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Model predictive control of a heat booster substation for ultra-low temperature district heating

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#SES4DH2018

4DH
4th Generation District Heating Technologies and Systems

Components

Storage tank

Heat pump to storage tank

Circulation heat pump

Heat exchanger for DHW

Ultra-low temperature district heating (ULTDH)

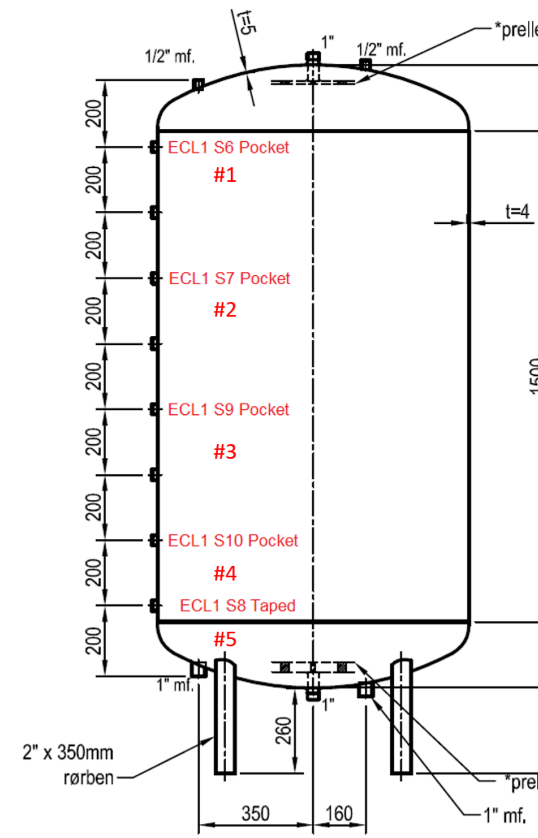
- Supply: 40°C, return: 25°C

Domestic water

- Hot water: 55°C, cold water: 10°C

Circulation loop

- Forward: 55°C, return: 50°C



Model Predictive Control (MPC)

- Optimal equipment scheduling
- Applied system dynamics
  - Smooth differential equations (smaller solver tolerance)
- Forecasted energy needs
- Minimise cost function (e.g. energy cost + discomfort)
  - Allows constraints (e.g. max. set-points)
- Re-initialisation of states

The process of model identification accounts for 70% of the effort for implementing an MPC controller (Henze, 2013).

System model

Modelica language in Dymola

- GUI for equation-based system modelling

Modelica Buildings Library from LBNL

- Open-source component library
  - (e.g. stratified tank, HP, pumps, heat ex., etc.)

JModelica

- Open-source simulation and optimisation

Component validation with real data

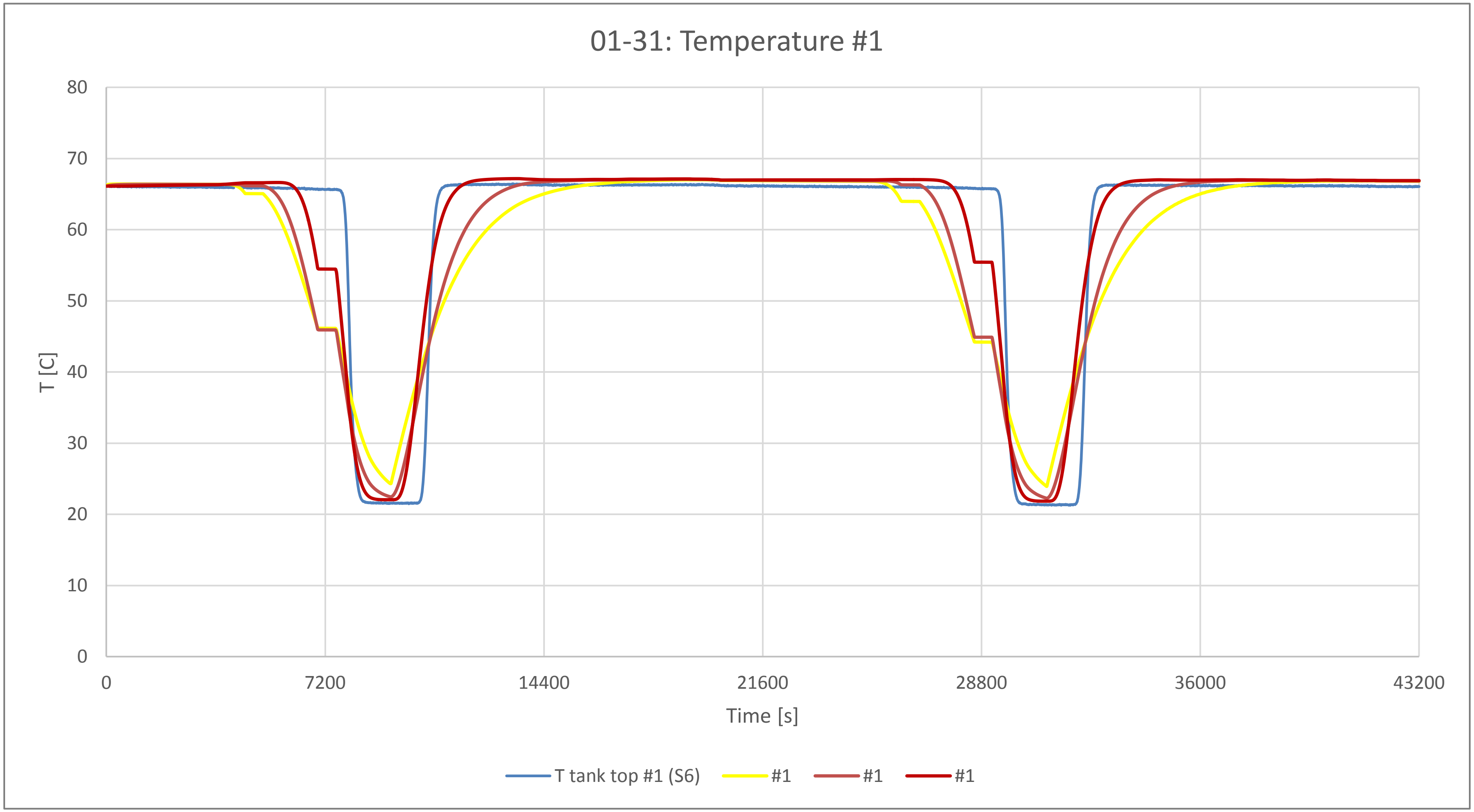
Input known parameters to component models

