CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Development of an Innovative Heat Supply Concept for a New Housing Area

Schmidt, D.[#1], Schurig, M. [#2], Kallert A. [#3], Orozaliev, J.[*4], Best, I.[*5], Vajen, K.[*6], Reul, O.[**7], Bennewitz, J.[***8], and Gerhold, P.[****9]

[#] *Fraunhofer Institute for Building Physics (IBP)*
Gottschalkstrasse 28a, DE-34127 Kassel, Germany
[1] dietrich.schmidt@ibp.fraunhofer.de

[*] *Institute for decentralised Energy Technologies (IdE)*
Kurt-Wolters-Straße 3, DE-34125 Kassel, Germany

[**] *University of Kassel*
Mönchebergstr. 7, DE-34125 Kassel, Germany

[***] *Staedtische Werke Kassel AG*
Königstor 3-13, DE-34117 Kassel, Germany

[****] *City of Kassel*
Rathaus / Obere Königsstraße 8, DE-34117 Kassel, Germany

Abstract

The energy demand of buildings for heating and cooling is responsible for more than one third of the world's final energy consumption. Therefore the identification of innovative heat supply concepts based on renewable energies is required. The utilization of renewable energies in combination with efficient supply technologies increases the "sustainability" of new housing areas.

For the new housing area "Zum Feldlager", located in Kassel (Germany), various supply concepts are investigated. Main objective is the development of an innovative and optimised heat supply concept based on renewable energies and a low temperature district heating. Central challenge in achieving this objective is the identification of the most promising and efficient technical solution for practical implementation. In order to identify the best possible system solution, different centralised and decentralised supply strategies have been investigated and compared.

The most 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 CO_2-emissions in comparison to the reference.

This project is a cooperative activity and of the Fraunhofer Institute for Building Physics (IBP) in Kassel, Institute for decentralized Energy Technologies (IdE), Kassel University, the City of Kassel and the local utility company Staedtische Werke Kassel AG.

The paper presents a description of the new housing area as well as the evaluation of the various supply concepts.

Keywords - low temperature district heating; new housing area; ground source heat pump; solar heat

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, different supply strategies have been investigated and compared. Main objective is the development of an innovative heat supply concept based on renewable energies and an optimised supply concept. Central challenges in achieving this objective 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 are considered. As a result, the focus of this project is on investigations on suitable centralised or decentralised supply concepts for a new residential area using renewable energy sources in a cost efficient way.

The project is carried out in two project phases. The first project phase consists of a study in order to identify the most efficient and economical heat supply concept. In the course of the second project phase a detailed concept will be elaborated which includes selecting, dimensioning and detailed cost determination of the various components.

This paper presents the results of the first project phase.

2. Short Description of the New Housing Area “Zum Feldlager”

The planning area "Zum Feldlager" 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 is implemented. 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 is also investigated. Furthermore the implementation of intelligent storage systems and thermal load shifting concepts are aimed.

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 demand 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 valid German energy saving ordinance EnEV 2014 [2].

Fig. 1 Map of the investigated area “Zum Feldlager”; City of Kassel/Germany [1].

Table 1 Assumptions for the buildings according to the pre-design [1]

Total number of buildings	127
Dwelling units	154
Persons per dwelling unit	4
Roof shape	SFH, SDH and TH = Gable roof, MFH = flat roof
Heat emission system	surface heating

3. Development and Comparison of Various Innovative Supply Concepts

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

<u>Determination of heat/ cool demand and DHW demand</u>

The monthly heat and cool demand as well as DHW demand is calculated corresponding to monthly balance method DIN V 18599 [3] including part 2 [4], part 4 [5], part 5 [6], part 8 [7] and part 10 [8].

The total annual energy demand according to the monthly balance method DIN V 18599 [2] is calculated for a heating demand of Q_{hd} = 1.199 MWh/a, for cooling demand Q_{cd} = 319 MWh/a and for domestic hot water demand Q_{DHW} = 365 MWh/a. These values correspond to a very good insulation standard of the buildings.

<u>Selection of supply variants</u>

Based on the determined monthly low energy demand different supply options are 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 are eligible. For economic reasons, the use of a natural gas powered CHP is examined as well. In general two decentralised (D1 and D2) supply concept and two centralised supply variants (C1 and C2) have been developed and compared. For the centralised supply options sub-variants have been analyzed, too.

