HIGHLY EFFICIENT, COST-EFFECTIVE SOLAR-GEOTHERMAL HEAT SUPPLY CONCEPT FOR MULTI-FAMILY HOUSES AND SMALL RESIDENTIAL AREAS

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ABSTRACT

In order to meet the targets of the European Renewables Directive (2009/28/EC) [1], it is essential to increase both, the share of renewable energy sources used for heating applications as well as the efficiency of today's conventional heat supply systems. As a step forward to face this challenge, an innovative, sustainable heat supply concept is being developed at the Research and Testing Centre for Thermal Solar Systems (TZS) of the Institute of Thermodynamics and Thermal Engineering (ITW) of the University of Stuttgart. **This concept, which is based on solar thermal and geothermal heat generation and advanced heat storage technologies, will be realized for the first time as a heat supply system for new apartment buildings. The key feature of the system is the fact, that on an annual basis only 1 kWh of electricity will be required to generate 10 kWh of heat.**

The concept mentioned above is in principle designed in a similar way as the energy concept of so-called "solar houses" or "solar active houses" with high solar fractions > 50 %, where heat is usually generated by solar thermal collectors and stored in large-volume hot water stores. Regarding the high efficient, cost-effective solar-geothermal heat supply concept introduced in this paper, about 50 % of the annual heat demand for domestic hot water and space heating can be provided by solar energy. Another 40 % of the annual heat demand is provided by shallow geothermal energy, and only an additional 10 % of the annual heat demand is required in the form of electrical energy to operate a compression heat pump. The high efficiency of the concept is derived from an efficient combination of the used technologies in conjunction with a specially adapted control strategy and the use of innovative key products. For example, the geothermal source system is based on highly efficient, slim, helical ground heat exchangers with high specific heat transfer capacities, which are immersed only up to 10 meters in the ground. In contrast to conventional borehole heat exchangers, the installation of these innovative heat exchangers is relatively low priced and, due to the small drilling depth, no hydrogeological problems are expected.

This contribution is focused on the presentation of the above described, newly developed system concept as well as first results of the design and simulation studies for a pilot heat supply system that is planned to be realized in a complex of three multi-family houses within a total living area of approx. 3 530 m² in the German city Crailsheim, which is located 80 km north-east of Stuttgart.

The development of the concept is part of the research project '1to10 – Development, testing and demonstration of a sustainable, standardized solar-geothermal heat supply concept'. In the conceptual design phase of the project, theoretical work for the realization of such systems is performed. Another key part of the design phase is for example the issue of a stakeholder analysis and, based on this analysis the development of a constellation of stakeholders.