- Heat exchanger
- Stratified tank model
- Heat pump model

Test data to validate models

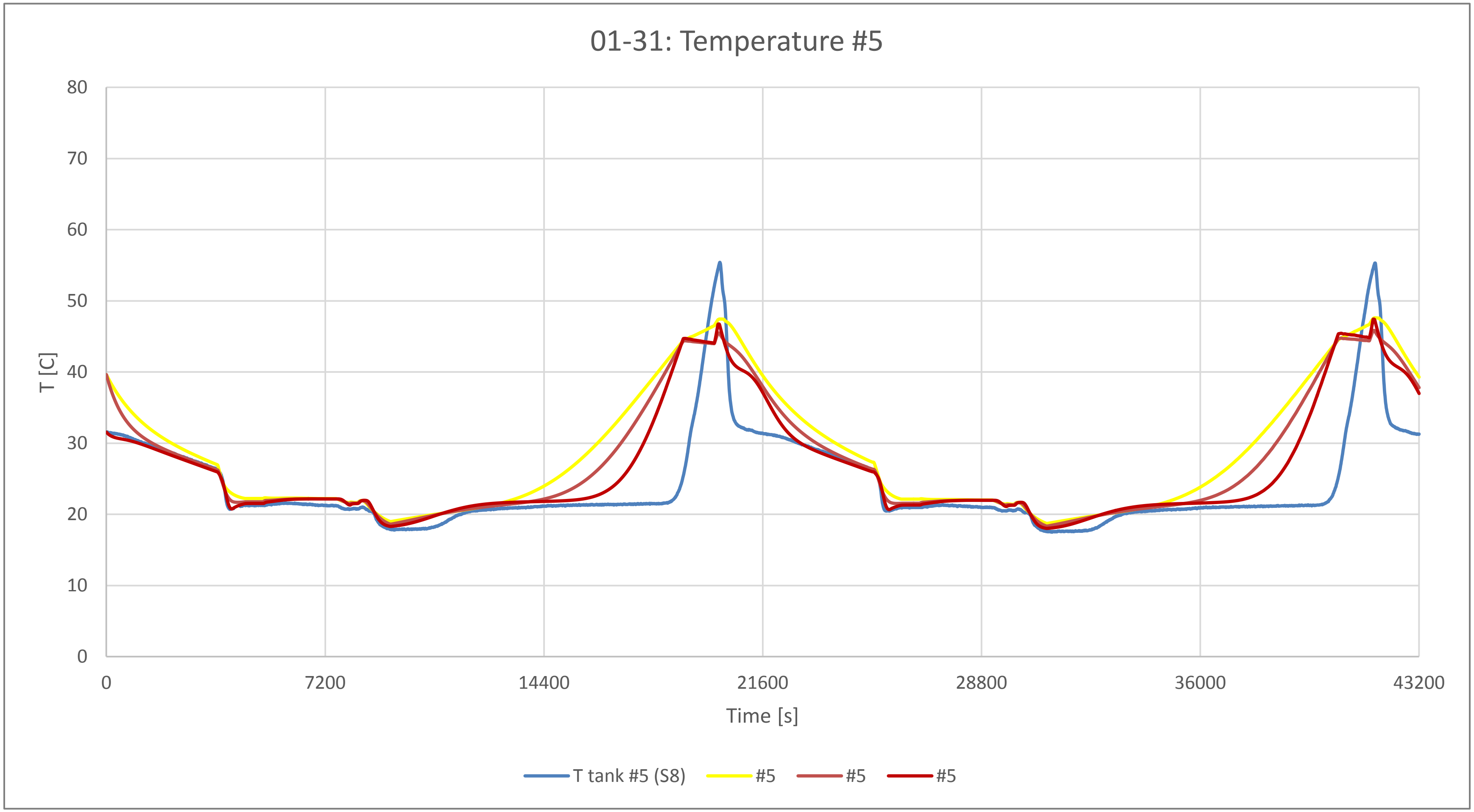
Default parameters for pumps and valves

Tank validation – Upper level



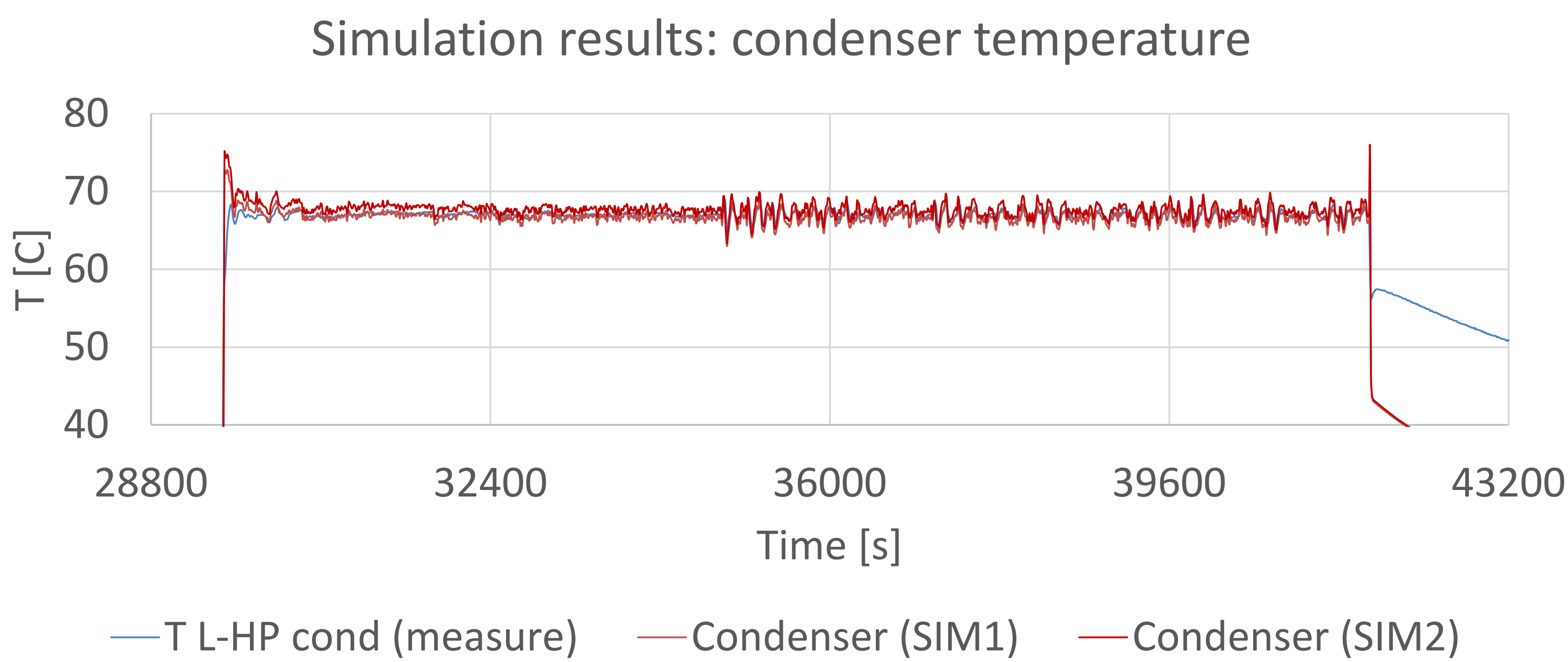
Ideally mixed layers may cause numerical diffusion

