PUMPING POWER PREDICTION IN LOW TEMPERATURE DISTRICT HEATING NETWORKS

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ABSTRACT

A low temperature network providing heat for domestic buildings and cold for a large data centre was modelled in the software Polysun based on simplified loads. The emphasis was set on the electric energy consumption of the decentralized circulation pumps. For this reason, the pump and hydraulic resistance model of the software Polysun was adapted in order to reproduce the characteristics of modulating high efficiency pumps. Energy consumption of the decentralized circulation pumps of less than 1% of the transferred energy was predicted from dynamic simulation with the new models. In order to challenge these predictions, the first four months of operation of a network in Zürich were monitored and analysed. Launched in December 2014, the network is equipped with an extended monitoring system, which records amongst others the network temperature evolution, the heat pump performance and the pumping energy consumption. The main heat pump providing heat to over 400 households at a mean temperature of 68°C reached an overall coefficient of performance (COP) of 3.7 in initial winter operation. This value corresponds to a remarkable overall efficiency factor (including primary and secondary circulation pumps) of 65%. Due to intense usage in winter months, but also slightly higher pressure drops than predicted, the pumping energy reached 1.6 % of the low temperature energy delivered to the heat pump and 1.1% of the cooling energy supplied to a data centre. Even though not all modelled consumers started operation during the monitoring period, the measured data was used to validate dynamic simulations and pump models. By introducing the measured loads and the effective hydraulic resistance to the simulation model, the measured pumping energy fractions could be closely reproduced with the simulation model.

Keywords: low temperature network, pumping energy, decentralized networks, undirected flow, monitoring data

INTRODUCTION

Thermal interconnection has a great potential to reduce primary energy consumption in areas with mixed heating and cooling demands. Several low temperature district heating networks working as heat source for efficient heat pumps in the residential sector as well as cold source for the climatisation of office buildings or other processes with large cooling demands have recently been built in Switzerland (general scheme in figure 1). Large borehole fields connected to the network serve as thermal storages for heat respectively "cold" between the seasons. Thermal losses form the borehole storage as well as in the piping network can be minimized by keeping the temperature of the network close to the average temperature of the surrounding ground. In the contrary to conventional district heating networks with directed flow and central pumping stations, the flow in such networks is generated by decentralized pumps for each connected heat pump (consumers) or "cooling station" (producers). For this reason, the flow in such a network is undirected, meaning that in one piping section the flow can be in both directions depending on the predominant operation mode (heating or cooling).

The interaction between different pumps connected to the network is highly dynamic and difficult to predict. A modelling approach, similar to the one presented in this contribution has been done by Kräuchi et al. in IDA-ICE [1]. However, detailed pump characteristics where not taken into account and pumping energy consumption was not explicitly analysed. Examples, where elevated pumping energy in the same order of magnitude as the energy consumption of the heat pumps based on measured data were reported in [2]. This shows how important an accurate consideration of circulation pump energy consumption is for the overall energy efficiency of low temperature networks.

In order to increase prediction precision, a more detailed pump- and hydraulics model was introduced in the simulation software Polysun [3]. With this model, pumping energy consumption in the range of 0.6...3.4 % [4] of the delivered low temperature energy was predicted for different decentralized heating and cooling units and different pump types of a low temperature heating and cooling network built by a large housing cooperative in the city of Zürich. First parts of this network started operation in the end of 2014 and monitoring data is analysed and compared to preliminary simulations in this paper.

