DYNAMIC ANALYSIS OF THE LOW-TEMPERATURE DISTRICT NETWORK “SUUSRTOFFI” THROUGH MONITORING

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ABSTRACT

The Lucerne University of Applied Sciences has been analysing and monitoring the low-temperature district heating and cooling network (LTN) “Suurstoffi” since 2012. The analysis showed that heating demand was twice as high as expected. On the other hand, waste heat from free cooling was much lower than expected. The higher heating demand and the lower heat recovery combined resulted in a negative energy balance and hence in an average temperature decrease of the ground storage over the last two years. First of all, a pellet oven was installed as an interim solution in order to supply additional heat to the LTN. Secondly, direct electric heating was used to support the domestic hot water production in order to reduce the energy demand out of the LTN. These temporary measures were only set up until the first part of the planned hybrid solar panels (PVT) were taken into operation in summer 2014. The upcoming data of the monitored summer 2015 will help taking the decision if the temporary measures have to be extended and if additional PVT panels need to be installed.

So far, the measured electricity demand to operate the LTN and the connected heat pumps was more than twice as high as expected. This is mainly due to the high electricity demand for temporary electrical heating for domestic hot water, circulation pumps and heat pumps. Thanks to the monitoring, hydraulic shortcoming, which caused the high electrical consumption of the circulation pumps, could be identified. The heat pumps consumed more electricity than planned due to the excess space heating demand and domestic hot water of the consumers. If, in addition to the electricity demand for the heat pumps, the electricity demand of the circulation pumps is taken into account, the overall network efficiency (yearly COP measured = 4.6) is lower than expected (yearly COP planned = 6.8).

As a result of the monitoring analysis over the last two years, the following outputs and outcomes could be provided:

- The real efficiency of the thermal network has been calculated and benchmarked
- Design mistakes have been identified and guidelines for planning have been developed
- The energy efficiency has been improved by optimizing the system operation
- The accuracy of the monitoring has been improved
- The influence of the user on the energy efficiency has been quantified.

Keywords: Monitoring, low-temperature, district heating and cooling network.

INTRODUCTION

The low temperature district heating and cooling network (LTN) ‘Suurstoffi’ in Risch/Rotkreuz close to Zug has been in operation since 2012. The LTN connects residential buildings, offices and industrial buildings (= consumers and producers) to a borehole heat exchanger (215 pieces à 150 m depth), which acts as a geothermal storage. In its final state, the whole district will include approximately 165’000 m² energy reference area and the geothermal storage will have more than 700 boreholes down to 250 m depth. Heating and domestic hot water are produced by means of decentralised heat pumps, which are connected to the LTN. Waste heat deriving from cooling installations in the buildings is used to regenerate the geothermal storages. Conventional (PV) and hybrid solar panels (PVT) installed on the roofs of the buildings shall cover the entire electricity demand for the buildings operation (heat pumps, circulating pumps, HVAC, public lighting, transport, building automation, etc.). In addition, the PVT panels shall supply additional heat to load the ground storage. This concept will reduce the non-renewable primary energy consumption and minimise the greenhouse gas emission during the operation.

Figure 1: Overview of the district "Suurstoffi", the red zone includes the building fields 2 (19'500 m², in operation since 2012) and 5 (27'000 m², in operation since 2013). Source: www.suurstoffi.ch

METHOD

In order to verify the objectives, the LTN "Suurstoffi" is being monitored for at least five years. Every heat and power flux as well as temperature change are measured in a 15 minute interval resulting in a total of about 400 data points over the building fields 2 and 5. The Lucerne University of Applied Sciences has been analysing the measured data since 2012.

The results have been regularly compared with the original calculations used for the network design. Some additional simulations have been executed in order to verify the gaps between the calculation results and the measurements. A comprehensive simulation model of the whole area is being developed to predict the energy balances in its final state. The measurements were used as a basis for the simulation models and hence improve the accuracy of the model. The simulation of different scenarios allowed to test the suitability of the concept and to generate suggestions for desirable improvements.

RESULTS

Figure 2 shows the comparison between the calculations for the first year of operation and the measurements for the period from October 1st, 2013 until September 30th, 2014 of the building fields 2 and 5.