Tank validation – Lower level



More layers improves convergence with actual data

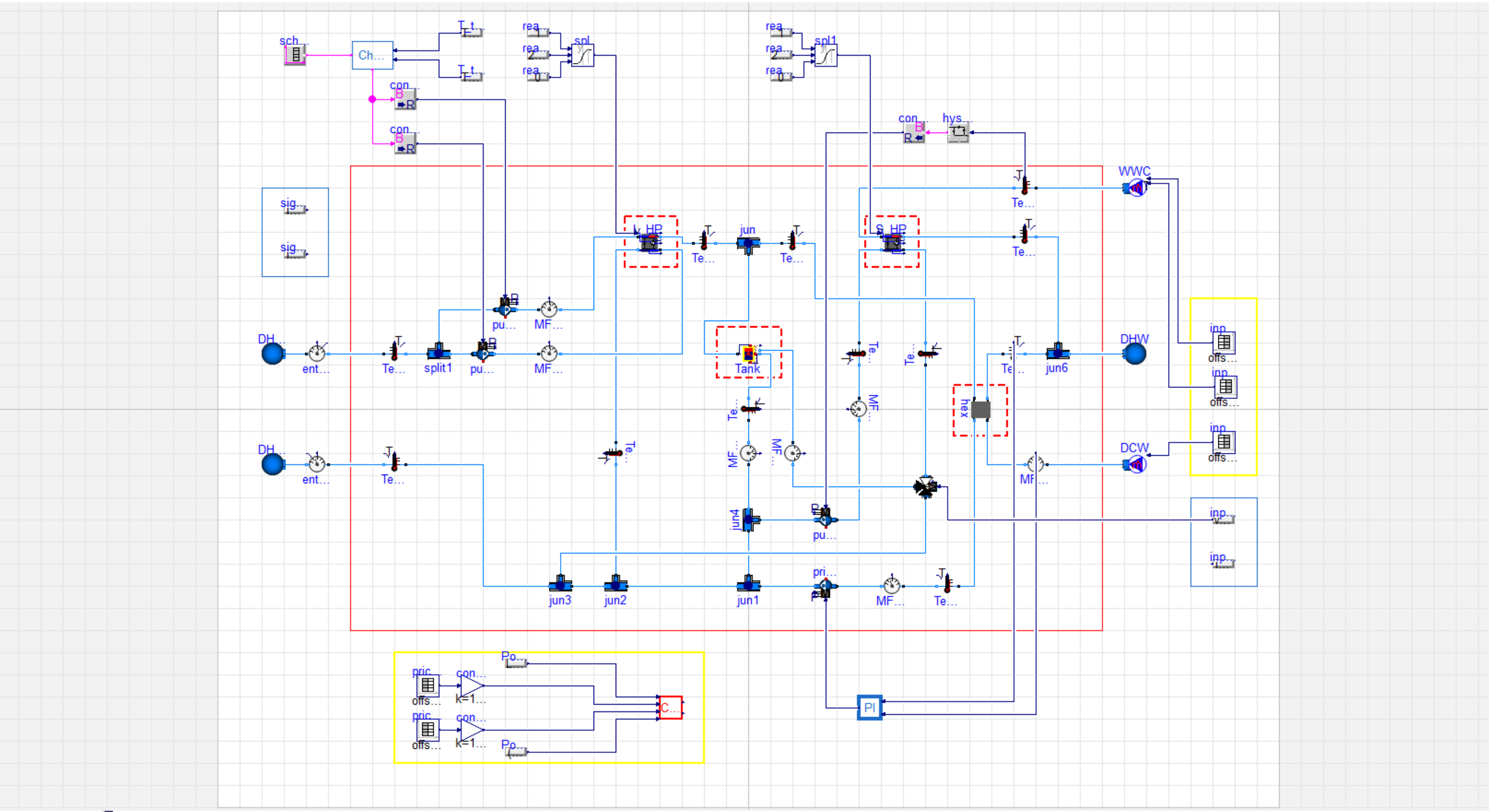
Large heat pump validation



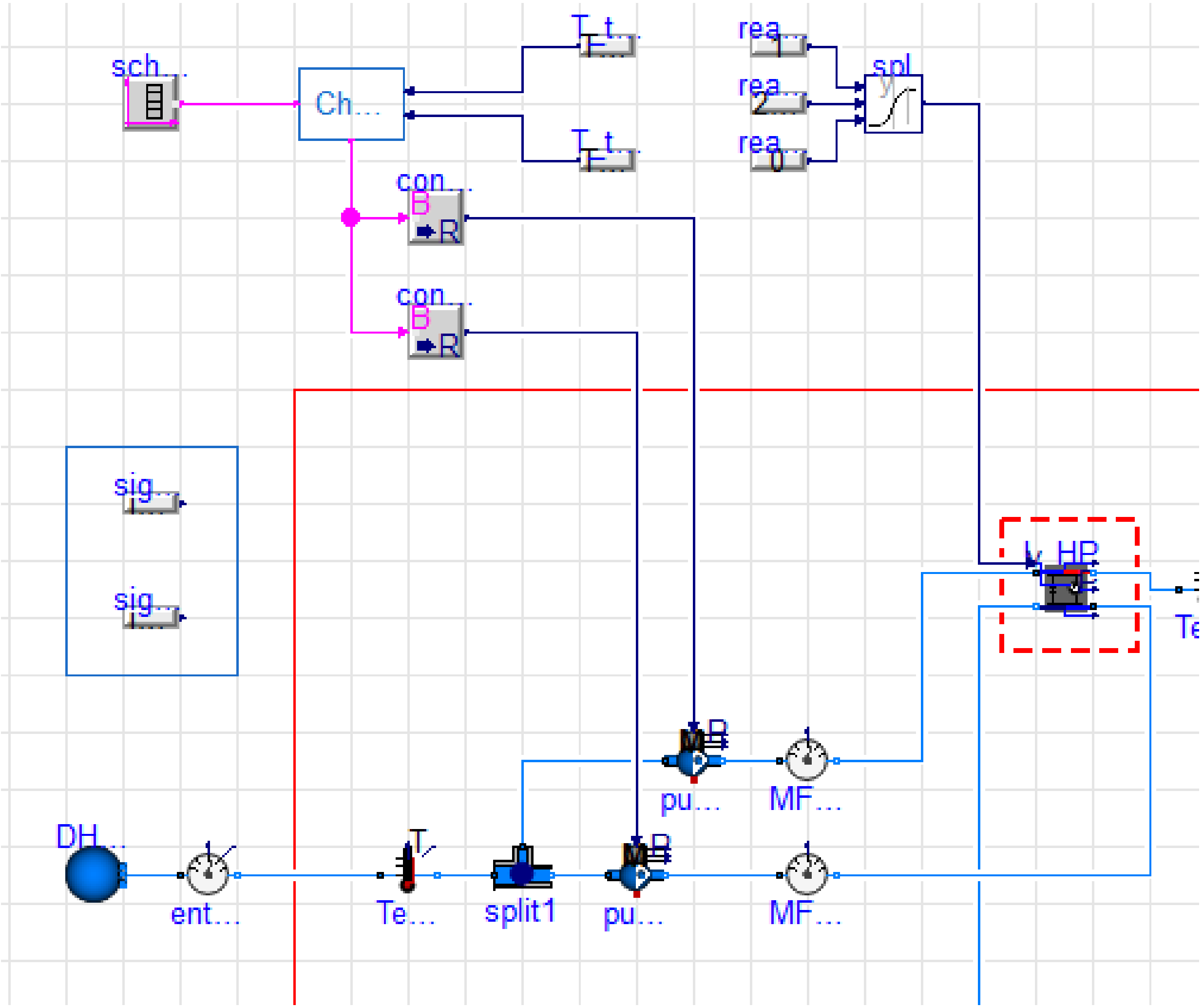
Error measurement/simulation results (working time)		
	SIM 1	SIM 2
Condenser mean absolute error [C]	0,27	0,86
Evaporator mean absolute error [C]	1,63	0,80

