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 city's heat needs
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: 2 m²
- PV generation efficiency: 20%
- Energy storage capacity: 5 kWh
- Energy storage Max power limit: 1 kW
- Domestic Load: Single House

Simulation Results (Annual):

<table>
<thead>
<tr>
<th>Total Energy Generated</th>
<th>Total Energy Transferred from Conventional Grid</th>
<th>Total Energy Transferred to Conventional Grid</th>
<th>Total Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.74 MWh</td>
<td>6.52 MWh</td>
<td>0.67 MWh</td>
<td>9.59 MWh</td>
</tr>
</tbody>
</table>
**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: 2m²
- 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):**

<table>
<thead>
<tr>
<th>Total Energy Generated</th>
<th>Total Energy Transferred from Conventional Grid</th>
<th>Total Energy Transferred to Conventional Grid</th>
<th>Total Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.98 GWh</td>
<td>1.04 GWh</td>
<td>1.56 GWh</td>
<td>6.46 GWh</td>
</tr>
</tbody>
</table>
Electric Grid Scenarios: Scenario-3 – Medium-sized City

City Grid Scenario (~75000 Houses)

Parameters:
- Number of PV panels: 200000
- Surface Area of each panel: 2m²
- 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):

<table>
<thead>
<tr>
<th></th>
<th>Total Energy Generated</th>
<th>Total Energy Transferred from Conventional Grid</th>
<th>Total Energy Transferred to Conventional Grid</th>
<th>Total Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1332.96 GWh</td>
<td>85.23 GWh</td>
<td>567.27 GWh</td>
<td>850.21 GWh</td>
</tr>
</tbody>
</table>
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):

<table>
<thead>
<tr>
<th>Total Renewable Energy Generated</th>
<th>Total Energy Transferred from Conventional Grid</th>
<th>Total Energy Transferred to Conventional Grid &amp; Storage</th>
<th>Total Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.9 TWh</td>
<td>130.57 TWh</td>
<td>0 TWh</td>
<td>139.47 TWh</td>
</tr>
</tbody>
</table>
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):

<table>
<thead>
<tr>
<th>Total Energy Generated</th>
<th>Total Energy Transferred from Conventional Grid</th>
<th>Total Energy Transferred to Conventional Grid</th>
<th>Total Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>89 TWh</td>
<td>61.3 TWh</td>
<td>10.8 TWh</td>
<td>139.5 TWh</td>
</tr>
</tbody>
</table>
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 onto each library example and corresponding component parameter values can be entered.
- The parameters in this record are 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.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air density</td>
<td>Energy storage capacity</td>
</tr>
<tr>
<td>Wind speed data file</td>
<td>Max allowable charge %</td>
</tr>
<tr>
<td>Turbine rotor radius</td>
<td>Min allowable charge %</td>
</tr>
<tr>
<td>Turbine generation efficiency</td>
<td>T&amp;D efficiency</td>
</tr>
<tr>
<td>Number of turbines</td>
<td>Voltage</td>
</tr>
<tr>
<td>Wind farm rated power</td>
<td>Energy storage rated power</td>
</tr>
<tr>
<td>PV panel tilt angle</td>
<td>EV car charging capacity</td>
</tr>
<tr>
<td>Solar irradiance data file</td>
<td>EV bike charging capacity</td>
</tr>
<tr>
<td>PV generation efficiency</td>
<td>EV car charging rated power</td>
</tr>
<tr>
<td>PV panel surface area</td>
<td>EV bike charging rated power</td>
</tr>
<tr>
<td>Number of PV panels</td>
<td>Max number of cars per station</td>
</tr>
<tr>
<td>Solar generation data file</td>
<td>Max number of bikes per station</td>
</tr>
<tr>
<td>Solar generation factor</td>
<td>Number of charging stations</td>
</tr>
<tr>
<td>Wind generation data file</td>
<td>EV car charging duration</td>
</tr>
<tr>
<td>Wind generation factor</td>
<td>EV bike charging duration</td>
</tr>
</tbody>
</table>
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 - Netherlands)
  - Electrical solar generation, wind generation and demand power data (2016 – Netherlands)
  - Heat demand data (2013 – Netherlands)
- 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
    □ Hourly horizontal surface irradiance data
  • Parameters
    □ PV panel tilt angle
  • Output
    □ Solar irradiance on the PV panel
  • Equation
    \[ E_{\text{module}} = E_e \times \cos \left( \frac{\pi \times \beta}{180} \right) \]