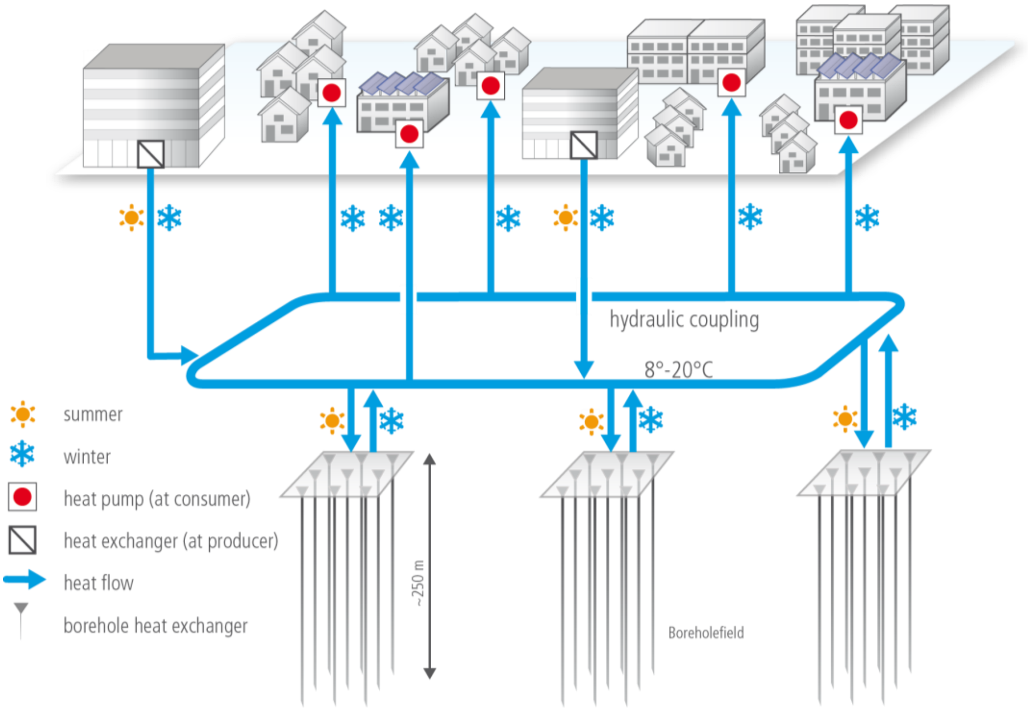

Figure 1 General scheme of a low temperature district heating network.

PRELIMINARY DYNAMIC PUMPING ENERGY MODELLING

The first construction stage of the low temperature network in question was integrated into the software Polysun based on a simplified outdoor temperature dependent load model. It consists of three “heating stations” with large heat pumps (consumer 1, 2 & 3) connected to the cooling unit of a data centre (producer) and a large borehole field for seasonal storage. The simulation scheme is given in figure 2 and the outdoor dependent load modelling in figure 3. A general description of this network is given in [4] and a more detailed description of the pump model and the simplified load modelling in [5]. The simulations of the dynamic pump interactions resulted in pumping energy consumptions reaching from 0.6 to 3.4% of the delivered low temperature energy (for consumer 1 with an efficient pump engine according to IE4 respectively consumer 2 with an intermediate pump engine according to IE2 standard).

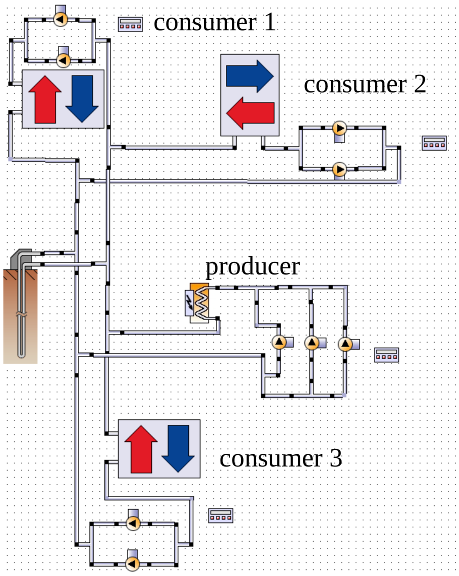

Figure 2 Simplified hydraulics of the first construction stage of the heating and cooling network as implemented in Polysun.

