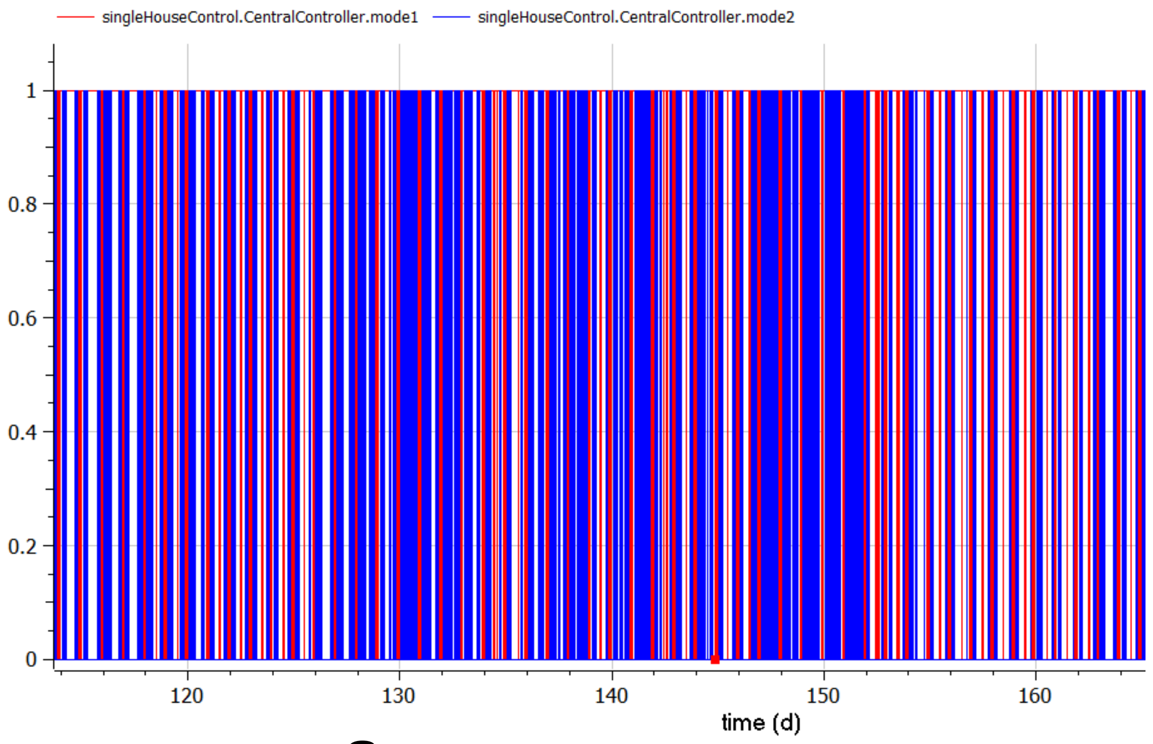


Temperature of the Tank

Heat Storage in Tank



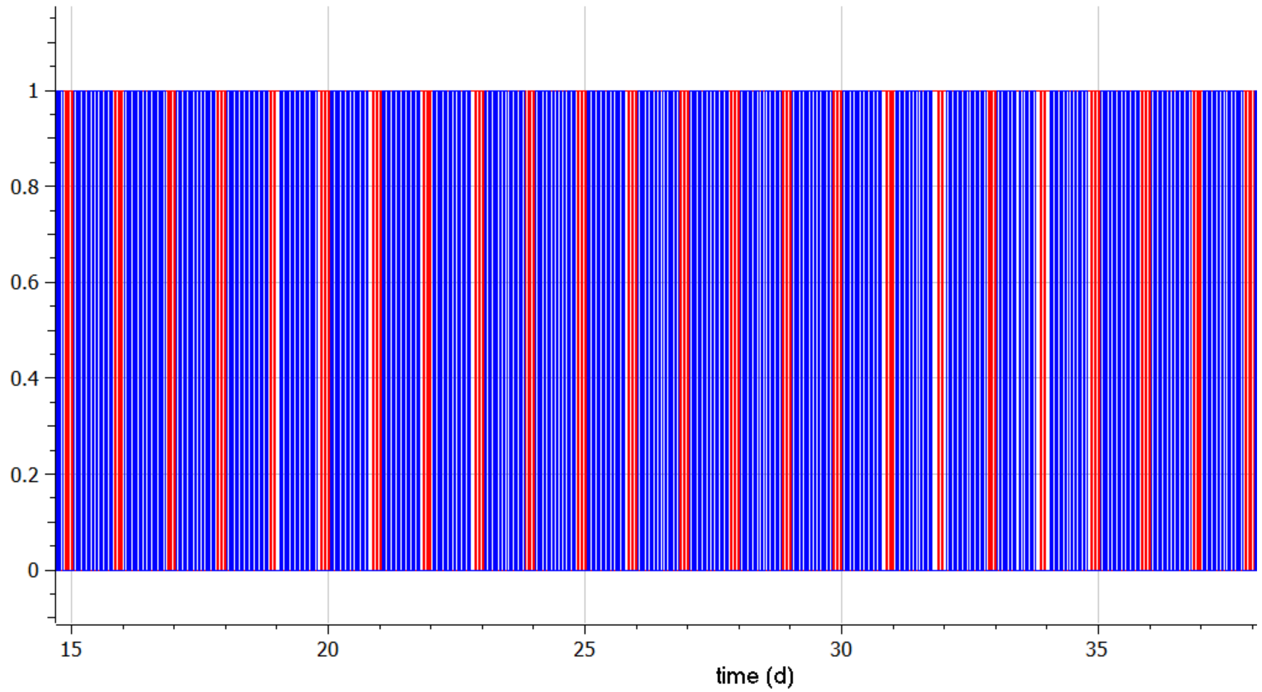
Central Controller Modes



Summer

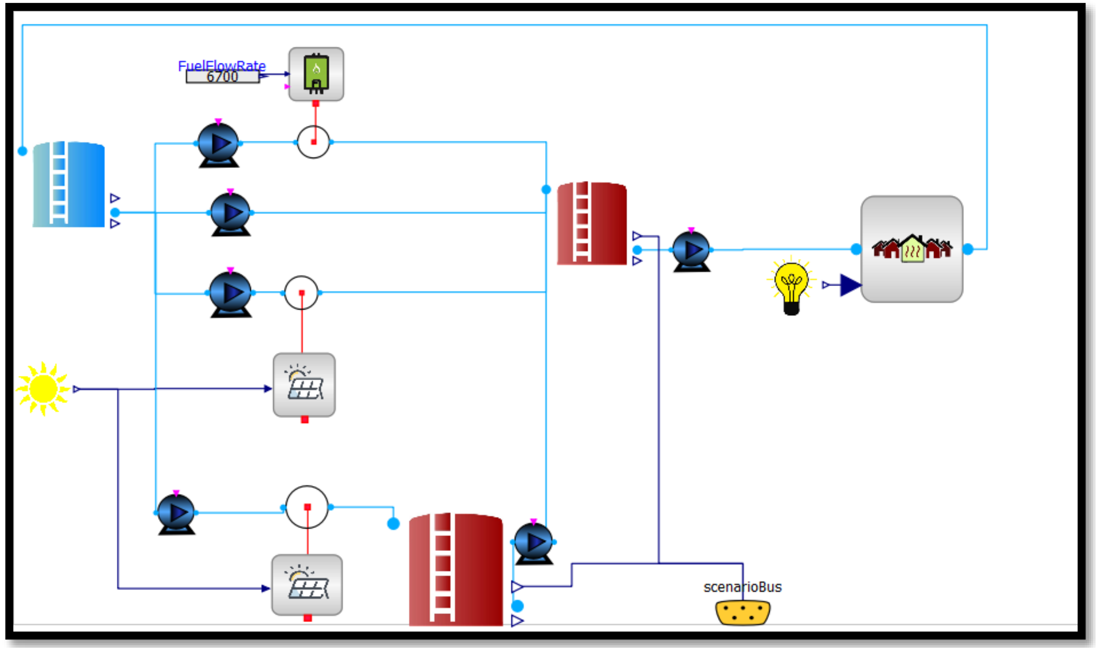
Boiler Mode

Solar Mode

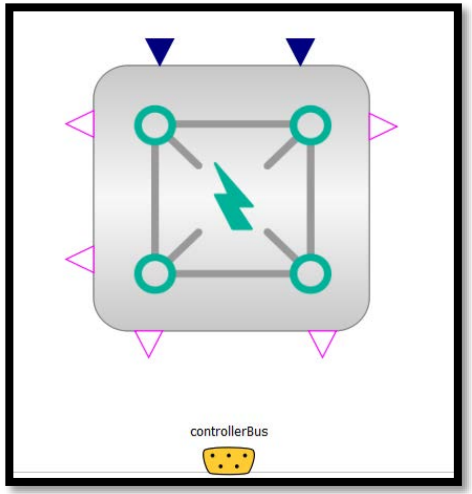


Winter

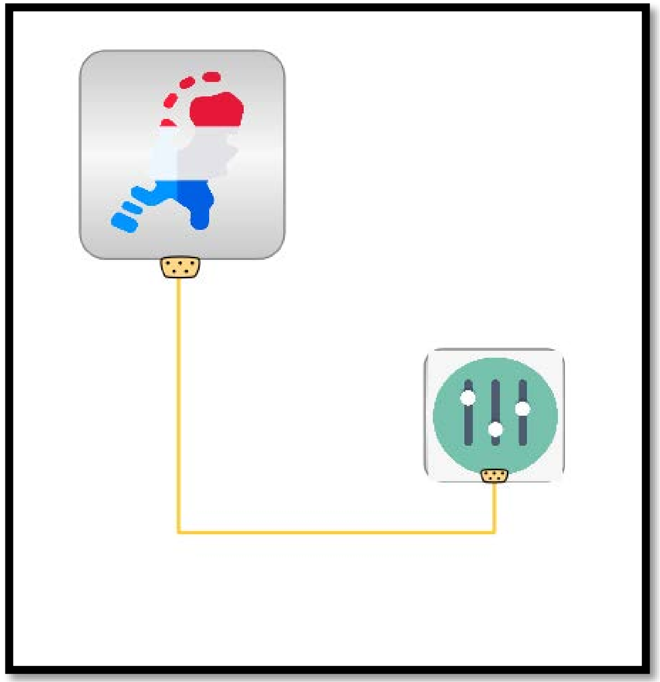
Test Examples – Thermal Scenario 3 (Netherlands - 2013)



