Geo-Solar District Heating
– Lessons Learnt from a not Realised Project

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Abstract. For the new housing area with approx. 130 low energy residential houses, located in Kassel, Germany, various supply concepts are investigated. Main objective of the project is the development of an innovative and optimised heat supply concept based on renewable energies and a low temperature district heating for later realisation. During the course of the project several heat supply concepts have been investigated and compared to give an input to the decision and realisation process. A promising heat supply concept is based on a central ground source heat pump in combination with a low temperature district heating (40°C supply temperature) for space heating and decentralised solar thermal systems for domestic hot water preparation. The advantages of this supply variant are comparable low annual heating costs and about 60% lower CO2-emissions in comparison to the reference system (decentralized air / water heat pump with solar thermal system). Due to time constraints it was decided not to realise the above mentioned energy concept. However, the research project took up the task to investigate the transferability of the concept in technological and economical perspectives to other locations and boundary conditions. From the results of the study the importance of a very high connection rate can be highlighted. Also the question of the particular business models for such capital demanding projects (high investment costs for the heating grid vs. low energy demand/sales) has been regarded.

1. Introduction
During the planning phase of new residential areas, the investigation of suitable energy sources and supply strategies is crucial. The use of renewable energy sources (e.g. solar energy and geothermal energy) offers great potential for a sustainable and efficient supply of heat. However for optimized usage of these resources, it is necessary to identify appropriate technologies to ensure efficient supply of the new housing area.

In order to identify the best possible system solution for the named housing area, different supply strategies have been investigated and compared. The main objective is the development of an innovative heat supply concept based on renewable energies and an optimised supply concept. Central challenges in achieving these objectives is the identification of the most promising and efficient technical solutions for practical implementation. Furthermore aspects of future network management as well as business models for distribution and operation have been considered. As a result, the focus of this investigation was on an assessment of suitable centralised or decentralised supply concepts for the new residential area using renewable energy sources in a cost efficient way.

The development of the energy concept has been carried out in two project phases. The first project phase consisted of a pre-study in order to identify the most efficient and economical heat supply concept.
In the course of the second project phase a detailed concept was elaborated which included selecting, dimensioning and detailed cost determination of the various components.

2. Description of the housing area
The planning area in focus is located in the city of Kassel (Germany). The area is surrounded by existing buildings of the district and is located in an urban ventilation path. For that reason combustion of oil or wood (fine dust emissions) should be avoided. Due to the location of the area a connection to the existing district heating network of Kassel is not feasible because of logistical and economic reasons. Instead a local district scheme was in focus for the planning. The concept involves principally the use of renewable energy sources (RES) such as geothermal and solar energy for low temperature district heating supply. The additional use of a combined heat and power (CHP) plant has also been investigated. Furthermore the implementation of intelligent storage systems and thermal load shifting concepts has been envisaged [1].

![Figure 1. Map of the investigated area. Source: City of Kassel/Germany [2]](image)

| Table 1. Assumptions for the planned buildings in the housing area [2], [3] |
|---------------------------------|---------|
| Total number of buildings       | 131     |
| Dwelling units                  | 253     |
| Persons per dwelling unit       | 2.3     |
| Total net dwelling area         | 28,975 m² |
| Roof shape                      | SFH, SDH and TH = Gable roof, MFH = flat roof |
| Heat emission system            | surface heating |

The new housing estate 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. All buildings have specific heat demands of 45 kWh/m²a and a specific domestic hot water (DHW) demand of 730 kWh/pers.a. Thus, the demand is significantly below the maximum energy demand for new buildings (< 50 kWh/m²a) according to the current German energy saving ordinance EnEV [4].
3. Development of innovative heat supply concepts

For the identification of a possible supply concept in a first step DHW, heating and cooling demands have been calculated. Based on the resulting energy demand suitable supply concepts have been elaborated.

3.1. Determination of heat/cool demand and DHW demand

The monthly heat and cool demand as well as DHW demand was calculated corresponding to the monthly balance method of DIN V 18599 [5] including part 2 [6], part 4 [7], part 5 [8], part 8 [9] and part 10 [10].

The total annual energy demand according to the monthly balance method DIN V 18599 was calculated for a heating demand of $Q_{hd} = 1.539 \text{ MWh/a}$, for cooling demand $Q_{cd} = 319 \text{ MWh/a}$ and for domestic hot water demand $Q_{DHW} = 382 \text{ MWh/a}$. These values correspond to a very good insulation standard of the buildings. From detailed simulations a heating load of 927 kW has been estimated [3].

3.2. Selection of supply variants

Based on the low determined monthly energy demand different supply options have been examined. Since it has been decided to supply the district preferably with renewable energy sources the utilization of near-surface geothermal energy by means of borehole heat exchangers (BHE), the use of solar energy or the installation of a bio-methane powered CHP have been found to be eligible. For economic reasons, the use of a natural gas powered CHP was examined as well. In general two decentralised (D1 and D2) supply concepts and two centralised supply variants (C1 and C2) have been developed and compared.