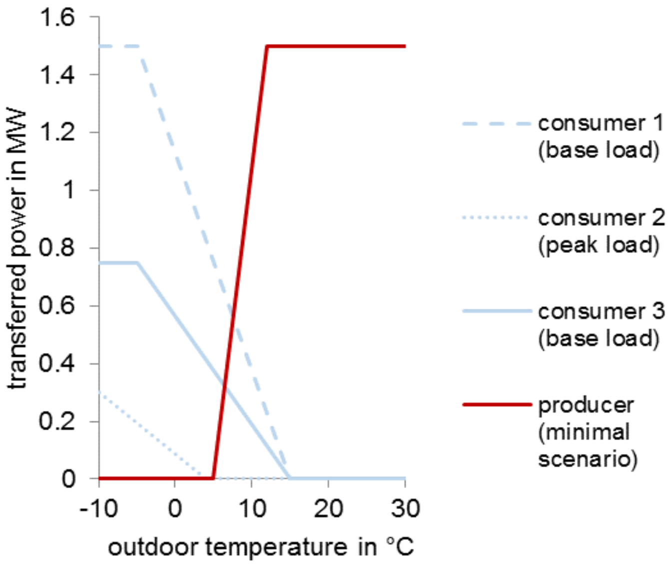

Figure 3 Outdoor dependent power consumption or delivery as used for the simplified dynamic modelling of the first construction stage of the examined network.

MONITORING RESULTS

In autumn 2014 the first consumer started its operation, and from 22.12.2014 on, detailed measurement data with a resolution of one minute is available. In the first winter only two operating units connected to the network were active:

Consumer 1: Large multi compressor heat pump with a nominal power of 2 MW providing domestic hot water (DHW) and Space Heat (SH) for over 400 households. The heat pump is retro fitted to the existing heat distribution system with a mean flow temperature of 68°C.

Producer: Data centre cooling integrated to the primary (direct) and secondary cooling cycle (sink of cooling machines) by heat exchangers.

The other consumers of stage one will start their operation in the heating period 2015/16.

System temperatures and heat pump COP

During the first months of operation, the temperature evolution was dominated by three phases (see figure 4).
Initiation: The heat pump of consumer 1 was working and first tests with the heat delivery from the producer where carried out.
Control adaption: The control algorithm of the producer was adapted. During this time no energy from the producer was transmitted to the network. Temperatures in the borehole field and at the source of the heat pump dropped to nearly 4°C (return).
Regular operation: Pump and mixing valve of the producer are being controlled in order to provide a fixed temperature to the cooling system on the secondary side of the heat exchanger. To this end, the temperature difference between flow and return on the primary side is variable. Temperatures in the system rise as a consequence of the energy input from the producer.

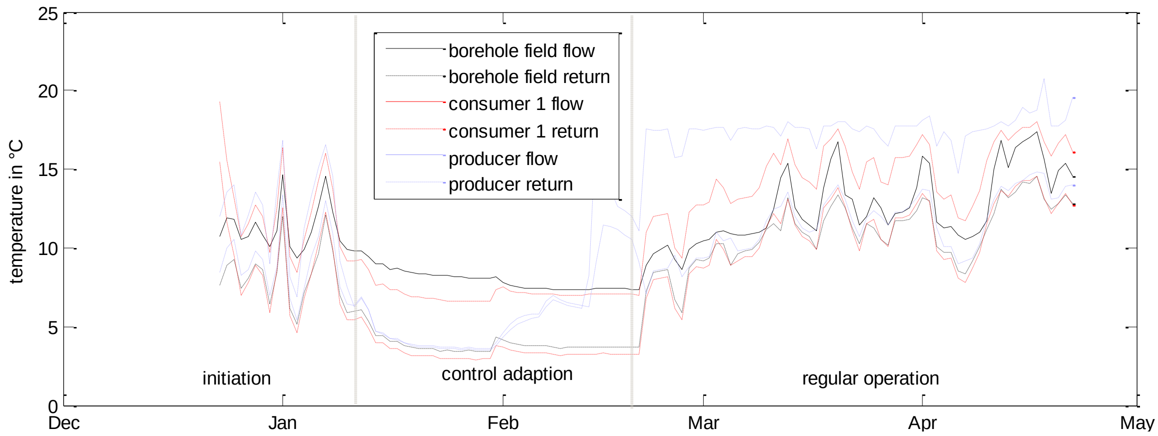

Figure 4 Temperature evolution at different points in the network (daily averages).

The total COP of the heat pump of consumer 1 equals 3.9 (for the heat pump only) and 3.7 (including auxiliary energy from primary and secondary side) during the four months of evaluation. The overall COP depends on the source temperature and varies between 3.2 and 4.3. In the contrary, the overall heat pump efficiency factor is less variable and remains between 62% and 67% (daily values, with two exceptional days). Because of the elevated supply temperature needed for the conventional housings (68°C) the heat pump COP is limited to values below 4 despite of the high efficiency factor.