Netherlands



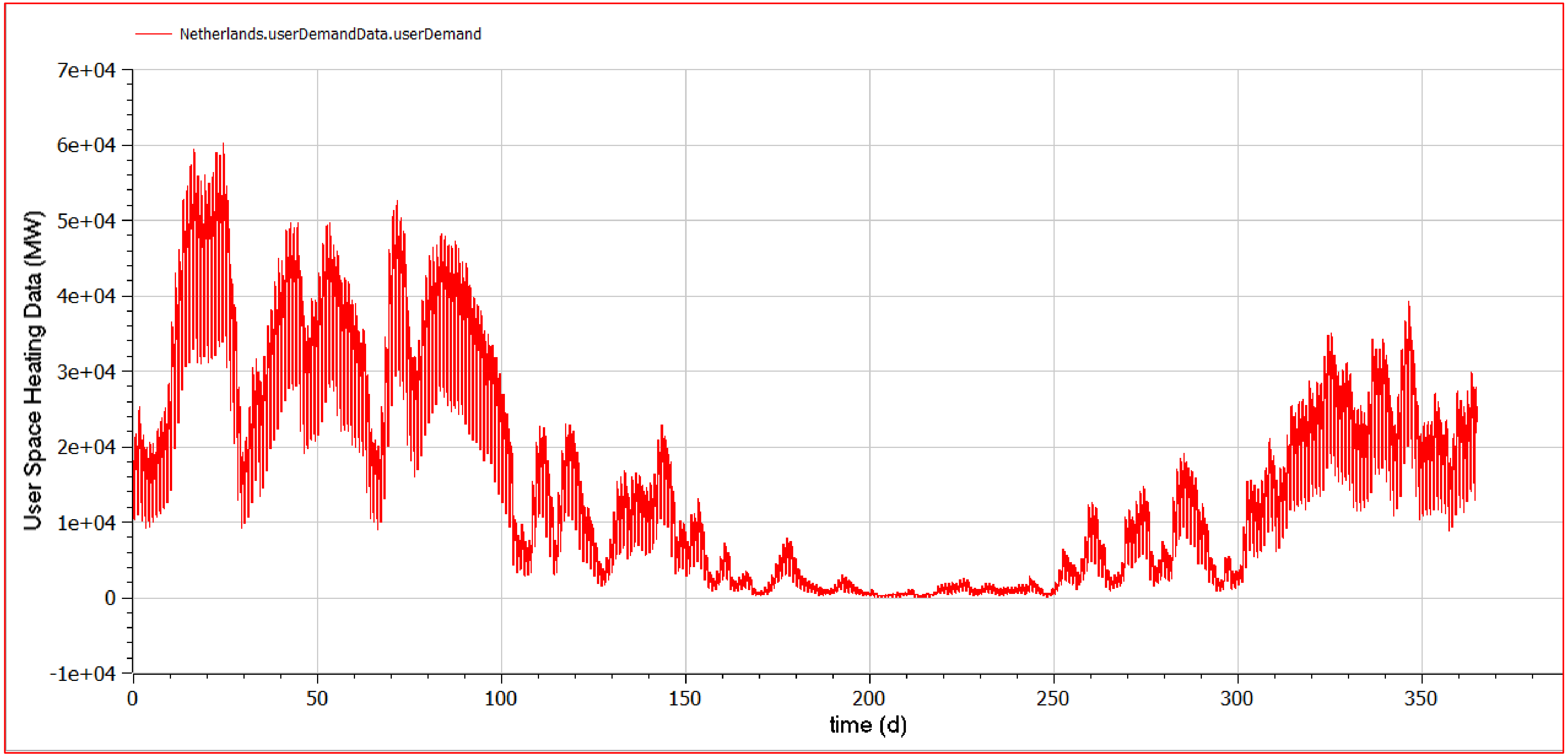
Netherlands Control



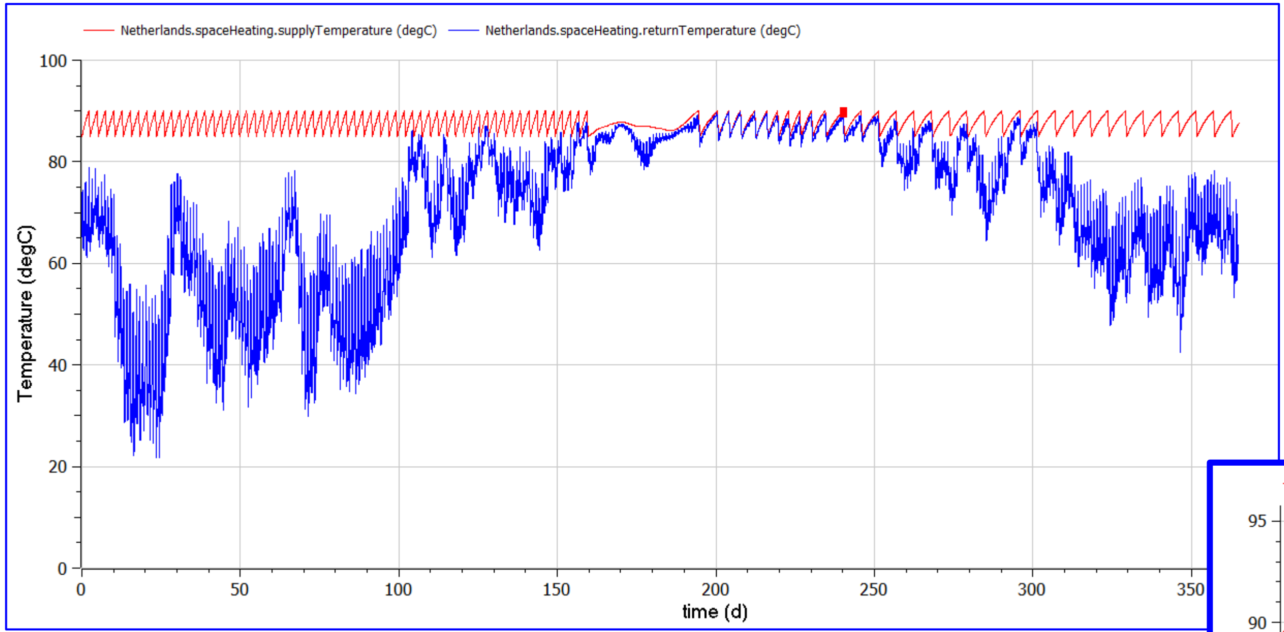
Annual Simulation – Netherlands

Annual Simulation – Netherlands

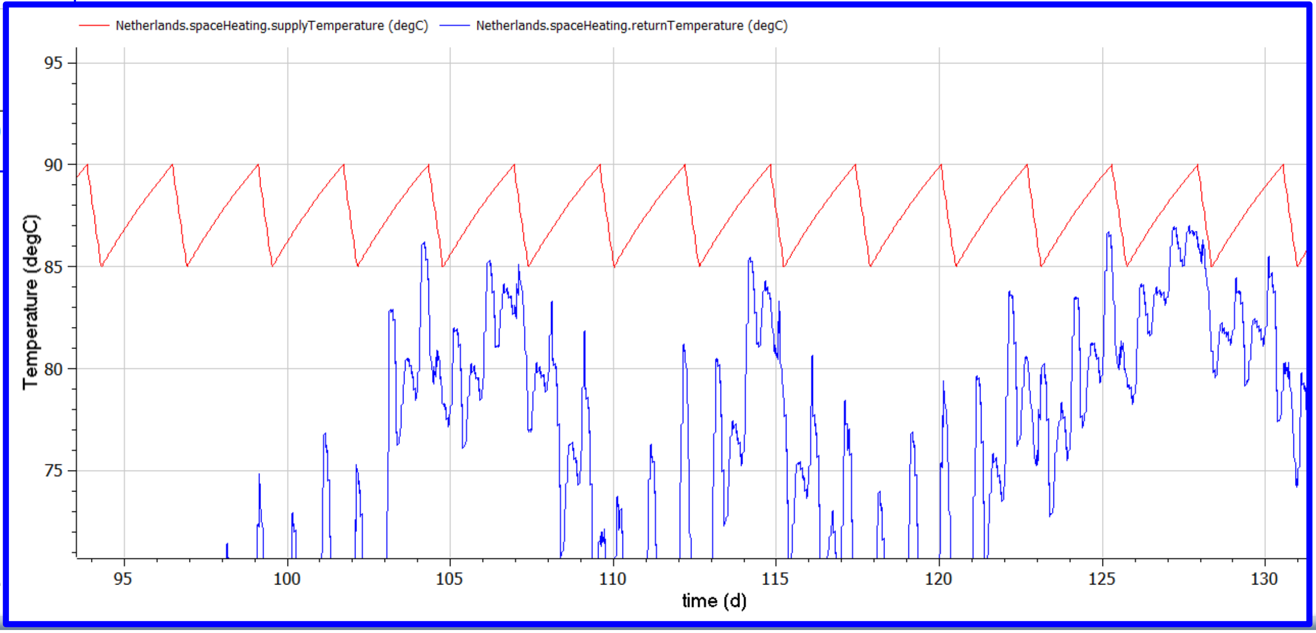
