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Renewable Low-Temperature District Heating of a New Housing Area in Kassel, Germany – A Case Study of IEA EBC Annex 64

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Abstract

The renewable low-temperature district heating of a new housing area in Kassel, Germany is one of the case studies of IEA EBC Annex 64 "LowEx Communties". The heat supply concept pursues the low exergy approach and is based on a low-temperature district heating network in combination with central and decentralized heat sources. The district heating network is fed by a central ground-source heat pump coupled with borehole heat exchangers. The low supply temperature of 40 °C is sufficient to cover the space heating demand of 127 buildings equipped with floor heating. The low supply temperature is crucial for high efficiency of the heat pump and low heat losses of the piping network. Hygienic domestic hot water preparation requires higher temperatures of up to 60 °C and is covered by decentralized solar thermal units with electrical back-up heaters. Thus, the district heating provides only the space heating during the heating period and is not in operation during summer. Furthermore, due to the limited area for borehole heat exchangers ground regeneration is necessary in order to avoid long-term undercooling of the ground. The ground regeneration will be done during summer by cheap uncovered solar thermal collectors, which are very efficient at low supply temperatures.

The paper presents the heat supply concept in detail and describes the challenges for a practical realization, as well as the aims of the research project, which shall support the detailed design of heat supply.

Keywords – low-temperature district heating, ground source heat pump, solar heat, IEA EBC Annex 64

1. Introduction

City of Kassel aims at developing a new environment-friendly housing area. Regarding the heat supply the following requirements have been formulated:

- significant reduction of the primary energy demand and CO_2 emissions in comparison to conventional heat supply systems
- use of renewable energies
- avoidance of fine dust emissions

In order to identify the best possible system solution, different centralized and decentralized supply strategies have been investigated and compared in the first phase of the project (detailed description of the results in [1]). Central challenge was to identify economically feasible solutions for the low heating demand of new residential buildings. As a result of the first project phase a geosolar heat supply concept has been selected for the housing area by the City of Kassel and the municipal energy supply company Kassel. The heat supply concept is based on the central ground source heat pump (GSHP) in combination with a low-temperature district heating for space heating and decentralized solar thermal systems for domestic hot water (DHW) preparation. This heat supply concept is economically and ecologically more favorable than a conventional solution (gas condensing boiler with solar DHW preparation). The total annual heating costs are 5% lower. Furthermore, CO_2 emissions and primary energy demand are approx. 60 % lower.

The second phase of the project aims at detailed elaboration of the innovative heat supply concept, including detailed dimensioning of all components, development of operation strategies and tariff models, identification and proof of sensitive parameters (e.g. geothermal characteristics of the ground or amount of buildings connected to the district heating).

The paper describes the new housing area, the geosolar heat supply concept and the aims of the second phase of the research project. The geosolar heat supply concept is one of the case studies of IEA EBC Annex 64 “LowEx Communties” as it pursues the low exergy approach.

2. The new housing area “Zum Feldlager”

The new housing area "Zum Feldlager" is located in the northwest part of Kassel, Germany, far away from the existing district heating nets. The area will be characterized by a very compact and south oriented construction; 1-2 storey detached and semi-detached houses in the north, two-storey terraced houses in the centre and large three-storey apartment buildings in the south, cf. Fig. 1. All buildings have specific heat demand of

40..45 kWh/m²a corresponding to a very good insulation standard and comply with the German building code [3].

No. of buildings	127
- Detached houses	46
- Semi-detached houses	32
- Terraced houses	37
- Apartment buildings	12
No. of dwelling units	154
No. of persons per dwelling unit	4
Heat emission system in buildings	Surface heating

Fig. 1 Map of investigated planning area "Zum Feldlager"; City of Kassel/Germany [2].

The total annual energy demand according to monthly balance method DIN V 18599 [4] is calculated for heating demand of 1200 MWh/a and for domestic hot water demand 365 MWh/a. The heating period is October to April. The required total nominal power for space heating is 580 kW.

3. Geosolar heat supply concept

The geosolar heat supply concept combines central and decentralized heat sources. The system consists of the following main components (Fig. 2):

- a central heat pump connected to borehole heat exchangers
- an electric boiler for peak load and backup
- low-temperature district heating network
- distributed solar domestic hot water systems
- uncovered solar collectors for ground regeneration

Unlike typical new (smaller) district heating systems in Germany with supply temperatures of 70..90°C, the district heating in the geosolar concept shall have only 40°C. This temperature level is, however, enough to provide the space heating of buildings via surface heating systems. The district network is fed by the central heat pump and the electric boiler during the heating period of 7 months. The heat pump uses the ground via borehole heat exchangers (90..130 boreholes, 120 to 140 m depth) as a heat source. Due to the favorable temperature levels, the heat pump shall achieve a seasonal performance factor of 4.9. The electric boiler covers peak load from 460 kW to 580 kW, i.e. upper 20% of the load, and serve as a backup for the heat supply. During the summer, the thermal district grid does not transport any energy to the buildings, but it is used to transport heat from the detached uncovered solar collector fields to the borehole heat exchanger for the ground regeneration. Thus, the thermal district grid is operated bidirectionally depending on the season.