Keywords: solar thermal, geothermal, heat supply concept, multi-family houses

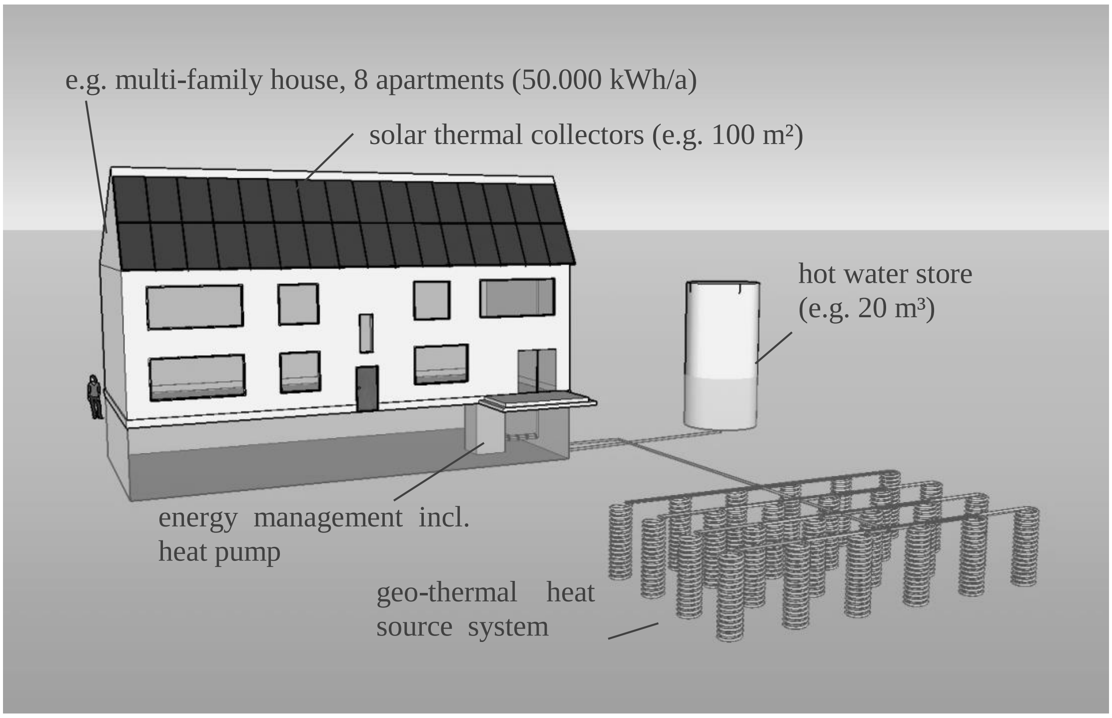

Figure 1: General 1to10 system concept

INTRODUCTION

Solar thermal as well as geothermal energy play a crucial role in the extension of the use of renewable thermal energy in Europe. The aim until 2050 is a contribution of 50 % of solar thermal energy to cover the European heating and cooling demand [2]. An essential step to reach this goal is to access the market of multi-family houses. In Germany, the share of residential units that are located in multi-family houses is 60 % of all existing residential units and this market segment is vastly untapped for solar thermal systems until now.

Essential aspects of the 1to10 heat supply concept on the basis of solar thermal and geo-thermal heat generation as well as heat storage are:

- Exceptionally high system efficiency – only 1 kWh of electricity required to generate 10 kWh of heat
- Only electrical connection required – no natural gas connection or storage for oil or wood pellets
- Large thermal capacities on both sides of the heat pumps allow relatively flexible operation times in off-peak periods which result in the stabilization of the electricity grid
- The combination of solar thermal energy and shallow geothermal energy reduces the size and therefore the investment costs of the geothermal system compared to a solely ground-coupled heat pump system.
- Consistently high energy efficiency ratios of the heat pumps and therefore low operation costs

DESCRIPTION OF THE PILOT SYSTEM

The 1to10 system (hydraulic scheme see Figure 2) consists of a solar collector loop which is hydraulically decoupled from the hot water store with an external heat exchanger. Two heat pumps are connected to the store: a high temperature heat pump provides heat for domestic hot water preparation using water at a medium temperature level of about 40 °C from the middle part of the hot water store as heat source. The condenser of the high temperature heat pump is connected to the upper part of the store. The second, ground coupled heat pump provides heat at medium temperature level for space heating to the middle part of the store. The evaporator of this heat pump is connected to the helical ground heat exchangers, which – if applicable – will be operated with water as heat transfer fluid. Surplus heat from the solar thermal collectors which cannot be stored in the hot water stores is used to heat up the ground. In addition to the effect of the regeneration of the earth, stagnation of the system can be avoided in summer.

The hot water store is the central component of the heat supply systems where all system circuits meet. For domestic hot water preparation, hot water is drawn from the upper part of the store to heat up domestic hot water in an external fresh water station. The space heating loop is connected to the middle part of the store.

