MODELLING OF LOW TEMPERATURE HEATING NETWORKS WITH IDA-ICE

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ABSTRACT

This work presents a library for the simulation of low temperature heating and cooling networks for interconnected buildings, heat suppliers and geothermal storage units. Its applications are illustrated by simulating a planned network (case study).

The library was created using the modelling language NMF (Neutral Model Format) and can be used out of the box in the simulation environment IDA-ICE. The library's elements are compatible with IDA-ICE standard elements and therefore integrate easily, such that extensive and project specific models of thermal networks can be generated. The simulation provides information for all aspects of the system. For the hydraulic part of the system, heat and mass flows, water pressure and temperature values within the entire pipeline network are calculated. Information about the soil temperature and the electrical power of the pumps are also provided. Thus, the library allows planning and optimization of thermal networks, especially of low temperature heating networks equipped with geothermal storages.

In the case study the main heat suppliers of the network are photovoltaic-thermal hybrid solar collectors (PV/T), and buildings act as heat consumers and heat suppliers (free cooling), which results in directional changes of the mass and energy flows. We present an approach to such versatile flow systems. Due to the equation system based modelling in combination with the integrated IDA-ICE solver even parallel flows (which are only partially determined by the demand and supply profiles) can be handled.

Additionally, we present selected results of our case study such as the temperature of the geothermal storage and the electrical power consumed by the circulation pumps.

Keywords: simulation, thermal networks, geothermal storage, IDA-ICE, Neutral Model Format (NMF)

INTRODUCTION

Low temperature thermal networks (LTN) are a specific type of thermal networks which are typically fed with waste heat or ambient heat supplied at a low temperature level. Consumers or producers (prosumers) of the LTN either withdraw heat by means of heat pumps (and lift the temperature level to their needs) or supply waste heat (cooling purposes) to the network.

The model components developed at the Lucerne University of Applied Sciences and Arts allow the simulation of two-pipe networks with changing mass flow directions. Typically, the decentralised circulation pumps are located nearby heat users and the geothermal storage serves as a hydraulic balancing of the mass flows between the two pipes.

The results shown in this paper build on the results presented at the BauSIM 2012 [1]. This previous paper described model components for temperature and mass flow as well as an application example. Further developments of the model components were presented at the BauSIM 2014 [2]. The model components were extended to include the variable "pressure" and a modular set-up was realized. This allowed the calculation of the mass flows distribution in parallel flows, and the gained modularity allowed the modelling of any arbitrary thermal networks. In order to validate the models, the same LTN example presented at the BauSIM 2012 was simulated with the new components.

Auxiliary components were added during later development phases. Functional macros were built up reproducing the typical structures of a LTN. Thermal networks could then be modelled faster and easier. In this work, some of the developed macros were applied to build up a real case LTN with solar heat supply and seasonal heat storage.

METHOD

Development of the models and simulations were performed in the IDA-ICE environment. The components were programmed in the modelling language NMF (Neutral Model Format) [3, 4] which allows to concentrate on the implementation of equation systems and less on programming their solution. The numerical solution was taken over by the commercial solver in IDA-ICE.

SIMULATION

In order to demonstrate the functionality of the main components, the hydraulic network of the study case has been simplified to a combined so called “plant unit” (“GZ”) and a “geothermal storage” (“ES”) (Figure 1, Figure 2). The component „ES“ contains the calculation of the temperature change within the geothermal storage. The model of the geothermal storage is in principle a perfectly mixed tank and thus defined by its volume, an assumed resistance-free heat transfer and resistance-free heat conduction. The ground temperature of the geothermal storage is therefore spatially constant. Heat losses are not considered. The storage capacity is assumed to be ideal in the sense that at any time the full amount of supplied heat is stored. Pressure drops are calculated in a separate component (“pipe”), which is provided in the standard IDA-ICE library. All elements used to model the plant unit are listed in Table 1.