Space Heating Demand Data(MW) - 2013



Domestic Supply and Return Temperatures

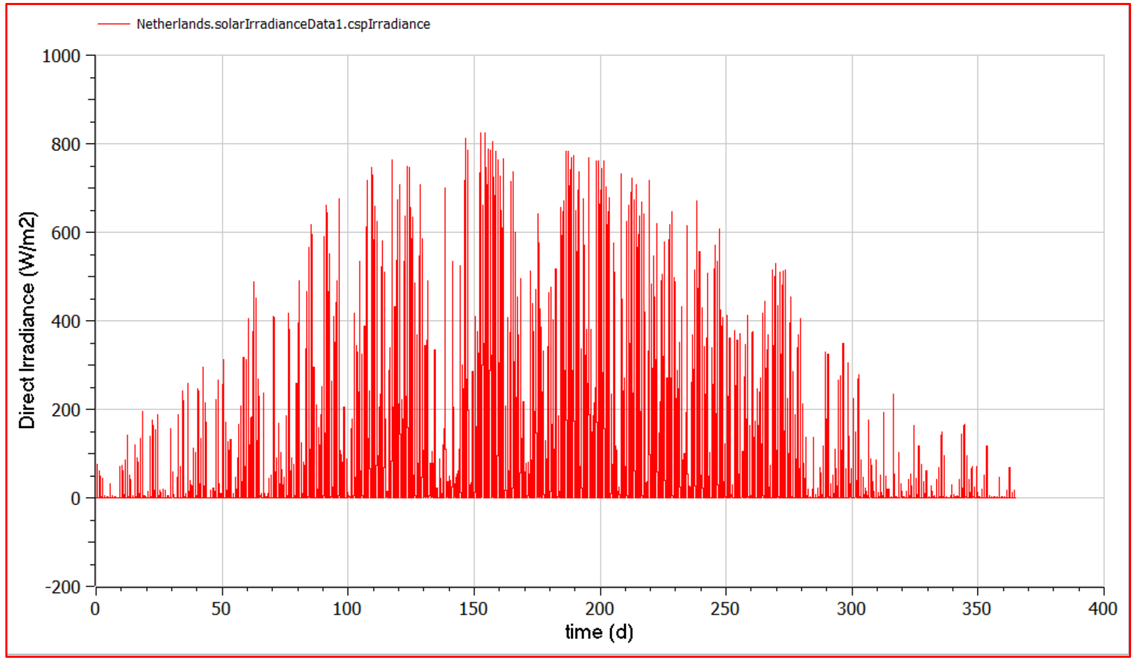


Zoomed In profile

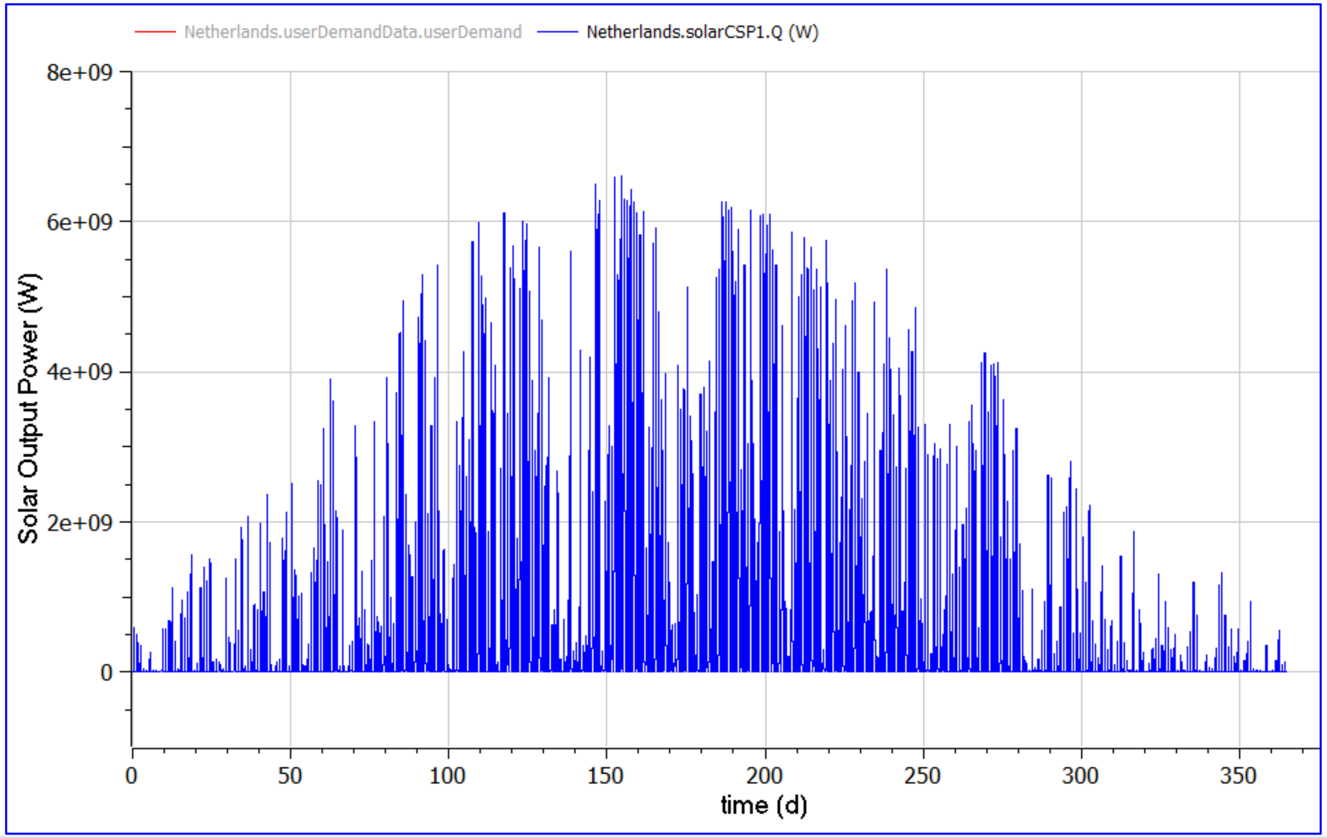


MODELICA

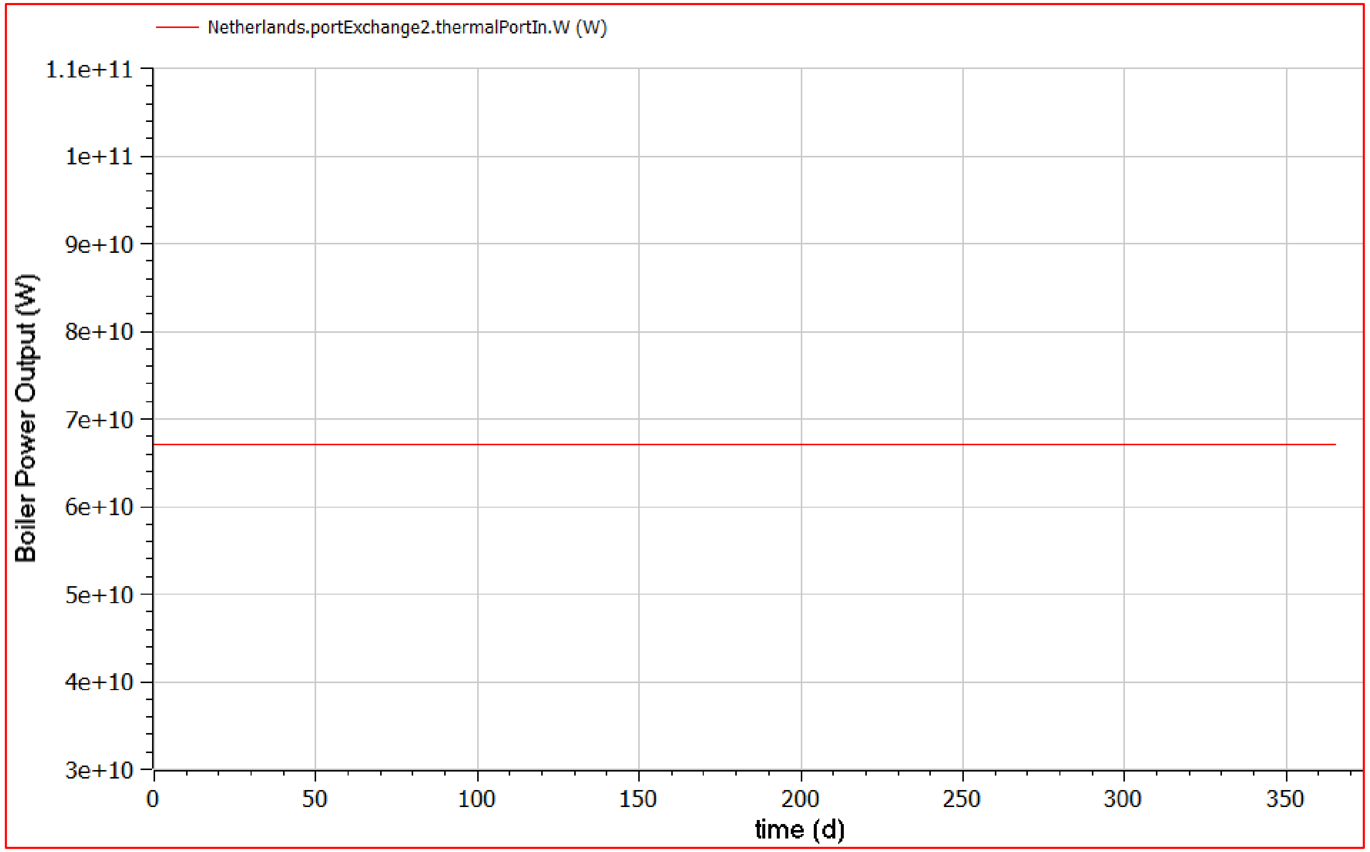