- \( E_e \) (W/m\(^2\)) - Horizontal surface data
- \( E_{\text{module}} \) (W/m\(^2\)) - Solar irradiance on the PV panel
- \( \beta \) (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
  - Hourly wind speed data
- Parameter
  - Air density
- Output
  - Wind power per unit area
- Equation
  \[ P_{wa} = \frac{1}{2} \rho v^3 \]

- \( P_{wa} \) (W/m²) – Wind power per unit area
- \( v \) (m/s) – Wind speed
- \( \rho \) (kg/m³) – PV panel tilt angle

![Sample wind speed data](image)

![Wind power data](image)
Utility: Solar Generation Data

• The annual hourly solar generated power data for a country is imported using the combi-table.

• Input
  - Country solar generation data

• Output
  - Solar generation power

Graphical representation

Generated solar power (GW)

Time (d)
Utility: Wind Generation Data

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

Graphical representation

Generated wind power (GW) vs. Time (d)
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
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
  - Irradiance on the PV panels
- Parameters
  - Surface area of each PV panel
  - Number of PV panels in the farm
  - Generation efficiency
- Output
  - Generated electrical power
- Equation
  \[ P_S = \eta_{se} \times E_{module} \times A_p \times n_p \]
  - \( P_S \) (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
  - \( \rho \) (kg/m\(^3\)) - PV panel tilt angle
  - \( \eta_{se} \) – Solar electric power generation efficiency

The example plot shows the solar power and the corresponding electrical power generated for \( n=12 \) panels of 2m\(^2\) 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
  - Wind power per unit area
- Parameters
  - Rotor radius of the turbines
  - Number of turbines in the farm
  - Generation efficiency
- Output
  - Generated electrical power
- Equation
  \[ A_t = \pi \times R_r^2 \]
  \[ P_w = \eta_{we} \times P_{wa} \times A_t \times n_w \]

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.
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**
    - Generated electrical powers
    - Demand powers (domestic demand & Charging station)
    - Can charge, can discharge flags from energy storage

  - **Parameters**
    - Energy storage power supply limit
    - Number of turbines in the farm
    - Transmission & distribution efficiency

  - **Output**
    - Stored power
    - Power from or to conventional grid (infinite source& sink)

  - **Equation**
    
    \[
    P_{ag} = \eta_{tnd} \times (P_{g1} + P_{g2})
    \]
    
    \[
    P_{td} = \eta_{tnd} \times (P_{d1} + P_{d2})
    \]

    - $P_{ag}$ (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
    - $\eta_{tnd}$ – Transmission & distribution efficiency
Components: Power Management System

• Control Algorithm Flow chart

\( P_{ag} \) – Available \textit{Generated power}

\( P_{td} \) – Total \textit{demand power}

\( P_{es} \) – Power transferred to \textit{energy storage}

\( P_{cg} \) – Power transferred to \textit{conventional grid}

\( P_{es\text{,}max} \) – \textit{Energy storage} power supply limit

\[\begin{align*}
\text{Start} \\
\text{YES:} & \quad P_{ag} \geq P_{td} \\
\text{NO:} & \quad \text{Go to Discharge} \\
\text{Discharge:} & \quad \text{YES:} \quad P_{td} - P_{ag} \geq P_{es\text{,}max} \\
& \quad \text{NO:} \quad P_{es} = 0 \quad P_{cg} = -(P_{ag} - P_{td}) \\
\text{Discharge:} & \quad \text{YES:} \quad P_{es} = 0 \quad P_{cg} = -(P_{ag} - P_{td}) \\
& \quad \text{NO:} \quad P_{es} = P_{es\text{,}max} \quad P_{cg} = P_{ag} - P_{td} - P_{es\text{,}max} \\
\text{Charge:} & \quad \text{YES:} \quad P_{ag} - P_{td} \geq P_{es\text{,}max} \\
& \quad \text{NO:} \quad P_{es} = 0 \quad P_{cg} = (P_{ag} - P_{td}) \\
\text{Charge:} & \quad \text{YES:} \quad P_{es} = 0 \quad P_{cg} = (P_{ag} - P_{td}) \\
& \quad \text{NO:} \quad P_{es} = P_{es\text{,}max} \quad P_{cg} = 0 \\
\end{align*}\]
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
  - Power from grid
- Parameters
  - Storage capacity
  - Min allowable charge %
  - Max allowable charge %
- Output
  - Stored energy
  - Boolean Flags: can charge, can discharge
- Equation
  \[ E_{es} = \frac{\int P_{es} \, dt}{3600} \]
  - \( E_{es} \) (Wh) – Stored Energy
  - \( P_{es} \) (W) – Power transferred to & from storage
  - \( E_{es\_cap} \) (Wh) – Stored Energy Max capacity