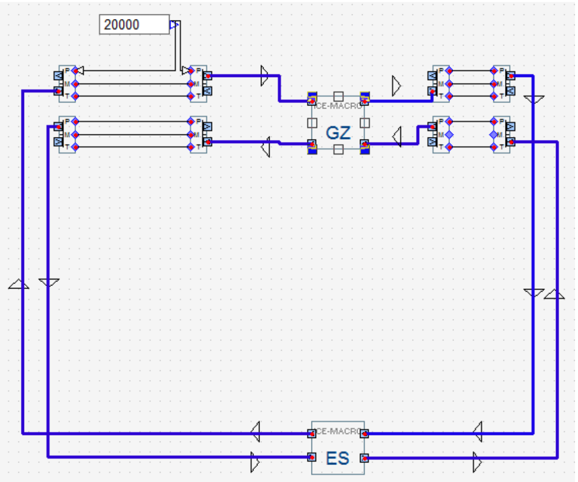


Figure 1: Simplified model of the hydraulic network

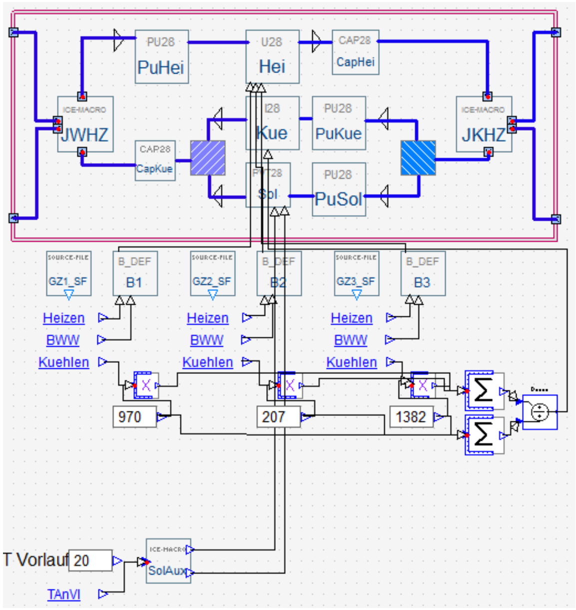


Figure 2: Plant unit (“GZ”)

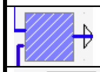
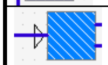
Element	Description
B1 - B3	Buildings (“B”) require the annual total consumed heat and the normalized profile for space heating and hot water. Therefrom load profiles are calculated and handed over to the component “Hei”.
Hei	Heat demand from the network is modelled by the component „heating unit“. The component aggregates the load profiles of several buildings („B1 – B3“). The resulting total load, in combination with the chosen temperature decrease in the network, is used to determine the massflow in the network. Based on the chosen heating system temperature and the calculated network temperature, the coefficient of performance (COP) of the heat pumps is calculated using the efficiency factor and Carnot-efficiency.
Kue	The component „cooling unit“ calculates, similarly to the component „Hei“, the mass flow in the network. This unit considers free-cooling only, which is typical for LTN. Input data are the annual total heat, a normalized cooling profil, and a constant temperature rise in the network.
Sol	The component „solar supply“ is an adapted version of the component “Kue”. Input data are the heat flux and a normalized profile (instead of the annual heat supply and a normalized profile). Furthermore, the chosen temperature rise is time dependent.
Pu..	The component „pump“ calculates the mechanical and electrical power, using the pressure difference, that results within the network between the inlet and the outlet of the pump. The electrical power is calculated based on the mechanical power and an overall pump efficiency. In case of a pressure decrease from the inlet to the outlet of the pump, the electrical power is assumed to be zero.
Cap..	Thermal inertia by the water mass contained in the network is modelled by the component “Cap”. A perfectly mixed tank is assumed, sized with the inner volume of the duct network.
JWHZ, JKHZ	Junction (T-element with one bi-directional connection and two uni-directional connections).
„Heizen“	Time dependent profile for heating
„BWW“	Time dependent profile for hot water
„Kühlen“	Time dependent profile for free cooling
SolAux	Macro for calculating of the solar supply data (heat flux, temperature rise in the network). These data were calculated using Polysun.
GZ1.. – GZ3..	Linked file with time dependent profiles for heating and cooling
„TAnVl“	Temperature in the network at the entrance of the heat exchanger of solar heat supply
	IDA-ICE library component „WaterMerge“
	IDA-ICE library component „WaterSplit“

Table 1: Elements of the plant unit

Considered pressure losses in the network were limited to the pressure losses of the geothermal storage. These losses were implemented using the IDA-ICE library component „pipe“. Thermal inertia in the network ducts was considered within the plant unit (components “Cap..” within macro “GZ”).