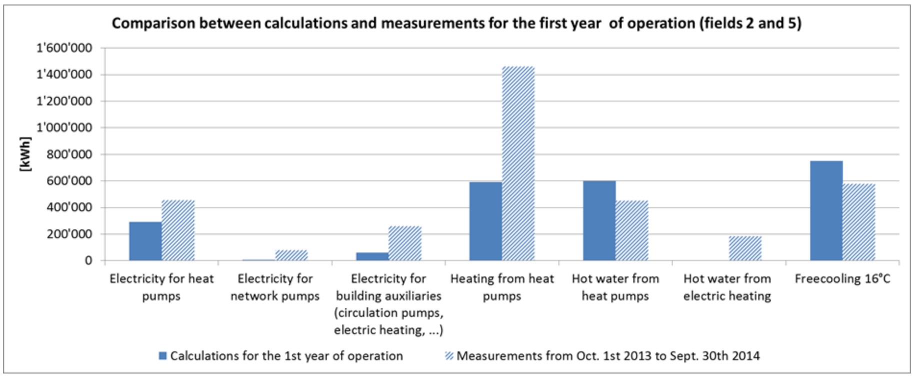

Figure 2: Comparison between calculations for the first year of operation and measurements for the period from October 1st 2013 until September 30th 2014 in the building fields 2 und 5.

The highest deviation was identified by the heat consumption. The results of the monitoring show a much higher heating demand than expected (590 MWh/a calculated and 1’460 MWh/a measured). The two main reasons for such a large gap between measurement and calculation are the overheating of rooms and the ineffective ventilation. The indoor air temperature measured during winter 2013 exceeded 22°C (design temperature: 20°C according to SIA) in more than 60% of the apartments in the building field 2. Furthermore, a majority of the rooms were ventilated by constantly opened windows, despite the mechanic ventilation system.

By means of dynamical simulations using the program IDA ICE it was proven that the higher indoor temperatures and the additional heat losses through natural and mechanical ventilation are the main reasons for the higher heat demand (see Figure 3).

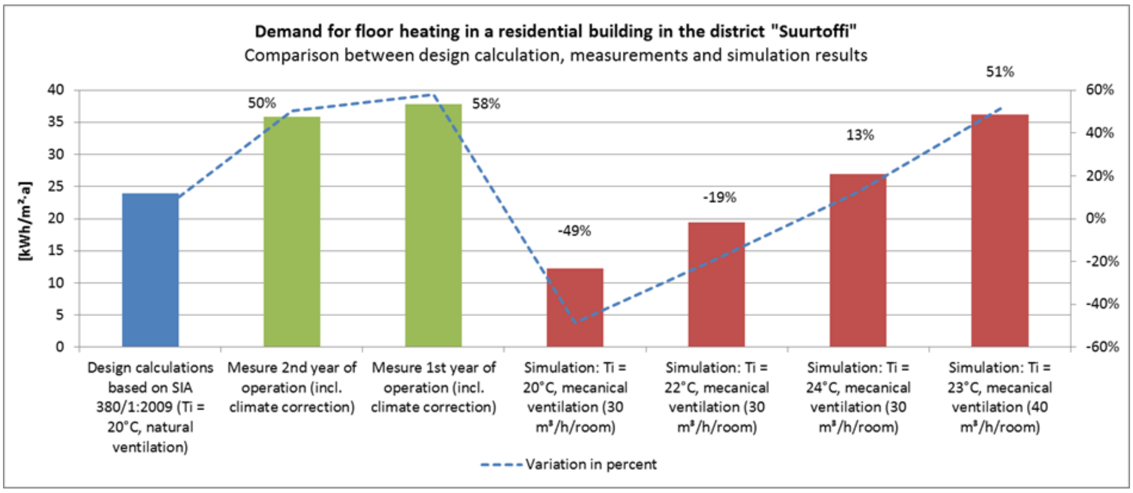

Figure 3: Comparison between design calculation, measurements and simulation results for the heat demand for floor heating in a residential building. [1]

Considering an indoor air temperature of 23°C and a mechanical ventilation with an increased air flow rate of 40 m³/h in each room (instead of 30 m³/h as planned), the simulated heating demand reached approximately the measured value.

The total electricity demand for the LTN (including the heat pumps, network pumps and building auxiliaries) was much higher than expected (360 MWh/a calculated and 800 MWh/a measured). The photovoltaic panels produced 346 MWh/a of electric power and could cover 43% of the total electricity demand for the network operation.