Solar Irradiance Data (W/m2) and Output Power



No of collectors	1900000
Collector Area	5.5 m^2

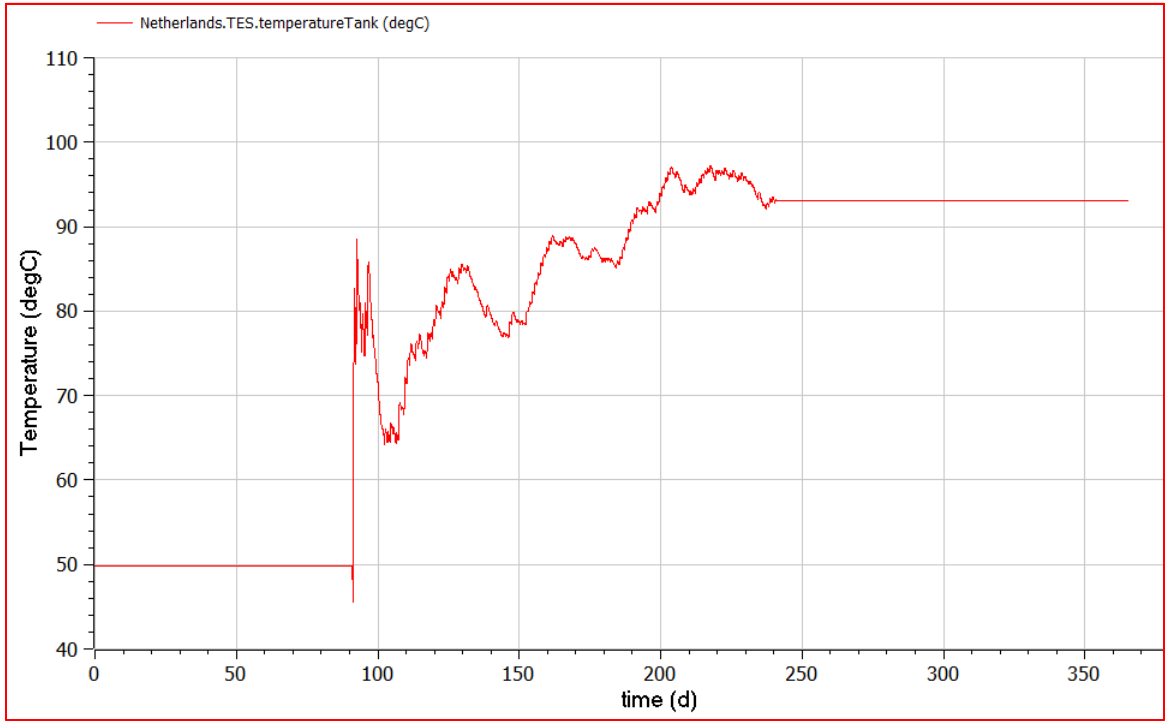


Biomass Boiler



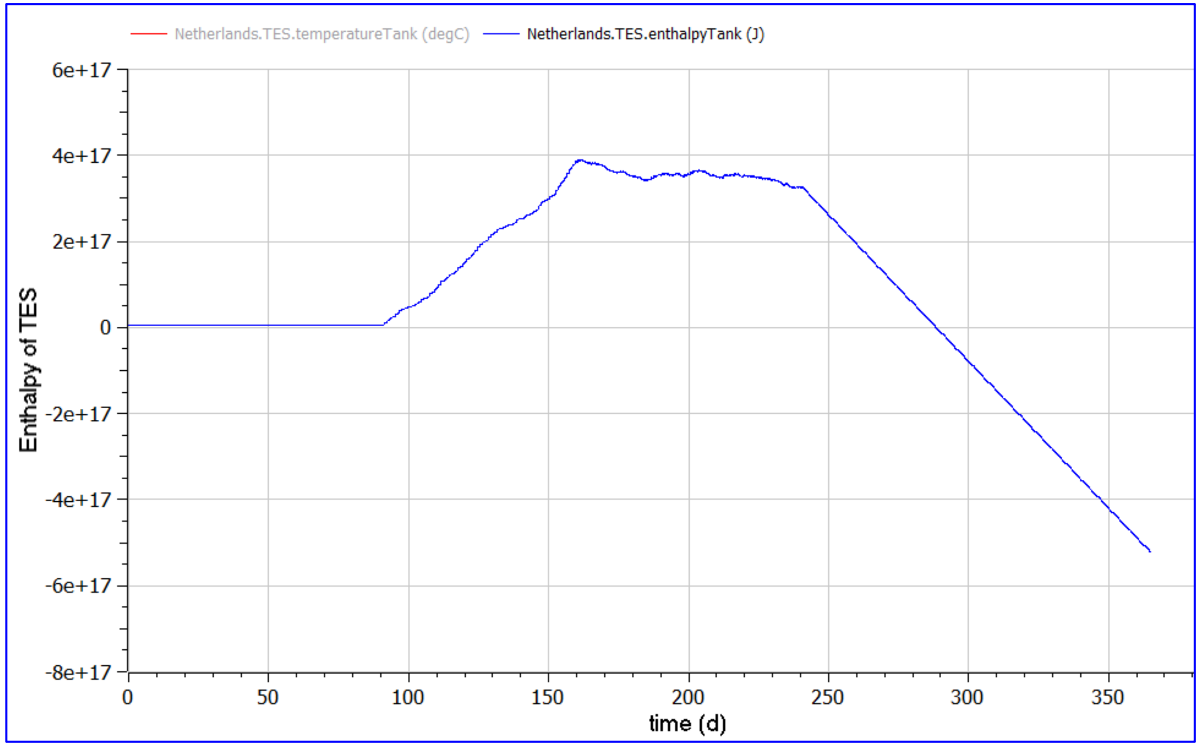
Boiler Water Temperature : 99 ° C
Boiler Power Output : 6700 MW