4. Outline of assessed decentralised heat supply variants

As part of the first decentralised supply concept (D1) a decentralised air / water heat pump system was investigated. During the summer months, the domestic hot water is prepared by solar thermal energy. The disadvantage of this concept is the high initial cost and the noise emissions of distributed generation units. As part of the second decentralised supply concept (D2) a decentralised gas fired condensing boiler with solar DHW supply was investigated. The first supply concept D1 served as a reference case for the more detailed assessment (see also [3]).

| Table 2. Overview of the investigated decentralised supply variants [1], [3] |
|---------------------------------------------------------------|
| **Decentralized heat supply variants**                        |
| Decentralized (D1): Decentralized air / water heat pump with  |
| solar DHW support                                             |
| Decentralized (D2): Decentralized gas fired condensing boiler|
| with solar DHW support                                       |
5. Centralised heat supply variants

Table 3. Overview of the investigated centralised supply variants [1], [3]

| Centralised heat supply variants | Description |
|----------------------------------|-------------|
| Centralized (C1):               | Centralized geothermal powered HP for district heating supply at low temperature level of 40°C. DHW preparation by solar/ heating rod |
| Centralized (C2):               | Centralized natural gas powered CHP for district heating supply in combination with demand-oriented power generation, a large heat storage and HP. |

5.1. Centralised heat supply variant (C1): heat pump and borehole heat exchangers

The first supply variant consists of a centralised heat pump connected to borehole heat exchangers (BHE). Depending on the operation, the ground acts as heat source and/or thermal storage. For the thermal regeneration of the ground unglazed solar collectors (swimming pool absorbers as a low-cost option) are intended to be used (see Figure 2). It is conceivable to use the district heating during heating period to provide (low temperature) heat.

![Figure 2. General description of hydraulic of centralised geothermal powered HP for district heating supply C1, [1] and [3]](image)

In supply variant (C1) a centralised ground coupled heat pump feeds the district grid at a temperature level of 40°C. The heat for space heating is supplied directly by the district heating network through the use of heat exchangers. For preparation of DHW different variants are possible. In case of separated domestic hot water preparation thermal solar collectors (e.g. flat-plate collectors) or a heating rod (with a preheating via district heating) could be used. The solar panels could be installed on the roof or on the planned carports.

The advantage of this supply variant is the direct use of heat for space heating from the grid (substation required). No decentralized heat pumps must be installed and thus the investments costs are significantly lower [3].

The DHW is stored in buffer tanks which are intended to be located in the thermal envelope of the buildings.
As storage option for heat for space heating the BHE field is also available. This field is planned at the border of the development area (see figure 1). The thermal regeneration of the ground takes place via unglazed solar absorbers. The absorber technology is very cheap and effective (approx. 1 €ct / kWh of heat in an installation area of approximately 1.400 m² [3]).

5.2. Centralised supply variant (C2): heat pump and CHP plant

In the second centralized supply variant a combination of a CHP plant (140kWel / 207kWth) and a ground coupled heat pump with 535 kW heating capacity has been investigated [1]. According to manufacturer's instructions the heat pump can achieve a COP greater than 4.0 even if the supply temperature is higher than 35°C. As fuel for the CHP plant natural gas is foreseen, renewable energy sources bio methane is also eligible but not calculated for the cost assessment. To increase the system efficiency a solar collector field (vacuum tube collector) is considered. Additionally a gas fired backup boiler is planned. The network operation temperature for space heating is 35°C - 50°C. For domestic hot water preparation the grid temperature will be increased to 70°C 1-2 times a day for ~ 1.5 h. As heat storage option for heat for space heating the BHE field is available, see variant C1. For the storage of high temperature heat of 70°C-80°C (variant C2), two buffers with a volume of 25 m³ are foreseen. It has been determined that this size is sufficient for the sole heating of all decentralized DHW storage tanks located in the buildings including heating of the district heating grid.

Three control strategies for the operation of CHP and heat pumps are eligible. The first possible strategy is the usage of the CHP plant in case of base load and the heat pump for covering the peak load. The second possible strategy is to run CHP and heat pump in parallel. In this variant the CHP plant charges the storage tank with high temperature heat.

The third strategy is to run the CHP plant during peak load and the heat pump during base load. The heat pump supplies the heat generated to the network or to the storage and thus covers the entire base load heat demand.

6. Foreseen network design and heat losses

Based on the investigated supply options (refer to Table 2 and Table 3), the selection of suitable district heating pipes has been made. Within the project the installation of PEX twin pipes (PN 6/10 bar) is considered. These pipes are cost effective and are characterized by low heat losses. The heat loss through the district heating network are estimated to be ~ 40 MWh/a, corresponding to ~ 2.5% related to the useful heat of 1.564 MWh/a [1].