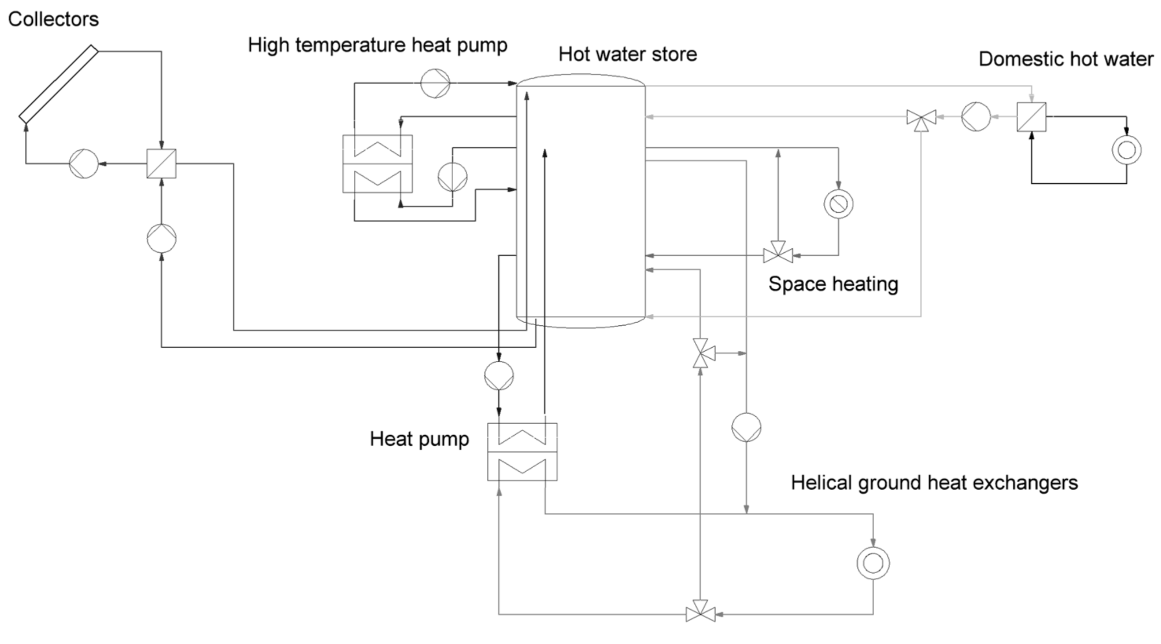

Figure 2: General hydraulic concept

Building characteristics

The building complex in Crailsheim, which is foreseen as pilot plant, consists of three multi-family houses with a total of 40 apartments. The annual heat demand for space heating is 135 000 kWh/a, the heat demand for domestic hot water preparation is 44 200 kWh/a, while half of the heat demand for domestic hot water is needed to provide a constant temperature of 65 °C in the circulation system. The orientation of the roof areas is south-west for two of the buildings and south-east for the third building. The flow temperature of the low temperature space heating system is 37 °C.

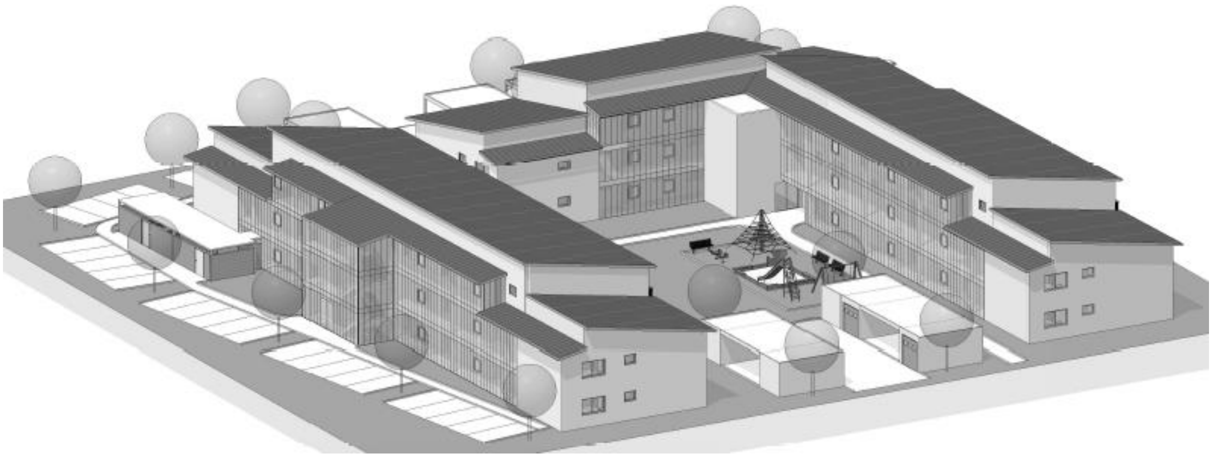

Figure 3: Building complex in Crailsheim, Germany. © Fessel Architekt GmbH

System components

Solar thermal **vacuum flat plate collectors** with a total gross area of about 250 m² will be installed on the roofs of the building complex. Due to the fact that the mono-pitched roofs of the buildings have a very small slope of 10°, it is necessary to raise the solar thermal collectors to a slope of 60° in order to increase the collector gain in winter and during the transition months with low sun positions, while at the same time reduce the solar gain in summer and therefore reduce stagnation times of the system. Additionally, reflector plates as displayed in Figure 4 on the left are planned to be realized in order to further increase the solar gain in times of low sun levels. The right side of Figure 4 shows the solar irradiation on the collector plane for collectors with a slope of 60° with and without reflector plates. As intended, the solar irradiation on collectors with reflector plates is significantly higher in the winter and transition months and in the same range or even less in the summer months.

