Innovative and sustainable Energy Supply Concepts for a new quarter in Mannheim, Germany

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Abstract

The former military area “Benjamin Franklin” in Mannheim, Germany, is converted in a completely new urban area with the aim of providing a high living standard and an innovative energy supply. The actual proposed energy supply concept for the sub quarter “Sullivan” was assessed. Two alternative concepts focusing on renewable energy sources have been developed. For this, some approaches from [1], [2], [3] have been applied and further extended. The developed concepts have been compared to the actual one, related to primary energy demand and economics.

Keywords: energy concepts, quarters, urban area, district heating, solar thermal, photovoltaic, heat pump

1. Introduction

Mannheim is a city in the Rhine-valley in Germany approx. 100 km South from Frankfurt with around 300,000 inhabitants. After the withdrawal of the American Army, the military area “Benjamin Franklin Village” was handed over to the city of Mannheim. Such a large area with around 1.4 million square meters almost in the city centre offers wide possibilities for further urban development. Strategic, future-oriented urban development implies not only architecture but also innovative energy supply. A similar realized and detailed evaluated project can be found in [3]

Not only due to the European and German goals of CO_2-emission reduction, the city of Mannheim decided to request a sustainable and renewable energy supply concept for the “Benjamin Franklin Village”. Further drivers for this innovative supply concept are the aim of creating attractive living areas and not least economic reasons. Besides several architectonical requirements the city of Mannheim demands a primary energy factor of fp = 0.55 for the heat supply for the buildings.

The area “Benjamin Franklin Village” is subdivided into five smaller urban areas with different focal activities such as living (Franklin center, Sullivan, area of Officers cantonment), services sector (Funari Barracks), and trade and commerce (Columbus area). Additionally the current development status varies depending on the remaining tasks to prepare the land for building. Since the pre-preparation of parts of the area is finished but the planning phase is not yet finalized, the authors decided to investigate several energy supply concepts for the living sub quarter “Sullivan” in detail, Fig 1.

As a result of an ideas competition, the city of Mannheim decided to award the local energy provider’s concept for supply energy to the sub quarter “Sullivan”. The core components of the concept are the already available district heating grid of Mannheim with a primary energy factor $f_p = 0.65$, which is able to provide additionally the heat for Sullivan, and a combination of an air to water heat pump and a photovoltaic (PV) system to reduce the primary energy factor. In this present concept, neither an adaptive control, nor a prognoses tool related to demand and weather is implemented. Therefore, the authors decided to assess the proposed energy concept in detail and to develop alternative concepts with the focus on a higher level of sustainability and innovation combined with an improved economic feasibility.

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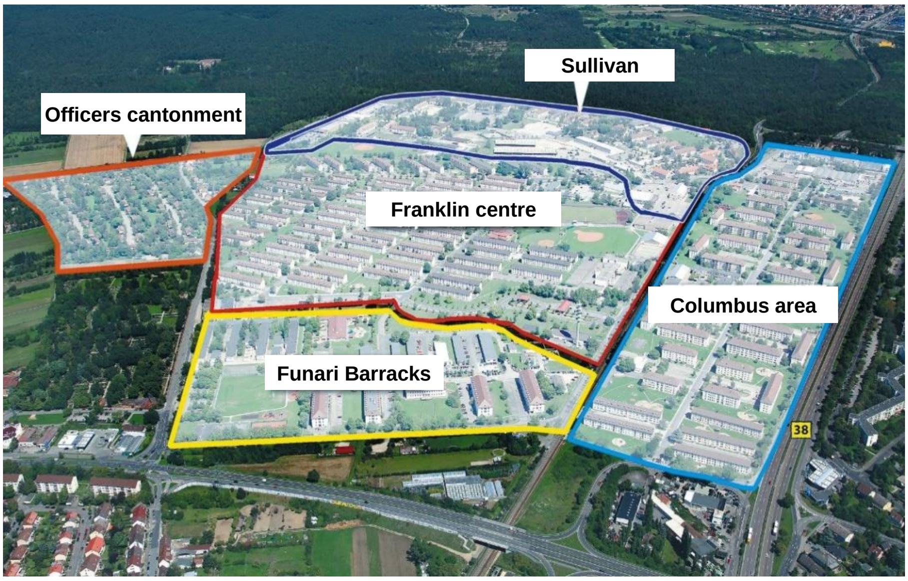

Fig. 1: Bird's view of the Benjamin franklin Village in Mannheim, Germany, incl. the subdivision into the five quarters, source: www.mz.de, modified by the author

In the following, the awarded concept is presented and further used as the reference concept for the three developed alternative concepts. The comparison between the in total four concepts comprises as key aspects the primary energy demand, CO_2 emissions and the economics.

2. Reference concept

The awarded concept of the local energy supplier uses as basis heat source the already existing district heating grid (primary district heating grid). This heating grid is located directly outside of the quarter "Sullivan" and can be extended by a secondary heating grid for providing heat into "Sullivan". Additionally, an air-to-water heat pump feeds heat into the grid. Since the temperature level of the heating grid is 70 °C, a special, double stage, high temperature heat pump will be installed. To reach the required primary energy factor for the heat supply in the urban sub quarter Sullivan, ca. 1 500 m² PV modules (250 kW_p) shall be installed. The provided electricity is used to operate the compressor of the heat pump. Fig 2 shows the scheme for this concept.