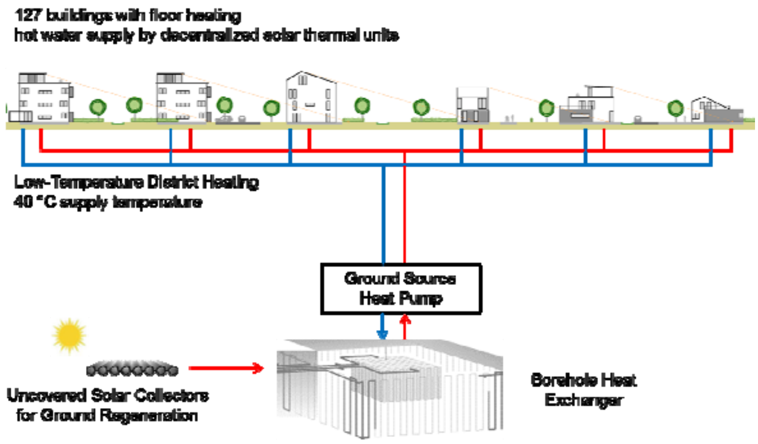

Figure 2: A principle scheme of the geosolar heat supply concept

Domestic hot water preparation requires higher temperatures of 45°C for single-family houses and 60°C for multi-family houses. It is not provided by the district heating, but by distributed solar thermal systems in every building with an electrical back-up. Due to the rather high electricity prices in Germany, it is advantageous to enlarge the collector area in comparison to conventional layout (e.g. 7.5 m² instead of 5 m² for a single-family house) and to use district heating to preheat the bottom part of the hot water storage during winter (Fig. 3). Simulation studies showed that larger collector areas and preheating by district heating in winter will reduce the auxiliary energy demand from 40% to 17% of the total energy demand for domestic hot water.

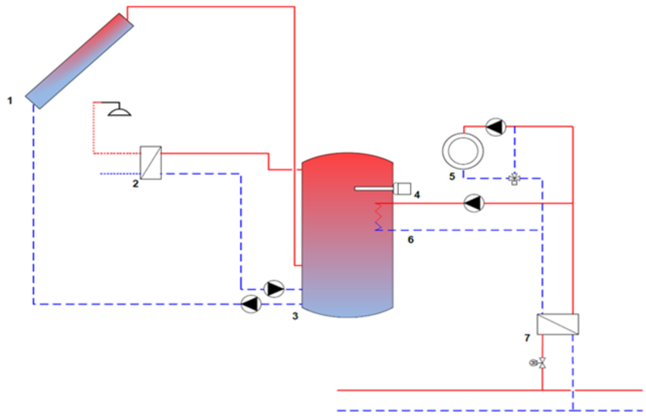

Figure 3: A principle scheme of domestic hot water and space heating supply in buildings. This scheme shows a water-driven drainback solar thermal system in combination with a instantaneous water heating system. A typical solar hot water system is, however, possible too.

Decentralized solar domestic hot water systems enable low supply temperature and seasonal operation of the district heating. Both factors lead to very low heat transport losses of 2.5 %. Such low heat losses are crucial for the economic feasibility of the district heating in areas with very low energy density (e.g. 500-1000 kWh/(a*m)).

The heat supply concept distinguishes between the heating and in the off-heating period operation modes (for easiness called “winter” and “summer” operation modes). Energy flows in each operation mode are shown in Fig. 4 and 5.

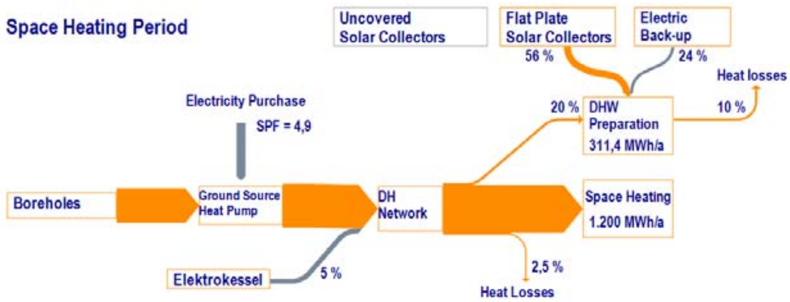

Figure 4: Energy flows during the heating period (Oct-Apr)

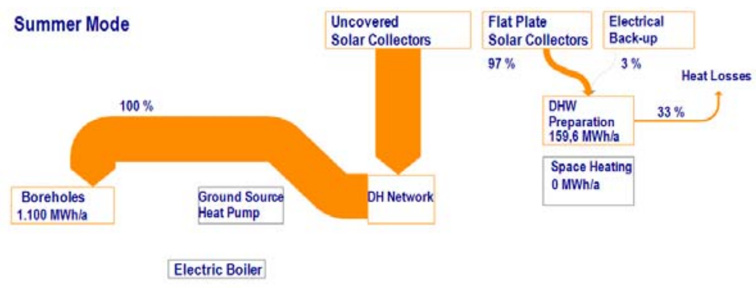

Figure 5: Energy flows during the off-heating period (May-Sept)