The configuration of the simulation model is shown in Table 2.

Element	Parameter	Value
Buildings	Annual heat for space heating (B1, B2, B3)	2340, 831, 3179 MWh
	Heating system temperature for space heating	32 °Celsius
	Heating system temperature for hot water	55 °Celsius
	Annual heat for warm water (B1, B2, B3)	793, 260, 1018 MWh
Plant unit	Temperature decrease in network at heating unit	4 °Celsius
	Temperature increase in network at cooling unit	4 °Celsius
	Total efficiency of circulation pumps	0.6
	Efficiency factor of heat pump (COP/COP_{Carnot})	0.5
Geothermal storage	Volume of ground	3'400'000 m^3
	Density of ground	2000 kg/m^3
	Specific heat capacity	1500 J/(kg K)
	Number of probes	746
	Depth of probes	186 m
	Inner diameter of probes	0.032 m
	Roughness	$0.045 * 10^{-3}$ m

Table 2: Configuration of the simulation model

RESULTS

The period of simulation was set to 2 years. Figure 3 shows the temporal development of heat output which is obtained (red) respectively fed into the temperature network by the buildings (blue) and the PV/T plants (yellow). The input time series for heating and cooling loads are normalized and base on measured load profiles [5], such that they can be scaled according to the annual total heating demand. The graphs in grey correspond to the heat flux to the building and the one in blue to freecooling.

The final energy supplied to the buildings (grey) is slightly higher compared to the heat obtained from the LTN (red). This difference corresponds to the electrical power obtained by the heating pumps and thus the red graph depends on the temperature of the network, which in turn defines the COP of the heating pumps.

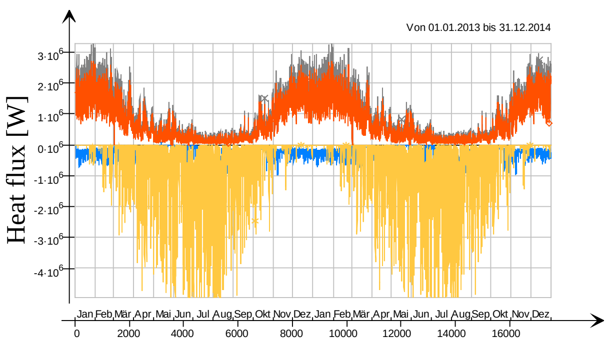


Figure 3: Heat fluxes of the plant unit; supply to the buildings (grey), heat extracted from the network (red), free cooling (blue), solar yields (yellow)

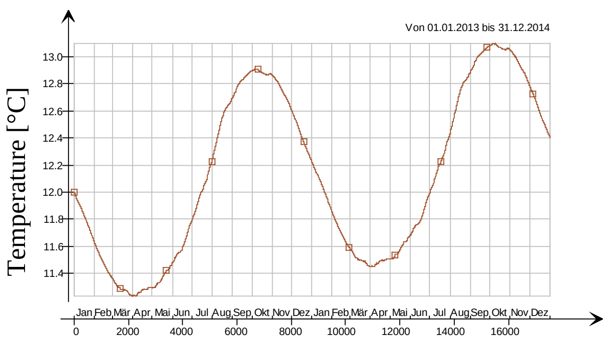


Figure 4: Temperature of the geothermal storage

During the two years the following heat quantities result:

- Heat delivered and consumed by the buildings: 16.86 GWh
- Heat obtained from the network for space heating and hot water: 13.99 GWh
- Heat feed into the network by freecooling: 5.03 GWh
- Heat feed into the network by PV/T plants: 10.12 GWh

This gives a surplus of heat fed into the network of 1.16 GWh. As a result the temperature in the geothermal storage is slightly higher (ΔT 0.4 K) than at the beginning of the simulation (Figure 4). The massflow of the geothermal storage shown in Figure 5 is driven by three decentralised circulation pumps, located at each prosumer. Their pumping power is shown in Figure 6 and clearly illustrates that the pumps alternate over time in sharing their main loads to drive the massflow through the geothermal storage.