Control Algorithm Flow Chart
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
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
  - Domestic demand power data
- Output
  - Demand power

The example plot shows the domestic consumption data for a group of houses (~200 Houses), probably air conditioning in a southern location.
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
  o Number of charging stations
  o Max number of cars & bikes per station
  o Charging duration for cars & bikes
• Output
  o Total charging station demand power
• Equation

\[ P_{ch} = n_{st} \times (n_{car} \times P_{ch_{car}} + n_{bike} \times P_{ch_{bike}}) \]
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

- Equations

\[
E_w = \frac{\int P_w \, dt}{3600}
\]

\[
E_{dd} = \frac{\int P_{dd} \, dt}{3600}
\]

\[
E_s = \frac{\int P_s \, dt}{3600}
\]

\[
E_{ch} = \frac{\int P_{ch} \, dt}{3600}
\]

- Graphical representation
Components: KPI (Key Performance Indicator)

- Equations,

\[
\text{Generation Effectiveness} = \frac{\text{Total Demand Power} - \text{Available Generated Power}}{\text{Total Demand Power}}
\]

\[
\text{Grid Power Ratio} = \frac{\text{Power Supplied from Grid}}{\text{Total Demand Power}}
\]

\[
\text{Generation Power Ratio} = \frac{\text{Available Generated Power}}{\text{Total Demand Power}}
\]

\[
\text{Storage Power Ratio} = \frac{\text{Power Supplied from Storage}}{\text{Total Demand Power}}
\]

\[
\text{Storage Effectiveness} = \frac{\text{Average Storage Energy}}{\text{Storage Capacity}}
\]
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.
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

- Base Components
  - Partial Models of Basic Component equations

- Components
  - Single components for small scenarios

- Compound Components
  - System/Compounded components for large scenarios
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.
**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
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
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

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

**Hot Pipeline System & Cold Pipeline System**

**INPUT:** WaterPort variables

**PARAMETERS:** Dimensions of the pipe

**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
**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

Annual Simulation – Single House

Single House

Single House Control

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
Solar Data

- Direct Irradiation Data
- Thermal Solar Collector Output Power

- Output Water Temperature
- Outlet Temperature
Biomass Boiler

Boiler Water Temperature: 99 °C
Boiler Power Output: 1500 W
Central Controller Modes

- Boiler Mode
- Solar Mode

Summer

Winter
Test Examples – Thermal Scenario 2 (~250 houses)

Annual Simulation – Small Community

Small Community

Small Community Control

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

Direct Irradiation Data

Solar Thermal Collector Output Power

No of collectors: 200
Collector Area: 5.5 m²
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

Winter

Boiler Mode
Solar Mode
Test Examples – Thermal Scenario 3 (Netherlands - 2013)
Space Heating Demand Data (MW) - 2013
Domestic Supply and Return Temperatures

Zoomed In profile
Solar Irradiance Data (W/m²) and Output Power

- No of collectors: 1900000
- Collector Area: 5.5 m²
Biomass Boiler

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

Source: Swedish SMHI (weather institute) in Norrköping

Data file screen shot
Source: Swedish SMHI (weather institute) in Norrköping

Horizontal and direct irradiance data was extracted from the datafile.

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

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)
Wind & Domestic Data

Source:

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

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)
Space Heating Demand Data

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

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