An environmental impact has been quantified for the geosolar concept and for the reference system (gas condensing boiler with solar DHW) in terms of primary energy demand and CO_2 emissions. Calculations were carried out using primary energy factors and CO_2 equivalents according the German Energy Saving Ordinance [3] shown in Table 1

Table 1. Used environmental impact factors

Parameter	Value
Primary energy factors	
- Natural gas	1.1
- Electricity	1.8
- Renewable energy (solar heat, geothermal)	0
CO_2 emission equivalents	
- Natural gas	0.228 kg/kWh
- Electricity	0.347 kg/kWh
- Renewable energy (solar heat, geothermal)	0

The results show that the geosolar heat supply concept leads to 61 % lower primary energy demand and to 64 % lower CO_2 emissions comparing to the reference system (Fig. 6). Furthermore, the total annual costs of both systems (include capital expenditures, operation and maintenance costs) were calculated using current prices and interest rates. No price increase of natural gas or electricity and no possible subsidies have been considered. Despite this fact, the geosolar heat supply had even 5 % lower total costs than the reference system. Such a small difference in costs is, of course, in the range of inaccuracy of cost estimations given the current planning stage of the building area.

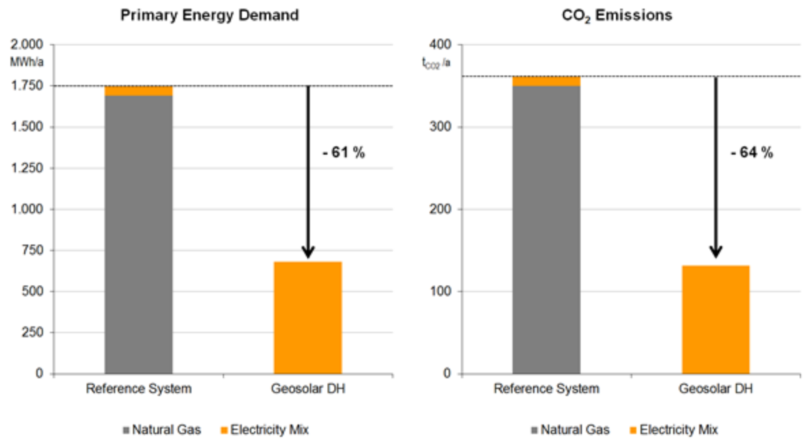

Figure 6: Primary energy demand (left) and CO2 emissions (right) of the geosolar and the reference heat supply system

4. Next steps for prepairing the practical realization

Given the significant environmental advantages and nearly the same costs as the conventional, fossil fuel based system, the geosolar heat supply has been selected for the new building area "Zum Feldlager" in Kassel. In order to prepare the practical realization, detailed elaboration of the innovative heat supply concept is planed within the second phase of the research project. The outcomes of the project shall include detailed dimensioning of all components and their adjustment to each other for best performance of the overall system, development of operation strategies, evaluation of possible tariff models, identification and proof of sensitive parameters (e.g. geothermal characteristics of the ground or amount of buildings connected to the district heating).

To reach these aims, a detailed simulation model of the whole heat supply systems will be established in TRNSYS. The system model will comprise heat sources, heat generation units, low-temperature district heating grid, building appliances and thermal building models. Using the thermal model a simulation-based component dimensioning and development of operation strategies will be carried out. In particular the following topics will be addressed:

- Adjustment between central and decentralized heat supply
- Optimization between the layout of the borehole field and solar regeneration of the ground
- Control strategies for the temperature-sensible heat generation technologies (solar thermal and geothermal heat pump)

- Control strategies of a bidirectional low-temperature heating grid
- Optimization of the overall system performance
- Formulating/Defining requirements for buildings and heat generation units

Furthermore, sensitive parameters for the design and costs of the components or the whole systems shall be identified and verified to increase planning security. For example, the physical properties of the ground have significant influence on the amount and the length of borehole heat exchangers and subsequently on their total costs. To gain more reliability about geothermal parameters, Enhanced Geothermal Response Tests (EGRT) will be carried out. Therefore, it is important to update continuously the economic assessment of the heat supply system.

5. Conclusions

An innovative renewable low-temperature district heating has been developed for the new housing area "Zum Feldlager" in Kassel, Germany. The so-called geosolar concept combines existing and proved technologies such as ground source heat pumps, solar thermal systems and a low-temperature district heating network. The concept pursues the LowEx approach by adjusting heat supply temperatures to the demand and minimizing electricity demand. The resulting overall system is very efficient with only 2.5 % heat losses in the district heating network despite the very low energy density of the housing area. Furthermore, it is significantly environmentally friendly than the reference system (gas condensing boiler with solar DHW) with more than 60 % less primary energy demand and CO_2 emissions. At the same time, the developed renewable heating system has about 5 % lower total annual costs in comparison to the reference system.

Detailed elaboration of the geosolar concept will be carried out within the second phase of the research project.

Acknowledgment

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