The total heat demand for space heating and domestic hot water was about 75% higher than expected (1.2 GWh/a calculated and 2.1 GWh/a measured). The total amount of heat extracted from the borehole heat exchangers to supply the heat pumps reached 1’600 MWh/a. Contrary to expectation, waste heat from the free cooling system was much lower than estimated (750 MWh/a expected and 580 MWh/a measured). One possible reason for the lower cooling demand is that the occupants were not well informed about the possibility of cooling their apartments.

The higher heating demand and the lower waste heat use both result in an overall decrease of the ground storage temperature. Figure 4 shows the network heat balance over the last two years (from January 2013 until December 2014). During summer season, the curve increases as a result of heat supply from free cooling, whereas in the winter, the curve decreases, due to the delivery of the heat pumps.

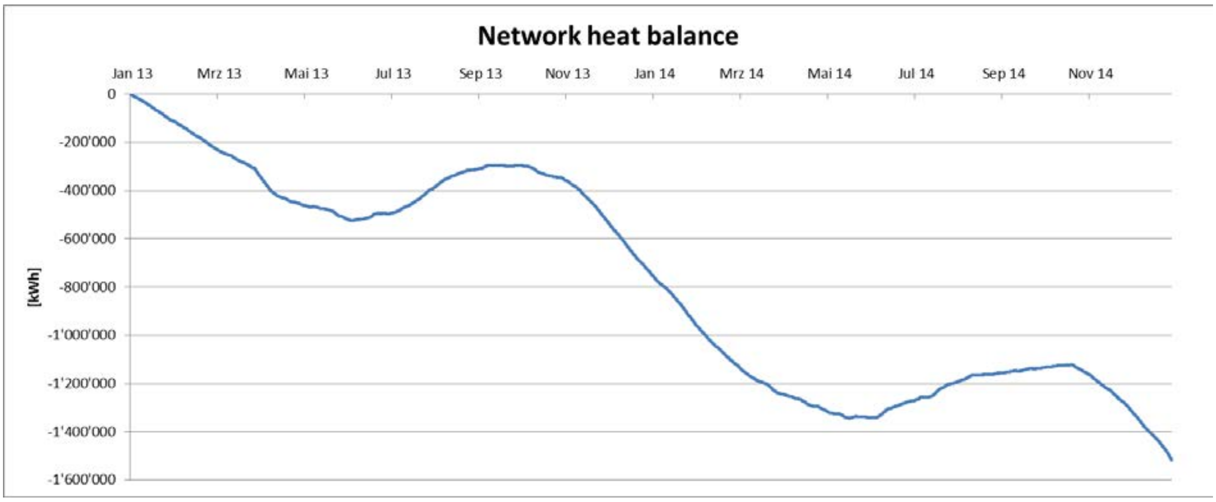

Figure 4: Network heat balance over the last two years (January 2013 – December 2014). Difference between heat demand of the heat pumps and heat supply of the free cooling in the building fields 2 and 5.

As an interim solution, a pellet oven was installed in order to supply additional heat to the LTN (640 MWh/a) until the hybrid solar panels were operational in summer 2014. Additionally, direct electric heating (184 MWh/a) was used to support the domestic hot water production in order to reduce additional heat withdrawal from the LTN. Despite the pellet oven, the annual heat deficit reached 380 MWh/a. The deficit results in a temperature decrease of the geothermal storage of about 0.6 K. The cooling tendency of the ground storage was verified through punctual measurements in one borehole heat exchanger a few meters under the ground. Figure 5 shows the measured water temperature in a borehole heat exchanger from May 2013 until December 2014. The comparison between the water temperature in May 2013 (11±0.3°C) and May 2014 (11±0.8°C) showed that the borehole heat exchanger field had almost recovered during that year. The network temperature will be locally higher because of the influence of the pellet oven. Considering the thermal inertia of the geothermal storage, the calculated temperature decrease should be observed in the upcoming months.