Circulation pump energy consumption

The decrease in COP by taking auxiliary energy into consideration is mainly due to decentralized network pumps. However, during the measurement period of four months, only a quantity of electric energy corresponding to 1.6% of the low temperature energy delivered to the source side of the consumer heat pump (evaporator) and 1.2% of the energy delivered to the user (heat pump condenser) was needed for the network pumps. At the producer, the network pumps only used an electric energy equal to 1.1% of the transferred energy. Differences in the control strategy of the producer and consumer 1 can be seen in figure 5, where the electrical power consumption from the pumps is compared to the transferred thermal power (at the low temperature level). For consumer 1 the pumping fraction increases with the delivered thermal power. This pump is controlled in order to provide a fixed temperature difference between flow and return. For such a control strategy, part load operation is favourable for the needed pumping power fraction.

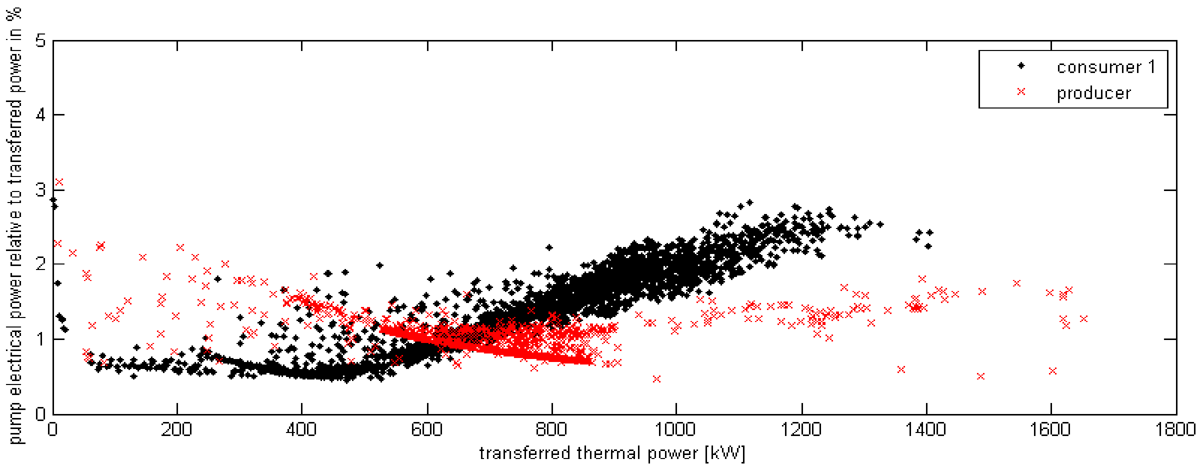

Figure 5 Electrical pumping power as a function of the transferred thermal power (hourly mean values).

The control strategy of the producer provides a constant temperature at the secondary side. For this reason, the temperature difference between flow and return is variable. With a high temperature, elevated thermal power can be transferred with relatively low flow rates. These operation states result in low relative pumping energy fractions. When the temperature difference decreases, less thermal power can be transferred with the same flow rate or pumping power. Consequently, the fraction of pumping power (relative to the transferred thermal power) increases.

VALIDATION OF PUMP MODEL

Even though only one consumer and producer were running during the measurement period, the measured data could be used to validate the simulation model. The measured heating and cooling loads were integrated into the simulation on a one minute time step base in order to test the pump- and hydraulic resistance model. Pumps were controlled in the software in order to provide the desired temperature difference. However the temperature difference was adapted to account for changes in the real control strategy. This affected mainly the control of the producer pumps in the third phase of operation (fixed temperature at the secondary side). Consumers 2 and 3, which are not yet operational, were also deactivated during simulations. From the simplified annual load modelling with all three consumers in operation, an annual electricity consumption of only 0.7% (consumer 1) respectively 0.6% (producer) of the transferred energy was estimated. However there where major differences between the simplified load prediction and the monitored operation:

1. The difference of only one consumer in real operation and three parallel consumers in the simplified model results in lower flow rates in the network and borehole field during winter operation. An even lower pumping energy fraction of 0.6% (consumer 1) of the transferred energy results from disabling consumer 2 & 3 in the simplified load model.
2. The simplified annual load consists of more part load operation than in the measurement period (winter). The pumping energy fraction increased to 1.0% (consumer 1) respectively 0.9% (producer) by introducing the measured winter loads into the model.
3. The measured pressure drop at the in- and outlet of consumer 1 where higher than predicted. By adapting the hydraulic resistance of the connection piping in order to reach the same pressure drop as measured, the modelled pumping energy fraction of consumer 1 further increased to 1.5%.