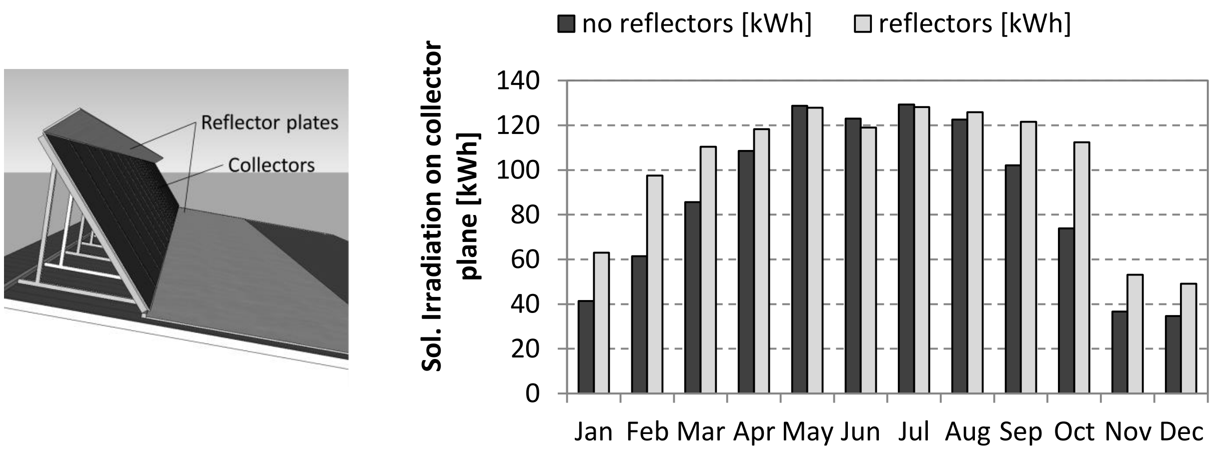

Figure 4: collector installation design with reflector plates (left) and the resulting irradiation on the collector plane (right; collector slope: 60°)

Two **heat pumps** will be installed in order to provide heat for space heating and domestic hot water. The first heat pump with a condenser power of about 50 kW_{th} is a ground coupled heat pump whose evaporator is connected to the ground heat exchangers. The first heat pump provides heat at a temperature level of about 40 °C to the middle part of the heat store. The second heat pump works at a higher temperature and provides hot water at a thermal output of about 4.5 kW_{th} and a temperature level of about 65 °C for domestic hot water preparation to the upper part of the store. Heat source of the high temperature heat pump is warm water from the middle part of the heat store.

The **helical ground heat exchangers** will be installed in the courtyard between the three buildings. About two hundred helical ground heat exchangers will be installed on a total area of 1 200 m². The **hot water store** will be positioned outside the buildings and is planned to be immersed partly in the ground in order to reduce the heat losses to the environment in winter. An innovative vacuum insulation additionally minimizes the heat losses of the hot water store to the environment. The hot water store has a volume of about 40 m³.

SIMULATION RESULTS

Table 1 contains the results of a first simulation setup which will be the basis for the planning of the system that will be realized at the site in the city of Crailsheim. In this system configuration, 1 kWh_{el} of electricity for the heat pumps ($W_{el,HP1} + W_{el,HP2}$) is used to generate 9.23 kWh_{th} of heat for space heating (Q_{SH}) and domestic hot water (Q_{DHW}) including the additional heat that is needed due to the heat loss of the store ($Q_{loss,sto}$). The solar fraction f_{sol}, which is defined as

$$f_{sol} = \frac{Q_d - Q_{evap,HP1} - W_{el,HP1} - W_{el,HP2}}{Q_d} \cdot 100 = \frac{Q_{sol,net}}{Q_d} \cdot 100 \tag{1}$$