To provide the heat of 16.86 GWh the electrical energy of 2.87 GWh were consumed by the heating pumps which equals to an annual coefficient of performance of 5.87. Another 0.013 GWh of electrical energy must be added for the circulation pumps. However, the model only takes into account the pressure drop of the geothermal storage but not the whole thermal network.

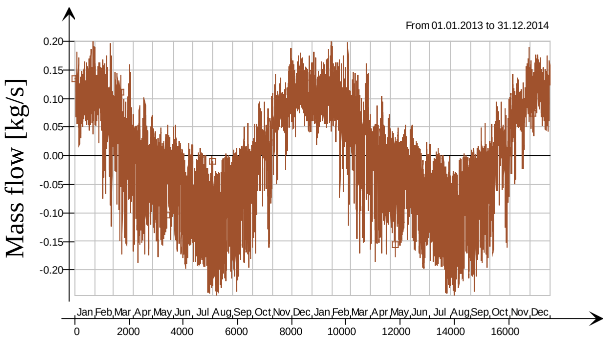


Figure 5: Mass flow in a probe of the geothermal storage

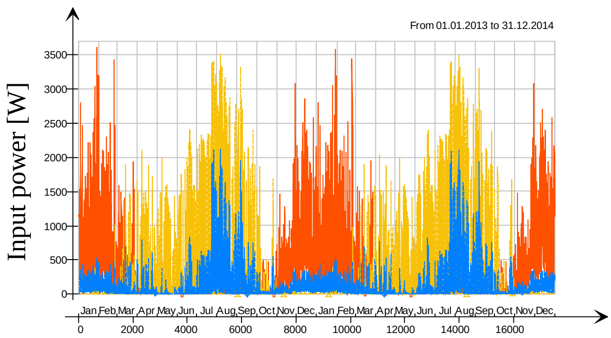


Figure 6: Electrical power consumed by the circulation pumps:
heating unit (red), cooling unit (blue), solar thermal supply (yellow)

DISCUSSION

The developed models allow the assessment of some design and planning issues. For instance the solar yield and the electrical consumption of the heating pumps can be realistically estimated based on the calculated temperature of the hydraulic network. Technical details in construction of hydraulic networks cannot be addressed with the models. However, the possibility is given to incorporate further components or to replace models as long as they have the same interfaces. In particular a 3-dimensional mesh model of the geothermal model is available from the distributer of the simulation platform.

The simulation results of the study case were checked using the energy balance on the heat flux of the geothermal storage. The integral of heat fluxes over the geothermal storage (Q_{ES}) equals the total heat produced and consumed by the plant unit (Q_{GZ}). A further check was investigating the temperature of geothermal storage. The stored heat was calculated using the heat capacity, the volume, the density of the ground, and the temperature change and found equal to Q_{ES}. Finally, the results of the simulation were found in good correspondence to results derived during the planning phase.

The electrical energy for the circulation pumps were of almost no significance compared to the electric energy consumed by the heating pumps (ratio about 0.5%). However, only the flow resistance of the geothermal storage was considered while all other flow resistances in the network were neglected.

CONCLUSION

A series of component models were developed which integrate with existing IDA-ICE libraries and allows the simulation of arbitrary thermal networks. All necessary and important system variables of a thermal network are calculated (mass flow, pressure, temperature, electrical power).

The components can be grouped in larger functional units (macros), as for instance, the here presented “plant unit”. These macros can be easily used to multiply the same functionality, or be used in new and different models. For instance, in [6] these components are used to simulate a bi-directional thermal network using several simplified plant units.

The study case clearly shows that these self-built model components are suitable for the conceptual design and the optimizing of thermal network in the planning phase. An even higher accuracy and a more detailed planning of the probe field (geothermal storage) should be expected using the 3-dimensional model of the geothermal storage (EQUA Simulation AB).

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