Table 2 Overview of the investigated decentralised supply variants

Decentralized heat supply variants	
Decentralized (D1):	Decentralized air / water heat pump with solar DHW support
Decentralized (D2): Reference Case	Decentralized gas fired condensing boiler with solar DHW support

Table 3 Overview of the investigated centralised supply variants

Centralised heat supply variants	
Centralized (C1a)	Centralized geothermal powered HP for district heating supply at low temperature level of 20°C, decentralized heat pumps and solar thermal systems for DHW supply.
Centralized (C1b)	Centralized geothermal powered HP for district heating supply at low temperature level of 40°C. DHW preparation by solar/ heating rod
Centralized (C2a)	Centralized natural gas powered CHP for district heating supply in combination with demand-oriented power generation, a large heat storage and HP.
Centralized (C2b)	Centralized renewable-powered CHP for district heating supply in combination with demand-oriented power generation, a large heat storage and HP.

4. Decentralized Heat Supply Variants (D1 and D2)

As part of the first decentralized supply concept (D1) a decentralized air / water heat pump system is 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 decentralized supply concept (D2) a decentralized gas fired condensing boiler with solar DHW supply is investigated. The second supply concept D2 serves as reference case for assessment and pre-selection of supply concepts.

5. Centralised Supply Variant (C1): Heat Pump and Borehole Heat Exchangers

The first supply variant consists of a centralized heat pump connected to borehole heat exchangers (BHE). Depending on the supply variant, 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 Fig. 2). It is conceivable to use the district heating during heating period to provide (low temperature) heat.

As part of the preliminary investigation further sub-variants have been developed (e.g. regarding different temperature levels).

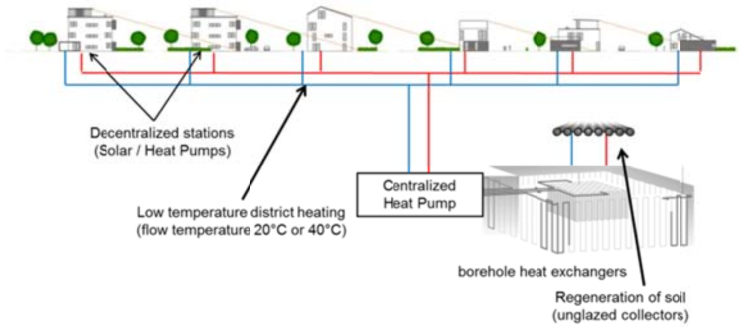

Fig. 2 general description of hydraulic of ccentralized geothermal powered HP for district heating supply C1

Description of supply variant (C1a)

In supply variant (C1a) a centralised ground coupled heat pump feeds the district heating grid at a temperature level of 20°C. In order to supply the building for space heating and domestic hot water preparation the temperature level must be raised. For this purpose two variants, or a combination of these variants depending on the required temperature level of 45-60°C (DHW preparation or space heating) are possible. First possibility is the application of a decentralized heat pump, which raises the temperature to the required temperature level for space heating and DHW preparation. The second possibility for decentralized reheating is to use thermal solar collectors (e.g. flat-plate collectors), wherein this variant is appropriate only during summer months. The solar collectors could be installed on the roof of each building or on carports.

The advantages of this supply variant are that heat losses in the network are very low and operation of the heat pumps is very effective. A possible weakness of the supply variant is the very low flow temperature. The lower the supply temperature the higher are the pumping costs and the high unit costs of de-central and small heat pumps.

Description of supply variant (C1b)

In supply variant (C1b) 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 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.

Storage technologies

The DHW and the heat for space heating (variant C1a) will be stored in buffer tanks which are located in the thermal envelope of the buildings.

As storage option for heat for space heating (variant C1a and C1b) the BHE field is also available. This field is planned at the border of the development area. 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 1.500 m²).

6. Centralised Supply Variant (C2): Heat Pump and CHP Plant

In the second centralized supply variant (including sub-variants C2a and C2b) a combination of a CHP plant (140kW$_{el}$ / 207kW$_{th}$) and a ground coupled heat pump with 535 kW heating capacity has been investigated. 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 fuels for the CHP plant both fossil fuels (C2a - natural gas) and renewable energy sources (C2b - bio methane) are eligible. 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.

Storage Technologies

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 25m³ 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.

Control strategies

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 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.