System model

Library includes six versions of booster station

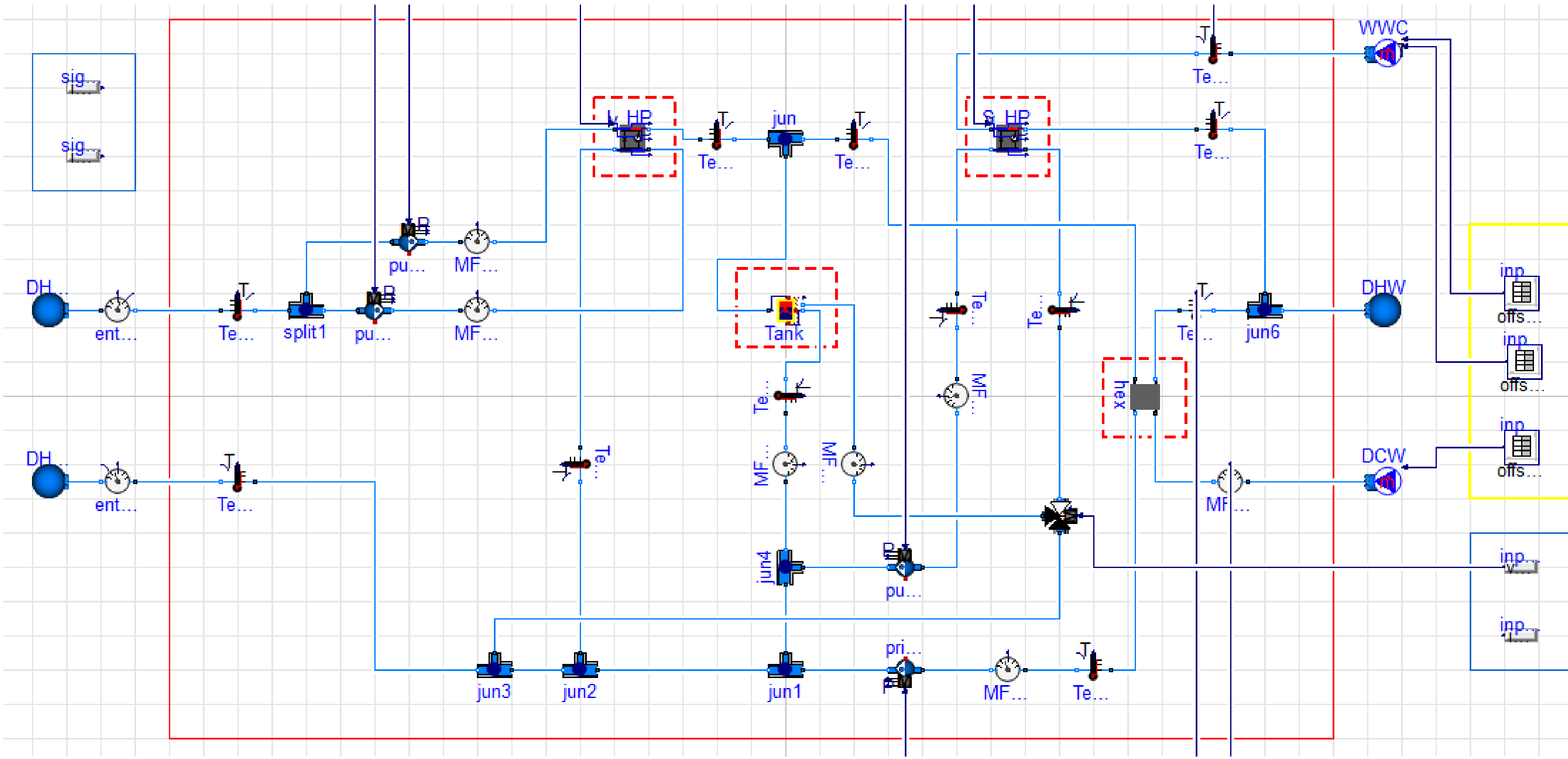


System model



System model

Modified tank model to include third port (circulation HP)

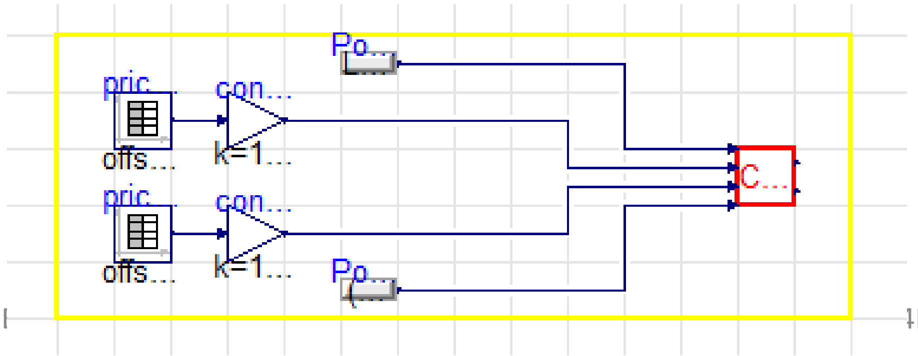


MPC of a booster station

Optimise

- When to charge tank
- Condenser and evaporator flow rates
- Heat source for circulation heat pump
  - Middle tank
  - Return
  - DH Supply (not included yet in model)