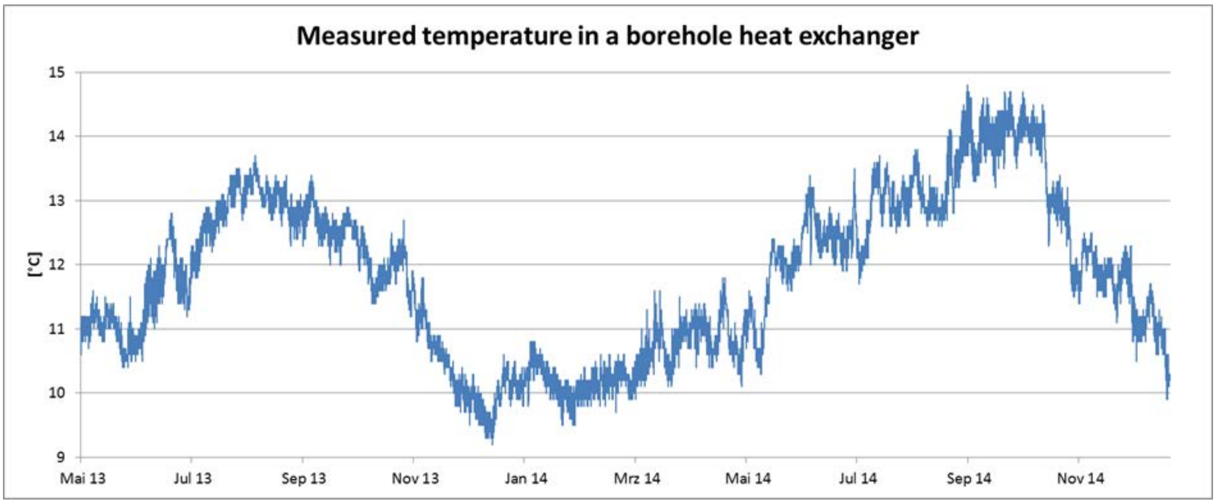

Figure 5: Measured water temperature in a borehole heat exchanger from May 2013 until December 2014.

Despite the heat deficit, the annual performance factor of the heat pumps was higher than expected (see Table 1). The main reason for the increase of the heat pumps efficiency was the partial production of the domestic hot water with the electric heating.

	Design calculations fields 2 and 5 (1st year of operation)			Measurements fields 2 and 5 (Oct. 1st 2013 - Sept. 30th 2014)		
Annual coefficient of performance heat pumps ($COP_{Heat\ pump}$)	Heating and hot water 4.1			Heating and hot water 4.2		
Annual coefficient of performance network ($COP_{Network}$)	Heating and hot water 4.1	Cooling 119.9	Heating + Cooling 6.8	Heating and hot water 3.8	Cooling 20.9	Heating + Cooling 4.3
Efficiency (Ɛ)						5.5

Table 1: Comparison between the calculated and the measured coefficients of performance and efficiency for the building fields 2 and 5.

The measured overall efficiency (yearly coefficient of performance) of the network reached 4.3 against 6.8 expected. The electricity demand for the district network pumps is included in this factor and shows the comprehensive efficiency of the LTN. The measured electricity consumption (81 MWh/a) of the network pumps was about eleven times higher than the calculated one (7 MWh/a). In such a case, a hydraulic analysis was recommended in order to identify problems as well as the possibilities of optimisation.

Figure 6 shows the difference between the measured energy consumption during the first and second years of operation in the building field 2. Despite the optimisation measures made during the second year of operation, the electricity consumption of the buildings auxiliaries had conspicuously increased. This is principally due to the use of electric heaters for the domestic hot water production. As a result, the heat pumps used less electricity during the second year of operation.