7. Planned Network Design and Heat Losses

Based on of the investigated supply options (refer Table 2 and Table 3), the selection of suitable district heating pipes is 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.

8. Assessment and Pre-Selection of Supply Concepts

For assessment and pre-selection of suitable supply variants different parameters and characteristics are considered. The parameters are classified into "technical", "economy" and "soft" factors; for each case a subdivision is made. The “technical” parameters include the primary energy demand, CO_2 emissions and space requirement for installed supply technology. Depending on the supply concept other parameters are 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 are considered. The economic parameters include 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 is of importance.

The "soft" factors include the consideration of the level of innovation and ease of use. 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.

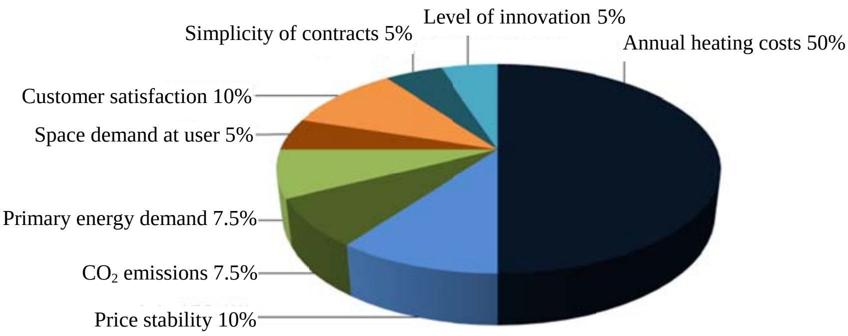

Fig. 3 weighting factors for assessment of supply concepts as discussed with the partners

9. Results

Based on preliminary studies two de-centralized (D1 and D2) supply variant and two centralized supply variants (C1 and C2) have been selected and assessed. As reference case for assessment and comparison of different supply options serves variant D2. This supply variant comprises decentralized gas fired condensing boilers with solar DHW. The annual heating costs amount to 3.207 €/a (26 Ct/kWh), CO_2 emissions are 368 t/a and the primary energy demand amount to 1.773 MWh/a.

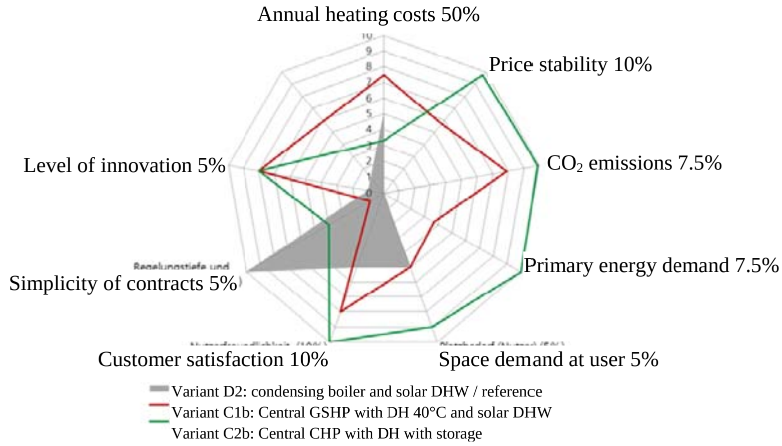

Fig. 4: comparison and assessment of the individual supply variations

The following figure contains the comparison and the detailed assessment of the individual supply variations.

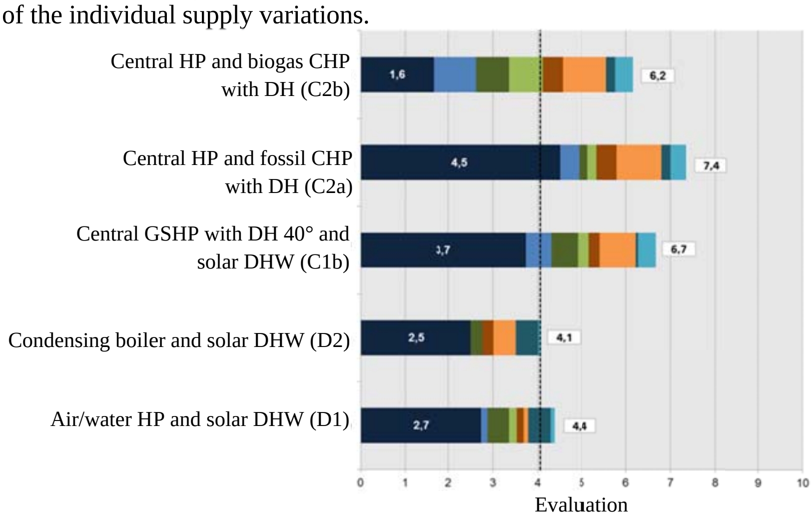

Fig. 5: Assessment and pre-selection based on weighting factors (see also fig 3)