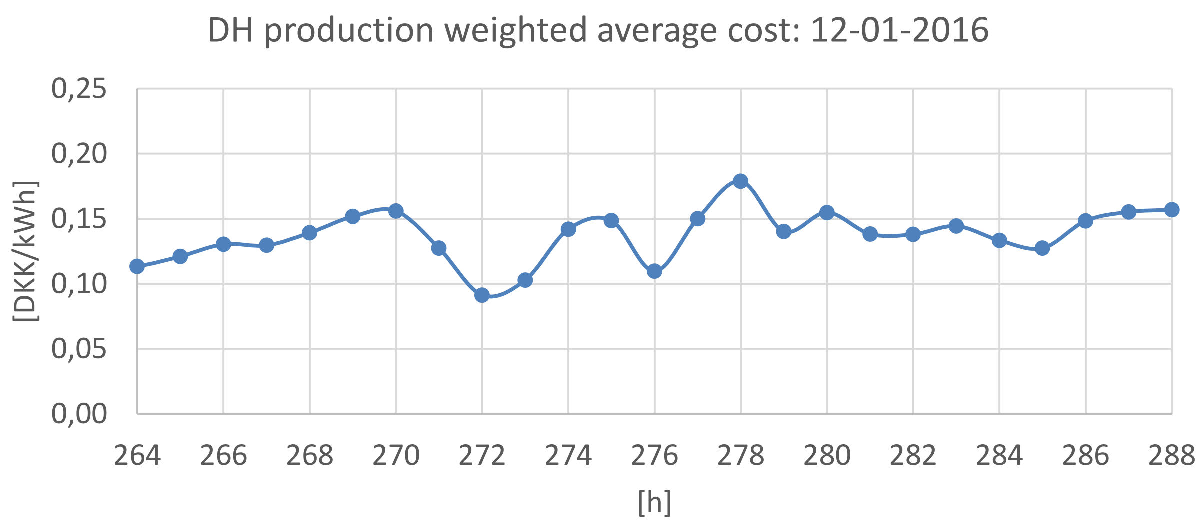
Based on energy costs



Cost function

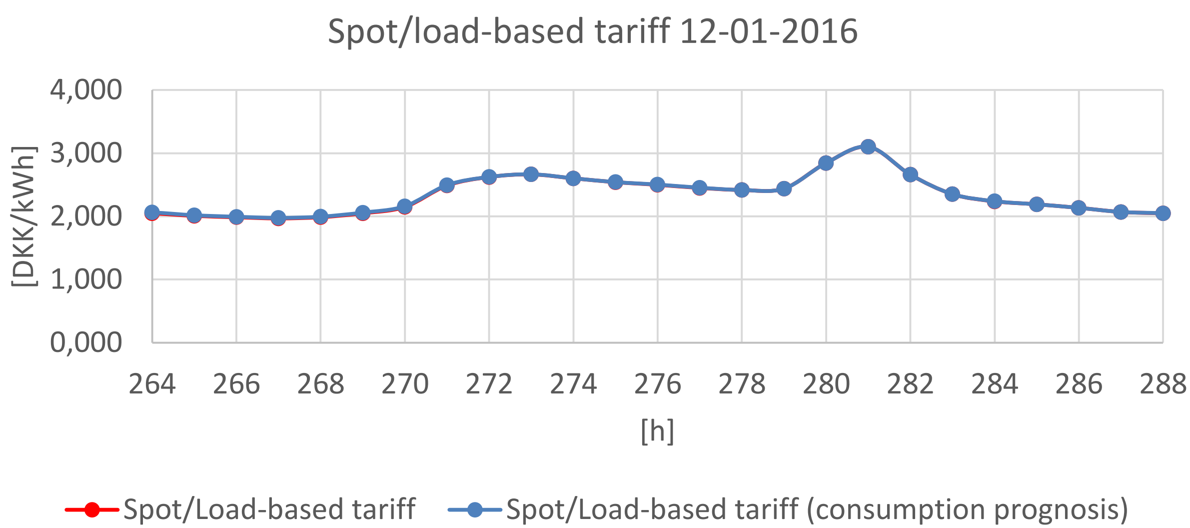
$$cost(t) = \int_0^t P_{elec} * price_{elec}\, dt + \int_0^t P_{DH} * price_{DH}\, dt$$

DH tariffs based on production weighted price from HOFOR



Electricity price

Average costs 2 [DKK/MWh]		
Actual energy	810	35,2%
System	150	6,5%
Taxes	1340	58,3%
Total	2300	100,0%