Thermal Energy Storage



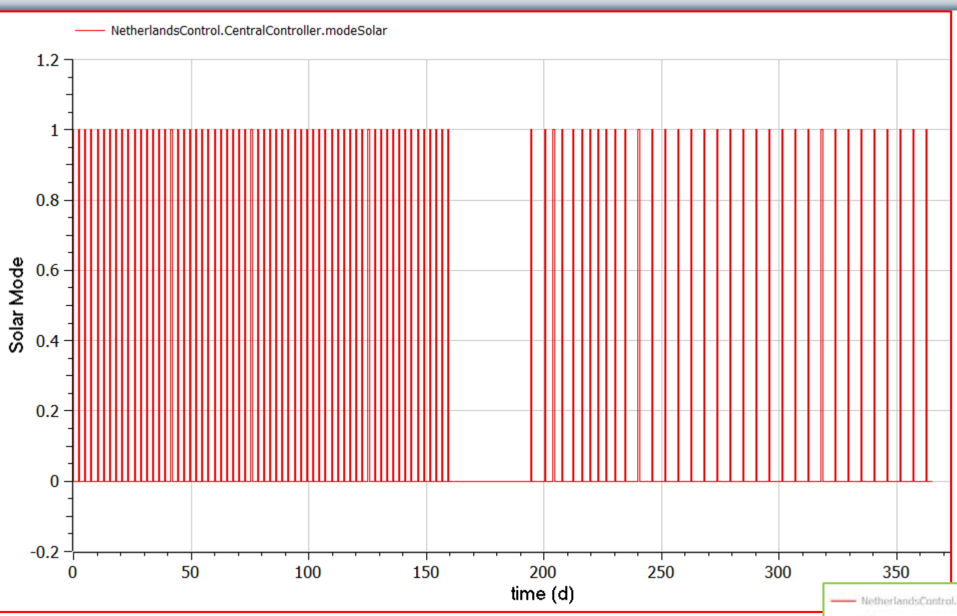
Temperature of the Tank

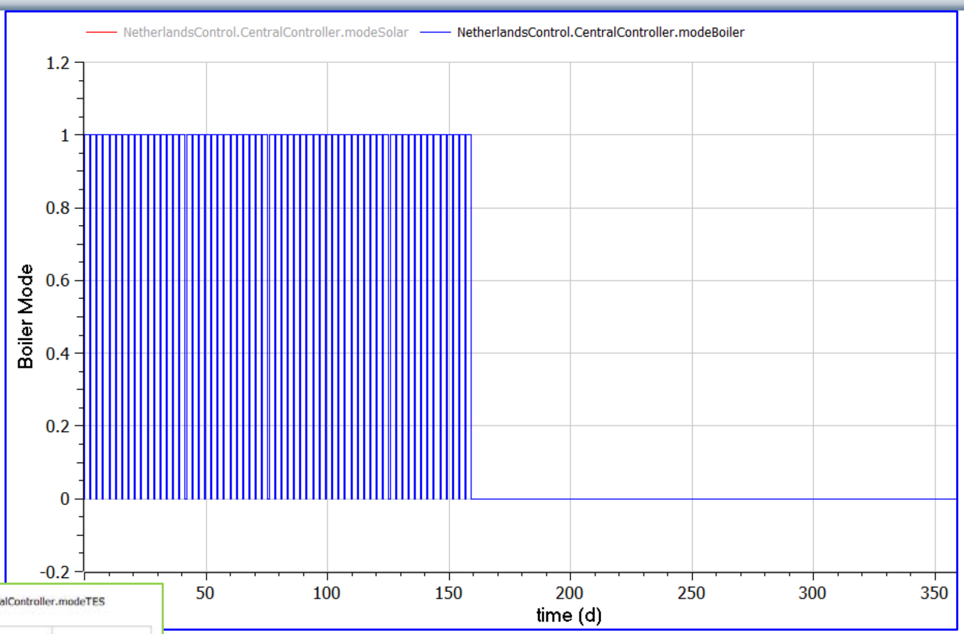
Heat Storage in Tank

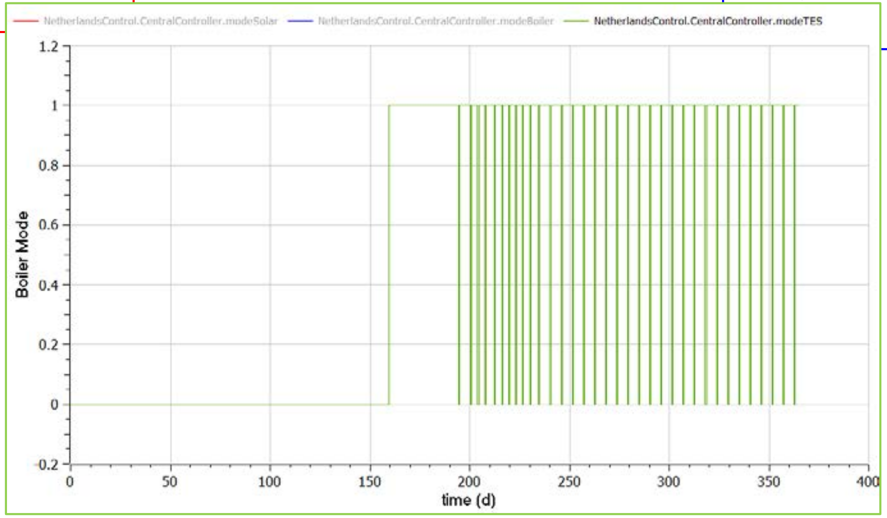


Thermal energy storage charged during summer months when heat load is less.

Central Controller Modes







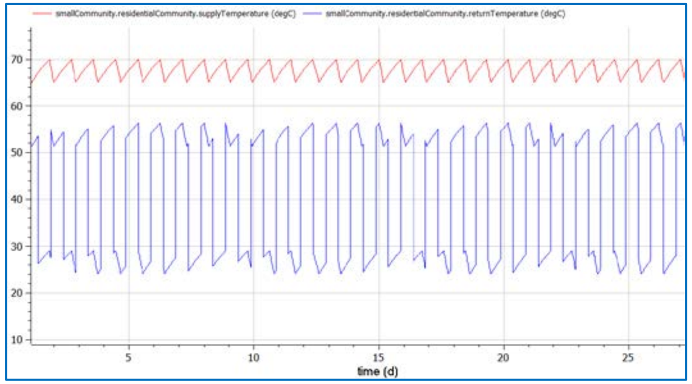
Boiler Mode

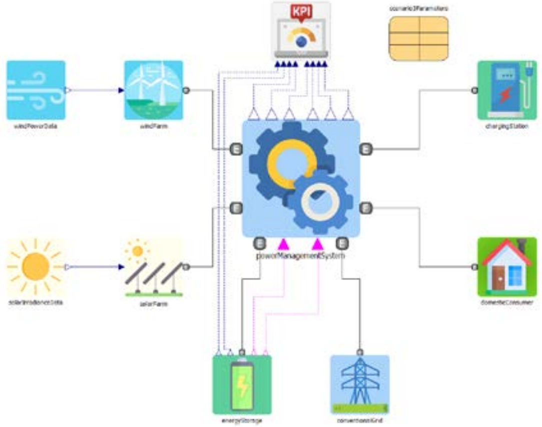
Solar Mode

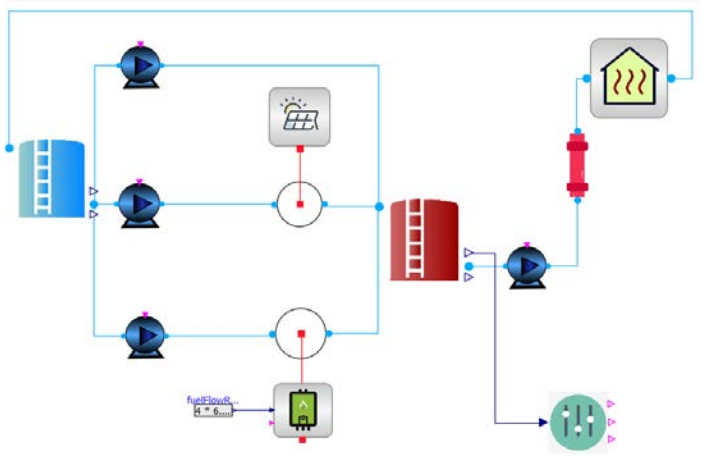
Thermal storage discharge Mode

Conclusions

- We have developed a Solar Thermal and Electric **Energy Library** and Scenarios
- Available as **open source**, OSMC-PL license, for general usage
- It is an **easy-to-understand low-to-medium** complexity library
- Easily **extensible** to include more model details
- Both **electric** and **thermal solar** energy, and wind power
- Thermal and electric energy **storage**
- Simple **controller** models
- Need to calibrate with better input data