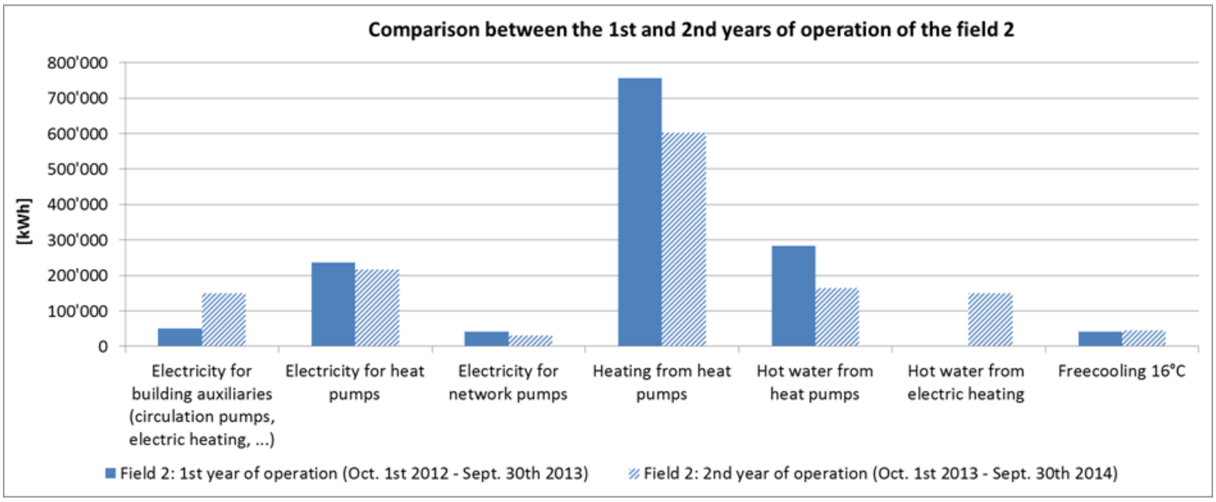

Figure 6: Comparison of the energy demand during the 1st and 2nd years of operation of the building field 2.

The overall heating consumption was reduced during the second year of operation. A major reason of the higher energy efficiency is due to warmer climate conditions as well as natural drying out of the building.

DISCUSSION

The importance of monitoring has been demonstrated once more in the project “Suurstoffi”.

- The measured values could be compared with the original planned values in order to the optimise processes and take early decisions in the planning sequence.
- Premature errors could be discovered and measures against them could be undertaken.
- The monitoring of the project constitutes an important data base and benchmark for future projects in the field of thermal networking.
- A simulation model of thermal networking could be calibrated with real data.

The monitoring of the project “Suurstoffi” is related to a significant amount of monitoring data points and some errors in measurements. Systematic data checks have to be performed in order to identify any inconsistency in the data logging and consequently to improve the monitoring accuracy. The data handling and verification is a crucial task in order to provide a solid database for formulating sound conclusions.

The monitoring analysis has been used for several studies since the area operation started. The measured data served as a basis for a multitude of simulations and benchmarks. For example, the future energy demand for the buildings in Suurstoffi East was estimated via measurements extrapolations and hence increased the accuracy of the SIA calculation due to consideration of the real user behaviour. Furthermore, simulations allowed quantifying the user influence on the energy efficiency (indoor air temperature, ventilation) and predicting the future energy demand.

By means of the monitoring and its analysis, the effective performance of the heat pumps and the low-temperature network has been calculated. Comparisons have been made with similar networks in order to identify optimisation potentials and design mistakes. The identified hydraulic problems by benchmarking the electricity consumption of the network pumps shows such a potential. Monitoring is an effective instrument commissioning an operation optimisation.

The analysis of changes in temperature in the borehole heat exchangers allows the ground storage to be supervised. In case of possible undercooling, appropriate actions can be implemented on time and hence prohibit damages on the technical equipment. By means of this detailed monitoring, the network undercooling in winter 2013 was avoided thanks to the operation of both the pellet oven and the electric heating for domestic hot water.

The major finding is the understanding of the dynamic performance of the LTN connected to various geothermal storages. This allows the development of a model predictive control system and hence an increase of the operational robustness of such systems. The complexity of LTN is high, but such concepts must not be susceptible. The key is to exploit synergies among the different elements by executing a comprehensive design process and implement predictive automation based on detailed monitoring data.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Norm SIA 380/1, Thermische Energie im Hochbau, SIA Schweizerischer Ingenieuren und Architektenverband, 2009.

[2] Brücker S.; Vetterli N.; Sulzer M., Menti UP.: Monitoring Suurstoffi-Areal Risch/Rotkreuz - Dynamik und Optimierung eines Anergienetzes, Status-Seminar «Forschen für den Bau im Kontext von Energie und Umwelt», September 2014

[3] Kräuchi P., Kolb M., Gautschi T., Menti UP., Sulzer M.: Simulation thermischer Arealvernetzung mit IDA-ICE. Status-Seminar, Sept. 2014

[4] Gautschi T., Sulzer M.: ETH Zürich, Hönggerberg Masterplan Energie, Schweizerisches Status-Seminar Energie- und Umweltforschung im Bauwesen, September 2008