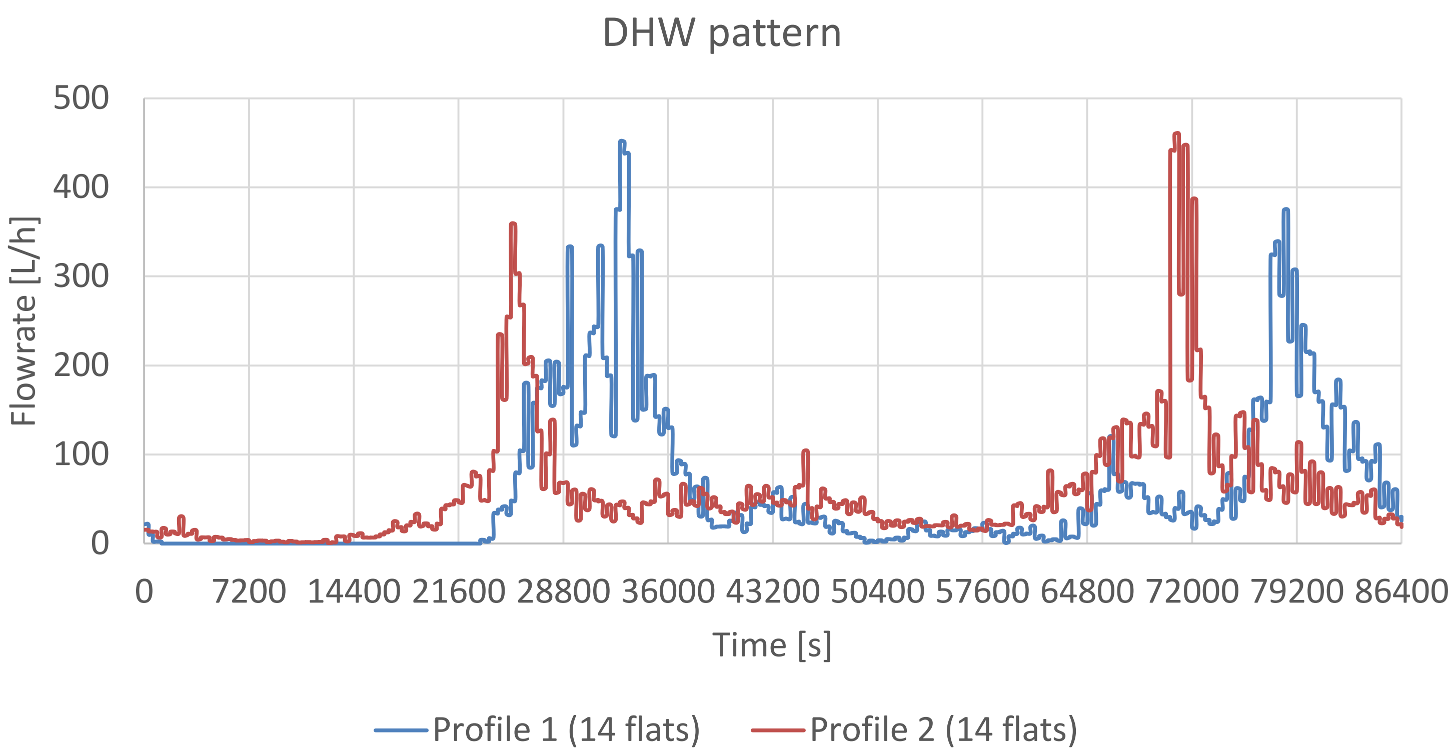
Method from Ulbig & Andersson (2010) ;
Data from Nordpool (spot price and load) & Danish energy statistics 2015 (https://ens.dk/en)