MODELICA

Solar Data

Source : Swedish SMHI (weather institute) in Norrköping

data-hourly-radiation-data-rad1h_92071_200701-202109 - Notepad

File Edit Format View Help

```
%1-hour means or sums of meteorological radiation data.
%SMHI radiation station 92071, Norrköping.
%Latitude= 58.583 degN, Longitude= 16.152 degE, Altitude= 43 m.
%Hour 0 represents data collected during the hour 00:00-00:59 UTC (SNT-1).
%Hourly mean irradiance values with unit of W/m² can also be regarded as hourly accumulated irradiation with unit of Wh/m².
%Xqf stand for "quality flag" for parameter X and is given as a 1-digit code for every observed value.
%Xqf= 1; Properly measured value.
%Xqf= 2; Hourly mean or sum value calculated from properly measured values from redundant measurements. Examples: G replaced by GID (advanced stations), SDIss replaced by SDG.
%Xqf= 3; Hourly mean or sum value calculated from 48 or more correct 1-minute mean values.
%Xqf= 4; Value interpolated from correct hourly values immediately before and after one erroneous/missing value.
%Xqf= 5; Modelled value, special case for I, D, and GID during tracker failure at advanced stations.
%Xqf= 6; Modelled value.
%Xqf= 7; Not yet defined/used.
%Xqf= 8; Manually corrected value.
%Xqf= 9; Missing value.
%File contents:
%Param:YYYY MO DA HO(UTC) Az Elev I qfI D qfD G qfG L qfL TA qfTA RH qfRH
%Units:YYYY MO DA HO(UTC) deg deg W/m² - W/m² - W/m² - W/m² - °C - % -
2007 01 01 00  34.386 -50.248   0.0 1    0.0 1    0.0 1  293.8 1    4.7 1   83.9 1
2007 01 01 01  53.487 -44.845   0.0 1    0.0 1    0.0 1  306.1 1    4.3 1   86.2 1
2007 01 01 02  69.678 -38.000   0.0 1    0.0 1    0.0 1  324.6 1    4.3 1   89.1 1
2007 01 01 03  83.768 -30.423   0.0 1    0.0 1    0.0 1  329.0 1    4.4 1   91.4 1
2007 01 01 04  96.595 -22.637   0.0 1    0.0 1    0.0 1  329.6 1    4.5 1   93.2 1
2007 01 01 05 108.825 -15.039   0.0 1    0.0 1    0.0 1  323.3 1    4.8 1   93.5 1
2007 01 01 06 120.954  -7.972   0.0 1    0.1 1    0.1 1  301.7 1    5.0 1   93.4 1
2007 01 01 07 133.333  -1.757   0.0 1    2.4 1    2.9 1  268.8 1    5.4 1   91.0 1
2007 01 01 08 146.177   2.987  25.0 3   18.1 3   18.7 3  283.2 1    5.5 1   89.0 1
2007 01 01 09 159.543   6.409  17.7 4   68.9 4   70.9 3  274.0 1    5.9 1   85.3 1
2007 01 01 10 173.316   8.212  10.4 1   73.5 1   74.3 1  301.0 1    6.3 1   84.3 1
2007 01 01 11 187.240   8.178   0.1 1   38.2 1   38.7 1  318.6 1    6.6 1   82.2 1
2007 01 01 12 201.003   6.310   6.9 3   36.3 3   41.7 1  314.5 1    6.8 1   80.5 1
2007 01 01 13 214.352   2.840   0.2 1   13.0 1   13.4 1  328.6 1    6.8 1   80.0 1
2007 01 01 14 227.180  -1.960   0.0 1    0.8 1    1.0 1  333.3 1    6.6 1   80.8 1
2007 01 01 15 239.550  -8.214   0.0 1    0.0 1    0.0 1  335.0 1    5.7 1   88.7 1
2007 01 01 16 251.681 -15.304   0.0 1    0.0 1    0.0 1  328.0 1    5.5 1   85.8 1
2007 01 01 17 263.930 -22.911   0.0 1    0.0 1    0.0 1  317.1 1    5.0 1   89.9 1
2007 01 01 18 276.800 -30.692   0.0 1    0.0 1    0.0 1  326.4 1    5.0 1   91.7 1
2007 01 01 19 290.963 -38.243   0.0 1    0.0 1    0.0 1  317.8 1    4.9 1   91.6 1
2007 01 01 20 307.259 -45.037   0.0 1    0.0 1    0.0 1  326.2 1    4.7 1   85.1 1
```

Ln 1, Col 1   100%   Windows (CRLF)   ANSI

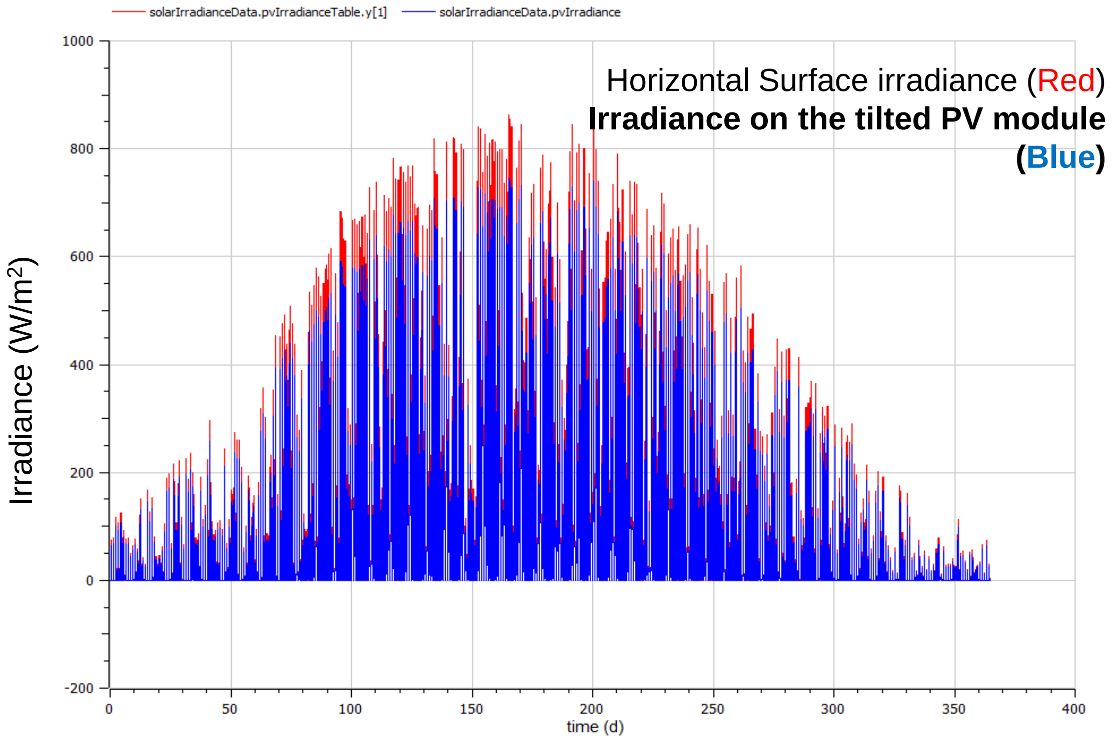
Data file screen shot

Solar Data

Source : Swedish SMHI (weather institute) in Norrköping

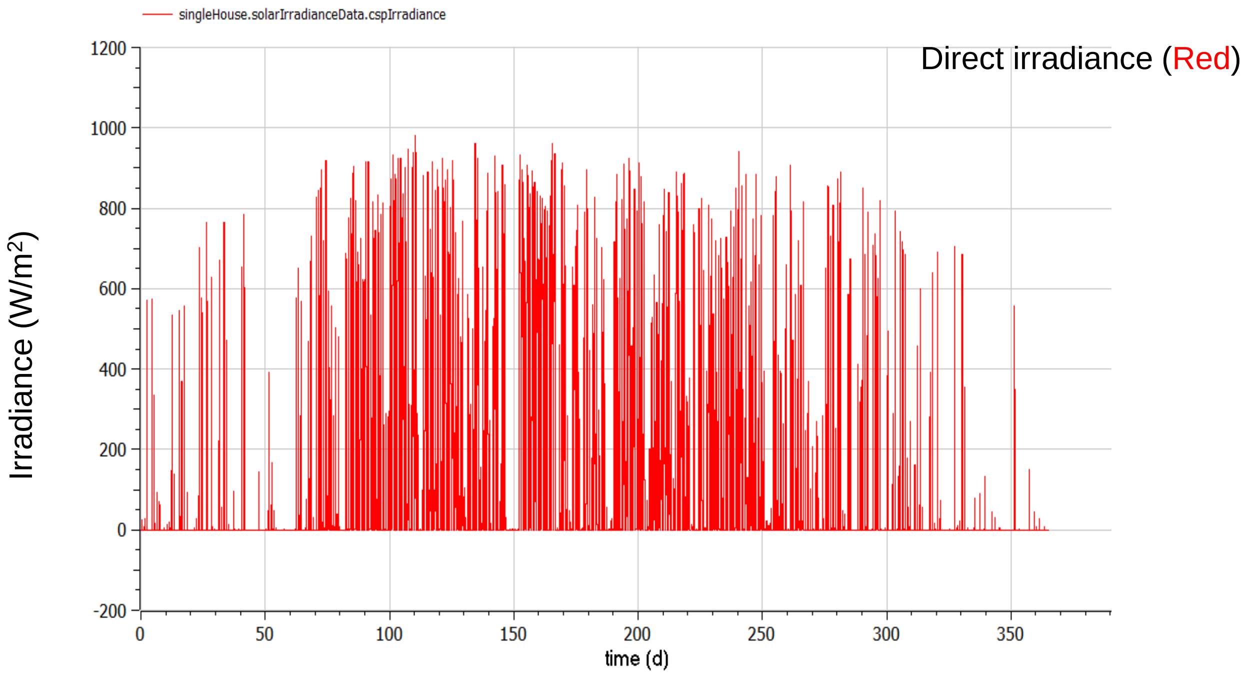
Horizontal and direct irradiance data was extracted from the datafile

Solar PV



The plot shows the module irradiance for an PV panel with tilt angle = 30deg.