7. Assessment and selection of supply the concept for the housing area

For assessment and selection of suitable supply variants different parameters and characteristics have been considered: The parameters are classified into “technical”, “economic” and “soft” factors; for each case a subdivision is made. The “technical” parameters include the primary energy demand, CO₂ emissions and space requirement for installed supply technology. Depending on the supply concept other parameters have been taken into account indirectly. For the HP the seasonal performance factor (SPF), for CHP the coefficient of performance (COP) and for the use of solar systems the efficiency of the absorbers, solar yield and solar fraction has been considered. The “economic” parameters included the annual heating costs (including investment and operating costs, maintenance costs and arising costs for the consumer) as well as price stability. Moreover the determination of the amortization period and the expected return on invest was of importance.
The "soft" factors included the consideration of the level of innovation and user-friendliness. Furthermore customer satisfaction and customer loyalty are factors that have to be considered, because they also potentially contribute to the successful implementation of the project. Both, the assessment parameters and the weighting factors have been discussed and decided by the project partners.

The key evaluation parameters with their weighting factors, which have been used for comparison of the variants, are shown in Figure 3. According to the weighting factors it turned out that the variants C1 (Centralized HP, decentralized DHW preparation by solar/heating rod – 40°C) and C2 (Centralized fossil powered CHP/HP) are the most suitable and selected solutions. Since the variant C2 integrates the combustion of fossil fuels, it has not been chosen for further investigation. In comparison to reference variant D2 both centralised variants are advantageous due to environmental issues (CO₂ emissions, primary energy demand). The supply concepts differ essentially with regard to the dependency on price of electricity (C1) and natural gas (C2). Finally the heat supply concept C1 has been chosen for a more detailed analysis based on the results from the first project phase [1]. The second phase consists of elaboration of the favoured supply variant and development of a detailed concept.

8. Discussion of the results
In particular renewable energy sources offer great potential for sustainable and efficient heat supply of buildings. However, for optimized utilization of these resources it is necessary to identify appropriate technologies to ensure efficient supply for the new housing area. For this reason, extensive studies have been carried out to identify suitable supply options. Since, in addition to the technical aspects economic aspects play a crucial role, it turned out that the centralized heat supply variants integrating a district heating grid (C1) seemed to be more favourable in comparison to the analysed variants [1]. For this supply variant a detailed feasibility study and a detailed estimation of costs has been conducted. Subsequently the development of a business model has been carried out.

The results of the detailed analysis [3] show that the besides of environmental reasons (e.g. lower CO₂ emission) the variant C1 is economical competitive when external funding (e.g. via the German National funding scheme for innovative district heating systems “Modellvorhaben Wärmenetze 4.0”) could be integrated. In this case the utility company is able to make a “competitive” offer to the end consumer. Otherwise the reference supply systems D1 turned out to have lower total heating costs. The reason turned out to be higher investment costs/capital costs for the BHE and the heating grid in variant C1. Furthermore, a high connection rate is crucial for a suitable business concept. The detailed techno-economic analysis shows that the connection rate is a crucial parameter with a very high sensitivity on the resulting annual heating costs, e.g. a 20% reduced connection rate of 80% results already in 7% higher estimated annual heating costs for the end user. In comparison to that the sensitivity of a better building standard (lower heat demand) has a much lower impact on the resulting estimated heating costs.
Although the technical/environmental as well as the economic parameter turned out to be favourable the decision has been taken not to realise the proposed and analysed supply system variant. The main reason for this were time constrains. The long time needed to get a permit to start the drilling for the BHE and utilise the ground together with delays in the planning were the reasons.

9. Conclusions and outlook
In order to identify the best possible system solution for a new housing area planned in Kassel (Germany), different supply strategies were assessed and compared. Main objective is the development of an innovative and optimised heat supply concept based on renewable energies and low temperature district heating. Central challenge in achieving this objective is the identification of the most promising and efficient technical solutions for practical implementation.

As a result from a first project phase [1] an innovative centralized heat supply concept (C1) has been developed and selected in a political process for realization. In the course of the second phase detailed analyses of the possible system design and operation are conducted. Furthermore aspects of future network management as well as business models for distribution and operation have been considered in a detailed study [3].

Mainly because of time constrains the decision has been taken not to realise the identified concept; the planned core drillings and Enhanced Geothermal Response Tests (EGRT) have not been carried out.

The project has shown that not only good system design integration innovative technologies in combination with a good economical parameters and a suitable business concept are important for a project realisation. Furthermore, these kind of innovative projects have special boundary conditions. There is a good chance that these kinds of projects are not going into realisation when common expectation on a design time frame and on the profitability is applied. Moreover, a good communication built on the trust between the project partners is a must.

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