Reference case: DHW Tapping Profile

Pseudo-random Python library

Shifted load profile for a 14 apartments

Profile 1: 1413 L/day Profile 2: 1397 L/day

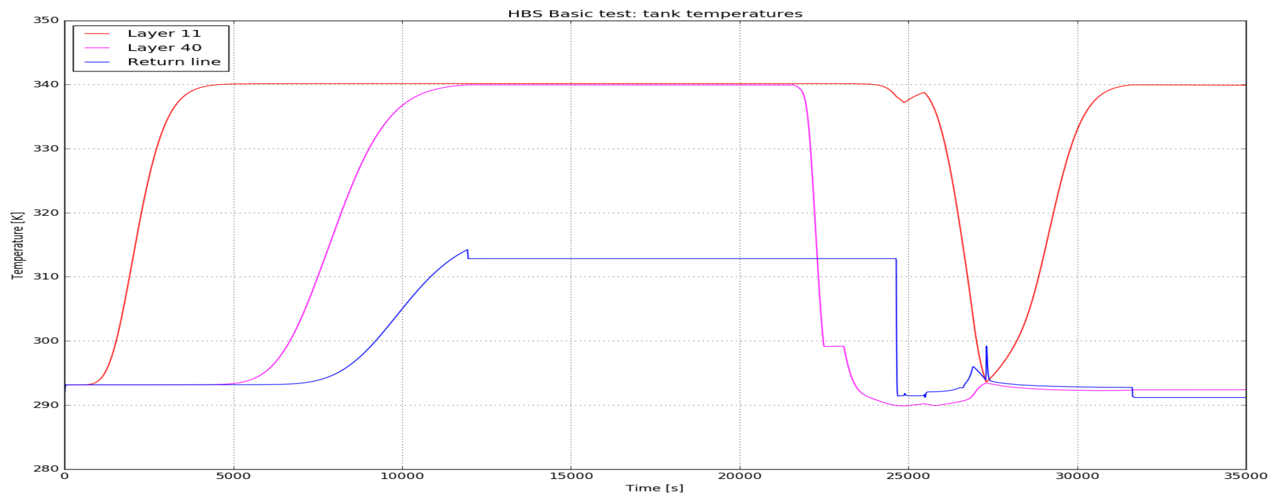


Simulation/Optimisation

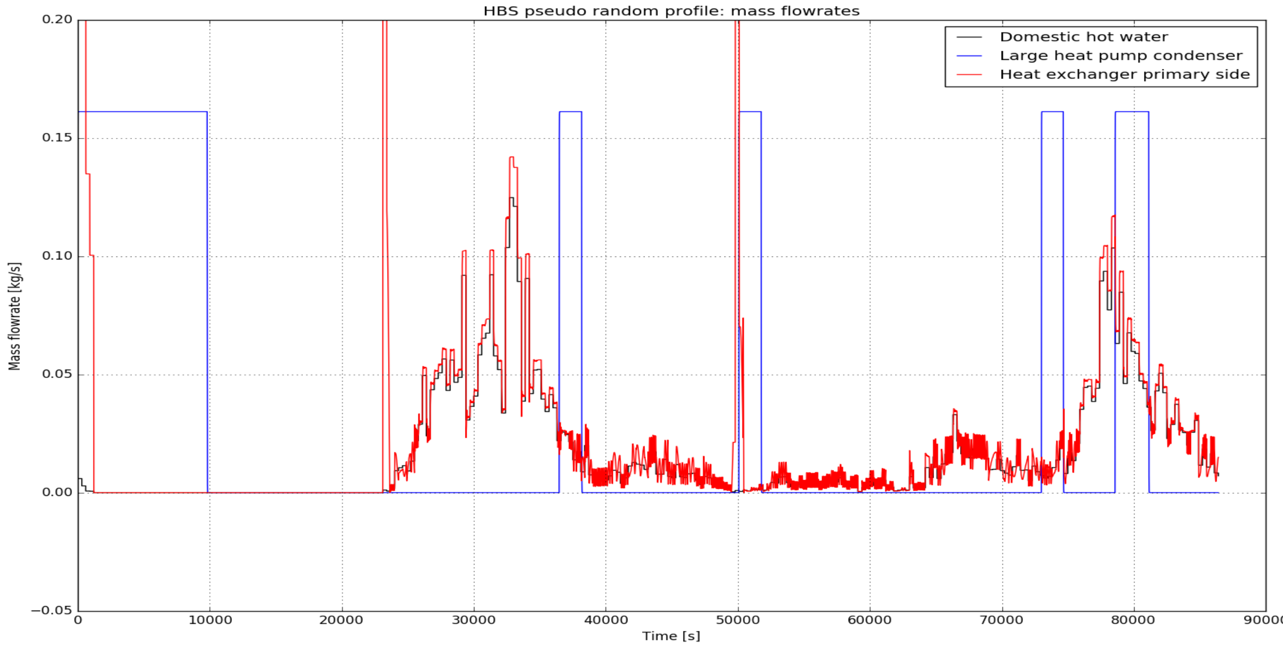
Compile as FMU in Jmodelica for optimisation

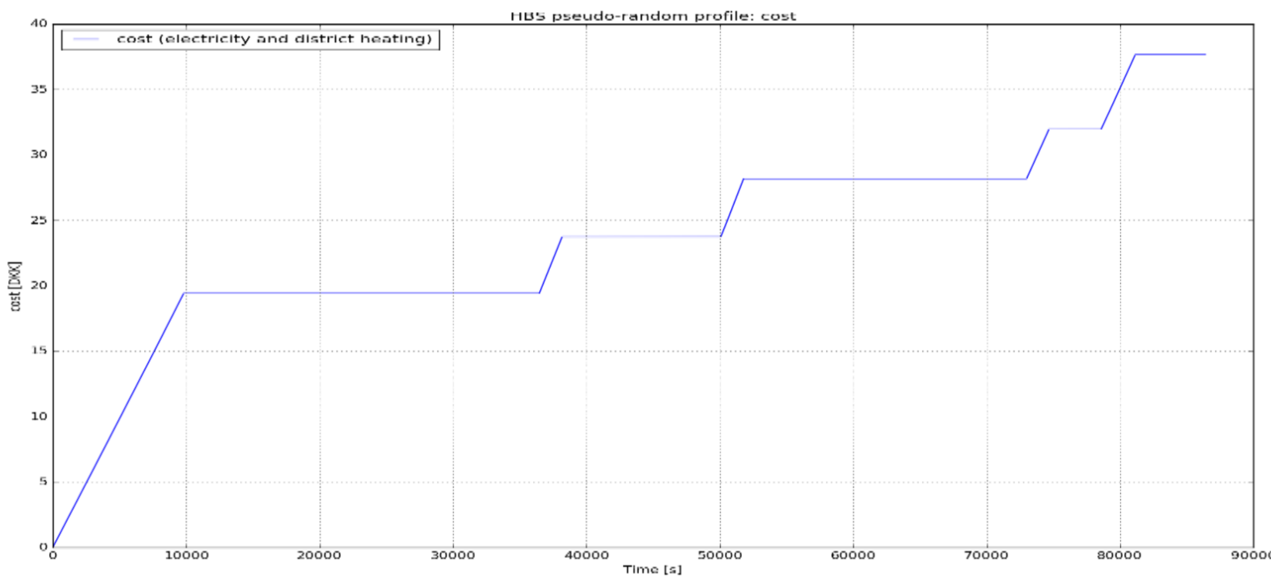
Issue in JModelica with block of code (Buildings Lib.)

Successful simulation, once removed everywhere



Simulation





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Next steps

- Add DH supply as potential circ. HP source
- Optimise controls in JModelica
- Test MPC with real data (offline)

Thank you for your attention.