Solar CSP (from Absolicon)



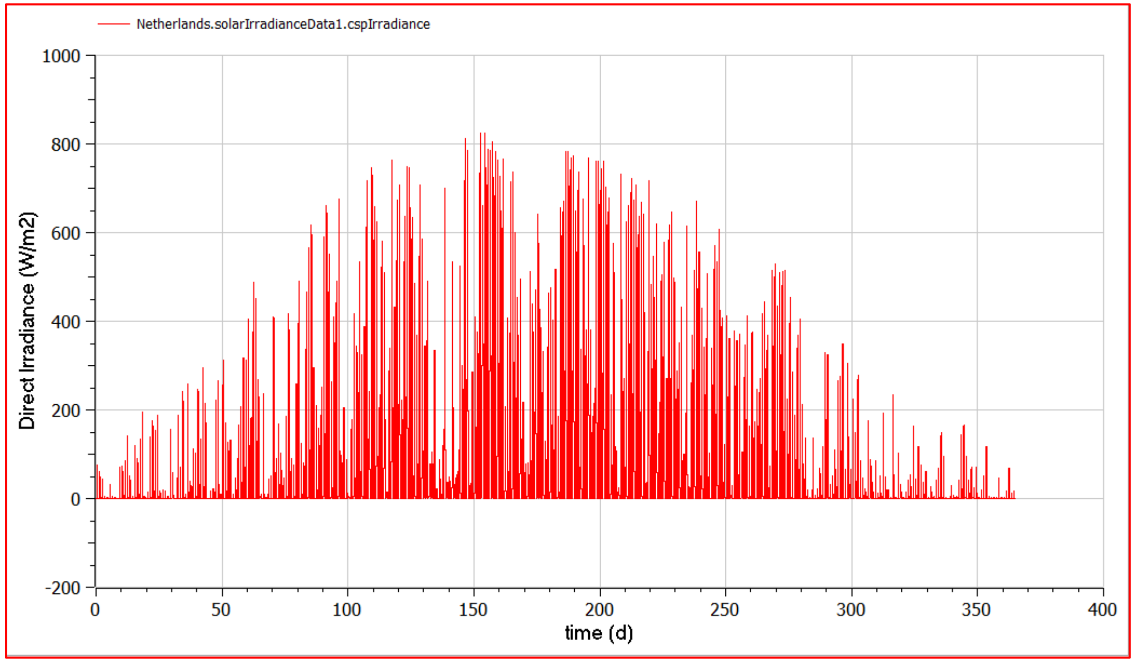
The plot shows the global irradiance on the solar collector

Solar Irradiance and Air Temperature Data

Source: Open Power System Data - Netherland , Year: 2013

[Data Platform – Open Power System Data (open-power-system-data.org)]

	A	BJ	BK
1	utc_timestamp	NL_temperature	NL_radiation_direct_horizontal
289299	2013-01-01T01:00:00Z	6.706	0
289300	2013-01-01T02:00:00Z	6.489	0
289301	2013-01-01T03:00:00Z	6.417	0
289302	2013-01-01T04:00:00Z	6.529	0
289303	2013-01-01T05:00:00Z	6.749	0
289304	2013-01-01T06:00:00Z	6.879	0
289305	2013-01-01T07:00:00Z	6.902	0.0003
289306	2013-01-01T08:00:00Z	6.839	0.3076
289307	2013-01-01T09:00:00Z	6.923	3.8352
289308	2013-01-01T10:00:00Z	7.085	24.9787
289309	2013-01-01T11:00:00Z	7.185	63.4547
289310	2013-01-01T12:00:00Z	7.049	74.4341
289311	2013-01-01T13:00:00Z	6.624	35.5017
289312	2013-01-01T14:00:00Z	5.902	8.68
289313	2013-01-01T15:00:00Z	5.033	0.2587
289314	2013-01-01T16:00:00Z	4.732	0
289315	2013-01-01T17:00:00Z	4.647	0
289316	2013-01-01T18:00:00Z	4.645	0
289317	2013-01-01T19:00:00Z	4.719	0
289318	2013-01-01T20:00:00Z	4.782	0
289319	2013-01-01T21:00:00Z	4.839	0
289320	2013-01-01T22:00:00Z	4.916	0
289321	2013-01-01T23:00:00Z	5.039	0
289322	2013-01-02T00:00:00Z	5.237	0
289323	2013-01-02T01:00:00Z	5.432	0
289324	2013-01-02T02:00:00Z	5.533	0
289325	2013-01-02T03:00:00Z	5.448	0
289326	2013-01-02T04:00:00Z	5.184	0
289327	2013-01-02T05:00:00Z	4.892	0
289328	2013-01-02T06:00:00Z	4.532	0



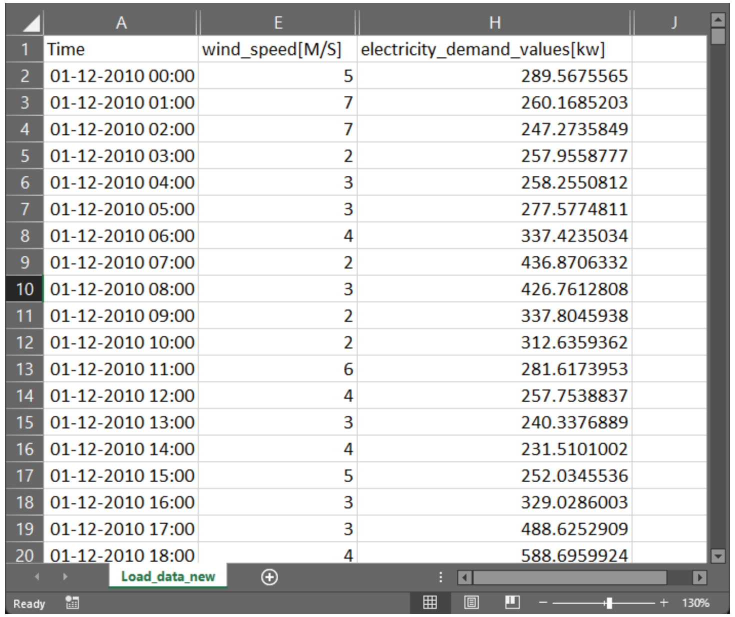
Wind & Domestic Data

Source:

Saman Taheri, Mohammad Jooshaki, Moein Moeini-Aghtaie, June 12, 2021, "8 years of hourly heat and electricity demand for a residential building", IEEE Dataport, doi: https://dx.doi.org/10.21227/dfvb-re49.

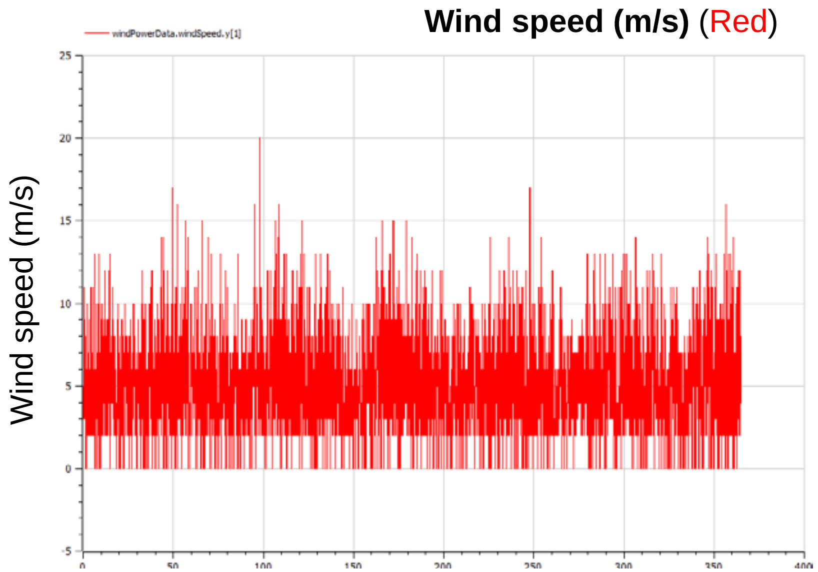
Web link:

https://ieee-dataport.org/open-access/8-years-hourly-heat-and-electricity-demand-residential-building

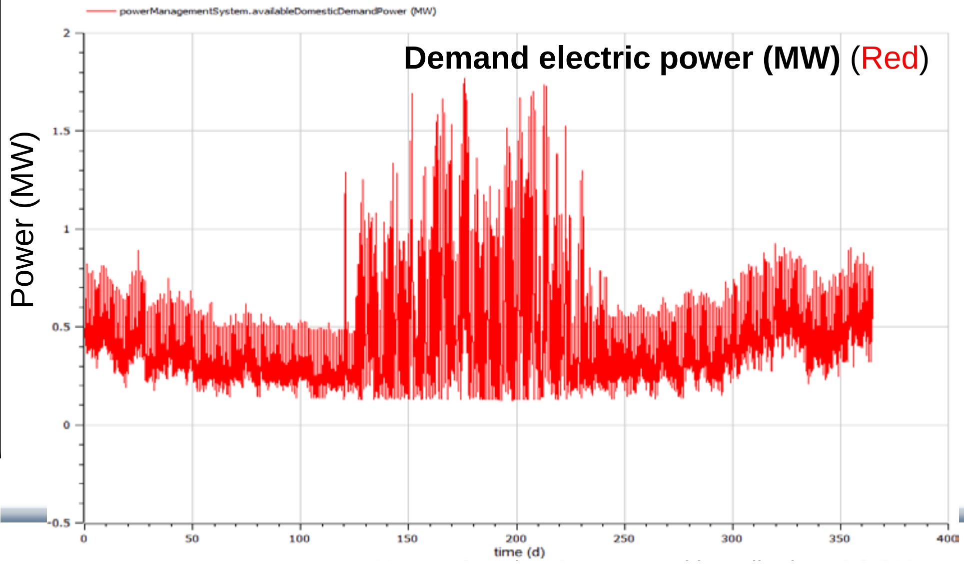


	A	E	H	J
1	Time	wind_speed[M/S]	electricity_demand_values[kw]	
2	01-12-2010 00:00	5	289.5675565	
3	01-12-2010 01:00	7	260.1685203	
4	01-12-2010 02:00	7	247.2735849	
5	01-12-2010 03:00	2	257.9558777	
6	01-12-2010 04:00	3	258.2550812	
7	01-12-2010 05:00	3	277.5774811	
8	01-12-2010 06:00	4	337.4235034	
9	01-12-2010 07:00	2	436.8706332	
10	01-12-2010 08:00	3	426.7612808	
11	01-12-2010 09:00	2	337.8045938	
12	01-12-2010 10:00	2	312.6359362	
13	01-12-2010 11:00	6	281.6173953	
14	01-12-2010 12:00	4	257.7538837	
15	01-12-2010 13:00	3	240.3376889	
16	01-12-2010 14:00	4	231.5101002	
17	01-12-2010 15:00	5	252.0345536	
18	01-12-2010 16:00	3	329.0286003	
19	01-12-2010 17:00	3	488.6252909	
20	01-12-2010 18:00	4	588.6959924	

Wind speed & demand power data file screen shot



The plot shows the extracted wind speed profile data.