is 58.3 %, where the heat demand Q_d is defined as the sum of the heat demand for space heating and domestic hot water and the heat loss of the store $Q_{sol,net}$ is the difference of the total collector gain and the surplus heat that is transferred from the store to the helical ground heat exchangers and $Q_{evap,HP1}$ is the low temperature heat provided by the helical ground heat exchangers. The fraction of the heat demand that is covered by the two heat pumps f_{HP} is 41.7 % and is defined as

$$f_{HP} = \frac{Q_d - Q_{sol,net}}{Q_d} \cdot 100 \tag{2}$$

Q_{SH} [MWh_{th}]	Q_{DHW} [MWh_{th}]	$Q_{sol,net}$ [MWh_{th}]	$Q_{evap,HP1}$ [MWh_{th}]	$Q_{loss,sto}$ [MWh_{th}]	$W_{el,HP1}$ [MWh_{el}]	$W_{el,HP2}$ [MWh_{el}]
135.24	44.20	109.18	57.97	7.88	17.91	2.38

Table 1: Annual heat balance of the 1to10 system, simulation results

The monthly heat balance of the system, which is displayed in Figure 5, shows that from May to September, almost the whole heat demand is covered by the gain of the solar thermal collectors and the heat pumps only provide a marginal share of the heat demand. In the winter months from November to January, the heat demand covered by the heat pumps is 71 –74 %. According to the simulations, during the transition months March, April and October, 65 – 80 % of the heat demand is covered by the solar thermal collectors.

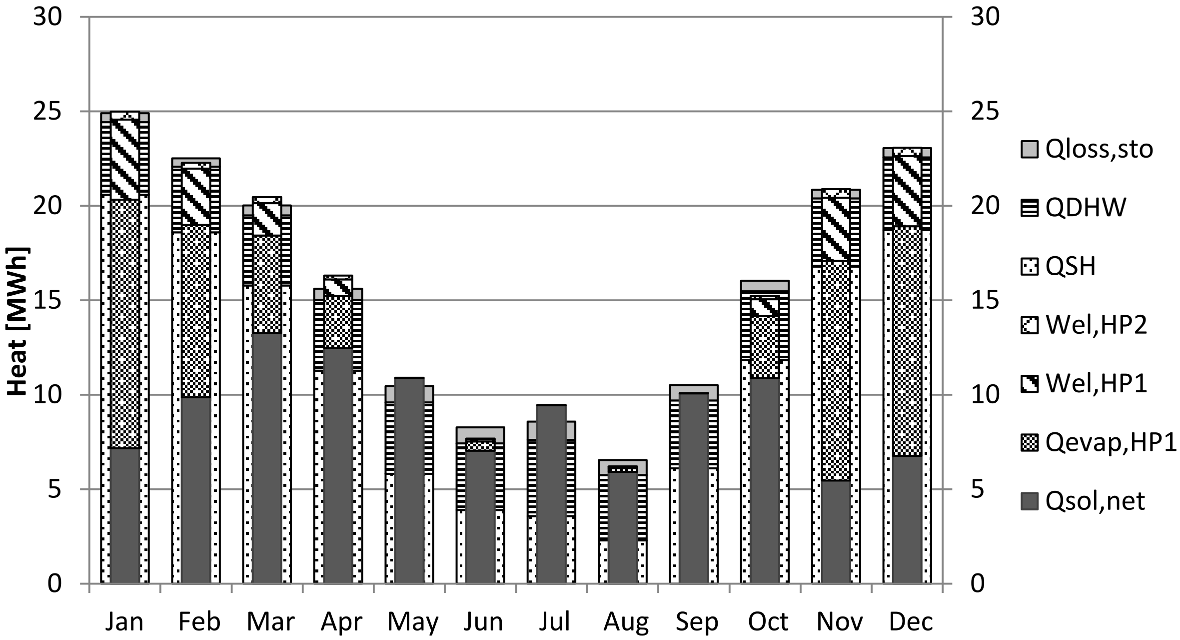

Figure 5: Monthly heat balance of the 1to10 system, simulation results

CONCLUSION

The presented simulation results are the starting point for the planning and dimensioning of the heat supply system to be realized in Crailsheim. Based on these results, the heat supply system with its site-dependent boundary conditions will be planned in an iterative process in collaboration with the architect and the contractor of the building project.

However, these first simulation results allow for the appraisal that the goals of the concept 1to10 can be achieved in this first pilot application.

ACKNOWLEDGEMENTS

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