For assessment and pre-selection of suitable supply variants different parameters and characteristics are considered. The key evaluation parameters, which are used for comparison of the variants, are shown in Fig. 5. According to the weighting factors it turned out that the variants C1b (Centralized HP, decentralized DHW preparation by solar/ heating rod – 40°C) and C2a (Centralized fossil powered CHP/HP, without boiler without solar) are the most suitable and selected solutions. The first variant is economically more favourable than reference variant D2 (Gas condensing boiler with solar). In comparison to reference variant D2 both variants are advantageous due to environmental issues (CO2 emissions, primary energy demand) too. The supply concepts differ essentially with regard to the dependency on price of electricity (C1) and natural gas (C2).

10. Discussion

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 preliminary studies were carried out to identify suitable supply options. Since, in addition to the technical aspects economic aspects play a crucial role, an evaluation was developed that combines both aspects.

It turned out that the centralized heat supply variants integrating a district heating grid are more favorable, especially because of the 5% lower annual costs (C1b). This is in contradiction to the common opinion that district heating grids are generally not cost efficient for low energy housing areas. The investigation for this particular project shows clearly the opposite.

11. Outlook

Within first project phase efficient and economical heat supply concepts have been identified. The next necessary step within the project consists of detailed elaboration of the selected heat supply concept. In this course the verification of information which is relevant for the design of system characteristics is intended in order to increase planning reliability. Based on knowledge gained in the first phase the second phase will be carried out. The second phase consists of elaboration of the favoured supply variant and development of a detailed concept. In the course of the second phase core drillings and Enhanced Geothermal Response Tests (EGRT) will be carried out this geotechnical investigations (for example to investigate ion the geological and hydrogeological site conditions and to establish assessment of the geothermal ground properties. , implementation of drilling) will be performed. In order to select and dimension of the system components Enhanced Geothermal Response Tests (EGRT) will be carried out. Subsequently the development of business model will be carried out. The last and final step includes detailed feasibility studies and a detailed estimation of costs.

12. Summary and Conclusion

In order to identify the best possible system solution for the 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.

Furthermore aspects of future network management as well as business models for distribution and operation are considered. As a result, the focus of this project is on investigations on suitable centralised or decentralised supply concepts for a new residential area using renewable energy sources.

Based on a preliminary study an innovative centralized heat supply concept is developed and selected in a political process for realization: C1b: Solar heating and geothermal powered heat pumps in a DH grid (40°C).

This variant is economically more favorable than reference variant D2 (Gas condensing boiler with solar). The annual heating costs are 5% lower compared to the references variant D2. Furthermore, this variant is advantageous due to environmental issues (CO_2 emissions and primary energy demand are approx. 63 % lower).

Acknowledgment

The content of the paper was developed as part of the above mentioned collaboration. The financial support given to the project by the City of Kassel and the Staedtische Werke Kassel AG is greatly acknowledged by the project partners. Furthermore, the financial support given by the German Federal Ministry of Economic Affairs and Energy to conduct the second phase of the project is highly acknowledged by all involved project partners.

References

[1] Development plan Nr. IV/65 „Zum Feldlager“; Architektur+Städtebau Bankert, Linker & Hupfeld, City of Kassel- Urban planning, building supervision and monument conservation; 02 February 2013.

[2] EnEV2014 - Regulation on energy-saving insulation and energy-saving systems engineering for buildings (Energy Saving Ordinance - EnEV); 01. Mai 2014.

[3] DIN V 18599-1: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting.

[4] DIN V 18599-2: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting –Part 2: Net energy demand for heating and cooling of building zones.

[5] DIN V 18599-4: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting –Part 4: Net and final energy demand for lighting.

[6] DIN V 18599-5: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting – Part 5: Final energy demand of heating systems.

[7] DIN V 18599-8: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting Part 8: Net and final energy demand of domestic hot water systems.

[8] DIN V 18599-10: 2011-08. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting - Part 10: Boundary conditions of use, climatic data.