Most demand during summer. Probably air conditioning in a southern location

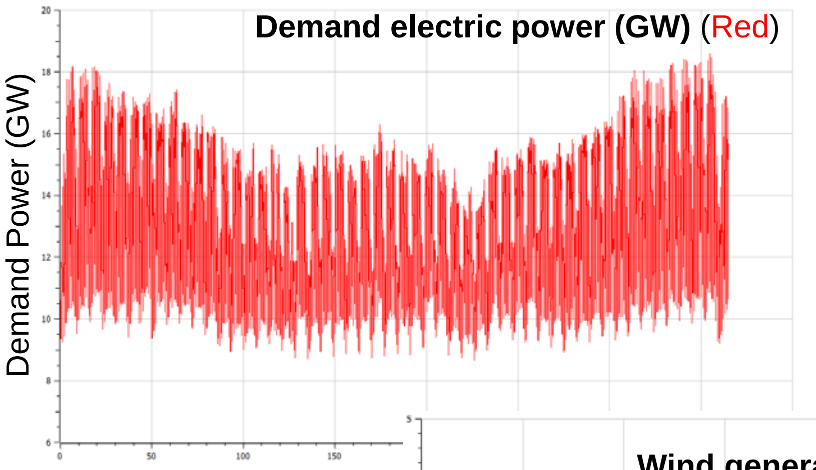
The plot shows the extracted domestic electrical power demand profile data.

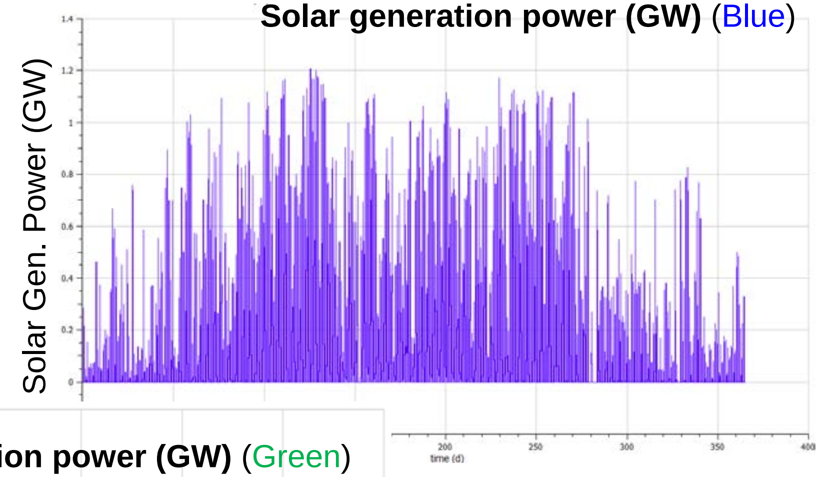
Solar, Wind Generation and Electrical Demand Data

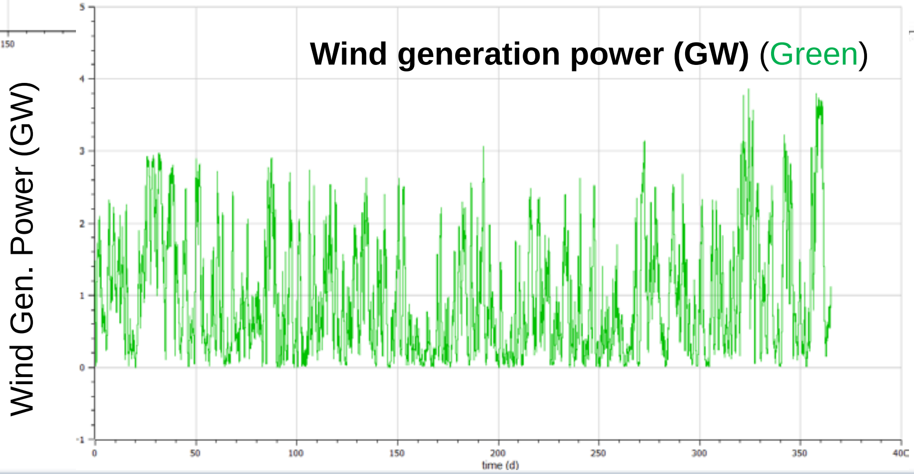
Source: Open Power System Data - Netherland , Year: 2016

[Data Platform – Open Power System Data (open-power-system-data.org)]

	A	HP	HR	HS
1	utc_timestamp	NL_load_actual_entsoe_transparency	NL_solar_generation_actual	NL_wind_generation_actual
8763	2016-01-01T00:00:00Z	10580	0	1482
8764	2016-01-01T01:00:00Z	10082	0	1225
8765	2016-01-01T02:00:00Z	9614	0	1149
8766	2016-01-01T03:00:00Z	9366	0	937
8767	2016-01-01T04:00:00Z	9369	0	620
8768	2016-01-01T05:00:00Z	9612	0	339
8769	2016-01-01T06:00:00Z	9973	0	219
8770	2016-01-01T07:00:00Z	10280	0	84
8771	2016-01-01T08:00:00Z	10608	29	31
8772	2016-01-01T09:00:00Z	11212	132	18
8773	2016-01-01T10:00:00Z	11532	233	17
8774	2016-01-01T11:00:00Z	11636	284	28
8775	2016-01-01T12:00:00Z	11703	281	66
8776	2016-01-01T13:00:00Z	11829	215	169
8777	2016-01-01T14:00:00Z	11935	123	294
8778	2016-01-01T15:00:00Z	12444	46	443
8779	2016-01-01T16:00:00Z	13617	9	561
8780	2016-01-01T17:00:00Z	13664	0	663
8781	2016-01-01T18:00:00Z	13393	0	893
8782	2016-01-01T19:00:00Z	12948	0	1137
8783	2016-01-01T20:00:00Z	12314	0	1036
8784	2016-01-01T21:00:00Z	11670	0	1190
8785	2016-01-01T22:00:00Z	10934	0	1319
8786	2016-01-01T23:00:00Z	10273	0	1444
8787	2016-01-02T00:00:00Z	9684	0	1540
8788	2016-01-02T01:00:00Z	9350	0	1632
8789	2016-01-02T02:00:00Z	9246	0	1676
8790	2016-01-02T03:00:00Z	9259	0	1657
8791	2016-01-02T04:00:00Z	9420	0	1725
8792	2016-01-02T05:00:00Z	9976	0	1630
8793	2016-01-02T06:00:00Z	10862	0	1628
8794	2016-01-02T07:00:00Z	12025	0	1599







Space Heating Demand Data

Source: Open Power System Data - Netherland , Year: 2013

[Data Platform – Open Power System Data (open-power-system-data.org)]

	A	JP
1	utc_timestamp	NL_heat_demand_space
43847	01-01-2013 00:30	18168
43848	01-01-2013 01:30	16428
43849	01-01-2013 02:30	12692
43850	01-01-2013 03:30	10470
43851	01-01-2013 04:30	10293
43852	01-01-2013 05:30	10764
43853	01-01-2013 06:30	11060
43854	01-01-2013 07:30	12437
43855	01-01-2013 08:30	14741
43856	01-01-2013 09:30	18028
43857	01-01-2013 10:30	21223
43858	01-01-2013 11:30	21100
43859	01-01-2013 12:30	21787
43860	01-01-2013 13:30	19944
43861	01-01-2013 14:30	18559
43862	01-01-2013 15:30	17469
43863	01-01-2013 16:30	17005
43864	01-01-2013 17:30	17474
43865	01-01-2013 18:30	17827
43866	01-01-2013 19:30	18468
43867	01-01-2013 20:30	19263
43868	01-01-2013 21:30	19887
43869	01-01-2013 22:30	20122
43870	01-01-2013 23:30	19975
43871	02-01-2013 00:30	19192
43872	02-01-2013 01:30	17348
43873	02-01-2013 02:30	13293
43874	02-01-2013 03:30	10973
43875	02-01-2013 04:30	11775
43876	02-01-2013 05:30	12357
43877	02-01-2013 06:30	12697
43878	02-01-2013 07:30	14265