Table 1 Pumping energy fraction in % of the transferred energy of measured data and model outputs from different loads and hydraulic resistances.

	Consumer 1	Producer
Prediction from annual simplified load	0.7 %	0.6 %
Prediction from simplified load, consumer 2&3 disabled	0.6 %	0.6 %
Simulation with measured load (winter)	1.0 %	0.9 %
Simulation with adapted hydraulic resistance (winter)	1.5 %	0.9 %
Measured (winter)	1.6 %	1.1 %

The remaining difference to the measured 1.6% (consumer 1) respectively 1.1% (producer) pumping energy fraction is assumed to result from modelling of the pumps and their control. Here, mainly the starting and stopping strategy of the pump control could not be reproduced correctly in the software. However, the effect of not well known hydraulic resistances and thermal loads is considerably higher than the deviations caused by pump modelling. The flowrate of the two users in operation is provided by several parallel and independently modelled circulation pumps. For this reason, the modelling approach is supposed to be valid also for more complicated networks with several consumers and producers in parallel. In order to validate this, further comparison will be done once other consumers are operational.

CONCLUSION

The first months of operation show that the examined low temperature network is well planned and dimensioned, thus working properly and providing low temperature energy for heating and cooling efficiently. The low auxiliary energy consumption results in a high overall heat pump efficiency of 65%. The overall COP in initial winter operation reaches a value of 3.7 at a mean secondary flow temperature of 68°C given by the retrofit heat delivery system. This COP-value is expected to increase, as mean annual network temperatures will be above the ones observed in the initial winter operation phase. For heat pumps to be built in future stages, serving modern buildings with a lower heating temperature level, significantly higher COP-values are anticipated. Only 1.6 % (consumer) and 1.1 % (producer) of the transferred energy is needed for circulation pumping. However, these measured values exceed the predicted values from annual loads. The deviation is mainly due to the measurement period in the winter months and to higher pressure drops than predicted. However, by introducing measured loads into the simulation and by adapting the hydraulic resistance, the simulated pumping power closely matches the measured data. This shows, that the model allows calculating the dynamic pumping power in such a network close to reality. Although only input data from one consumer and one producer were available, the model is supposed to be valid for more consumers, as the interaction of several pumps at two locations with independent flowrates in the opposite direction was considered. Deviations are caused rather by the estimation of the hydraulic resistance and loads than the simulation model.

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REFERENCES

1. Kräuchi Ph, Kolb M, Gautschi Th, Menti U-P, Sulzer M, Modellbildung für thermische Arealvernetzung mit IDA-ICE, BauSim2014 Fifth German-Austrian IBPSA Conference, Aachen, Germany, 2014
2. Vetterli N, Brücker S, Monitoring Suurstoffi – Monitoring einer thermischen Arealvernetzung in Kombination mit einem Erdsondenfeld, Jahresbericht 2014, Bundesamt für Energie BFE, Bern, 2015
3. Ruesch F, Kolb M, Gautschi T, Rommel M. Heat and cold supply for neighbourhoods by means of seasonal borehole storage and low temperature energetic cross linking, Proc. of CISBAT 2013, Lausanne, Switzerland. 2013
4. Ruesch F, Scherer J, Rommel M, Wärme- und Kälteversorgung mit Erdsondenfeldern – Vergleich von Messdaten und vereinfachter Abbildung in Polysun,18. Statusseminar brenet, Zürich, Switzerland, 2014
5. Velasolaris AG, Polysun - Simulationstool für Energiesysteme mit Schwerpunkt auf Solarthermie, Available from: www.polysun.ch, Winthertur, Switzerland, 2014