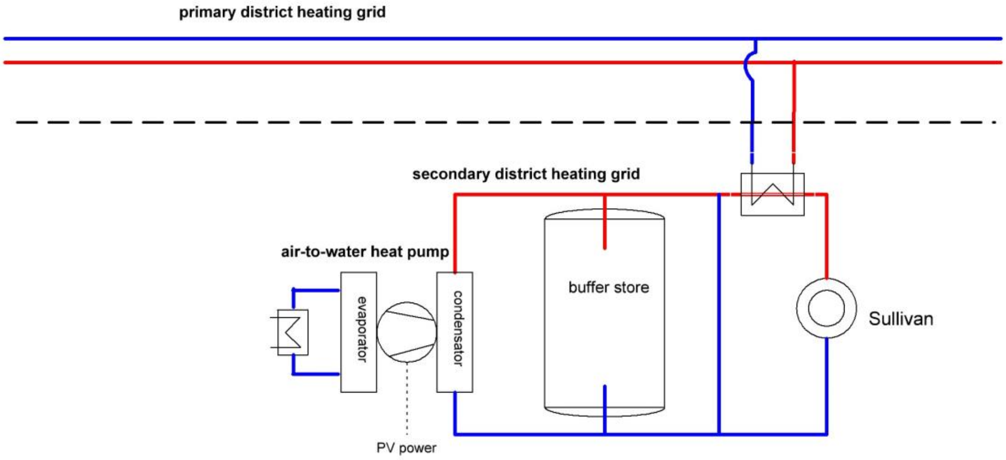

Fig. 2: Scheme of the reference concept comprising heating grid, air-to-water heat pump and PV

Detailed simulation studies show that the primary district heating grid feeds the entire year heat into the secondary heating grid. The air-to-water heat pump provides only a small share of the energy. During summer, the available PV power and the ambient air temperatures are much higher than in winter when the maximum heat load occurs. Therefore, the energy share delivered by the heat pump is significant higher than during winter times. The total energy delivered by the heat pump is 980 MWh/a with a seasonal performance factor of 3.0. This represents 15 % of the total energy demand of the urban area. Even during the summer months, the heat pump covers less than 50 % of the heat demand. The amount of energy provided by the heat pump balances exactly with the amount of energy required to reduce the primary energy factor of the entire system from 0.65 (primary district heating grid) to 0.55. Since all further developed concepts compete with this conventional concept, it is defined as “reference concept”.

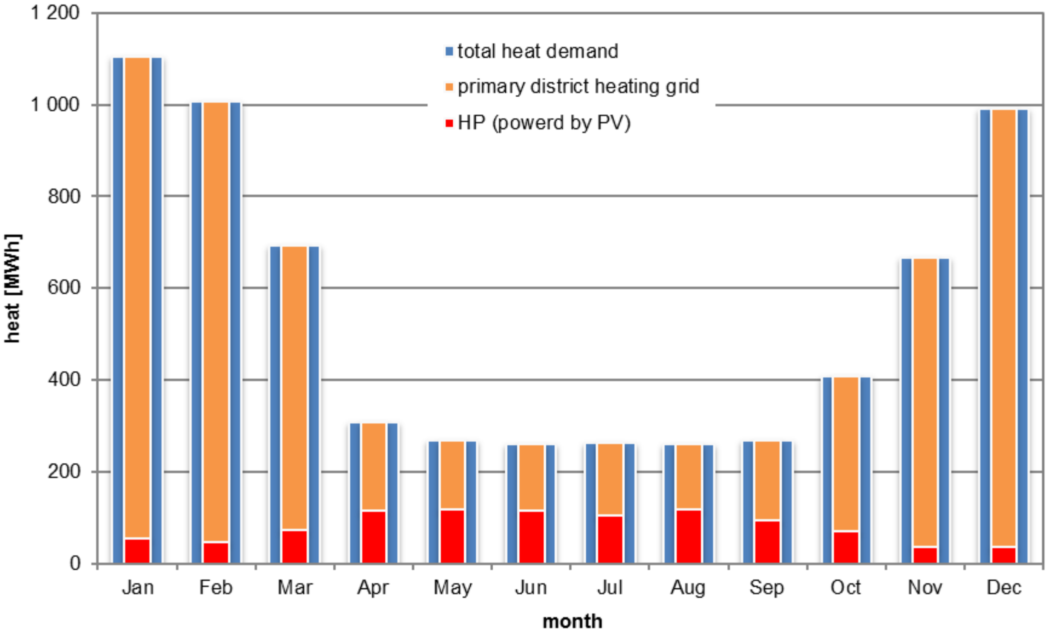

Fig. 3: Energy balance of the reference concept

3. Alternative concepts

For additionally reducing the primary energy factor of the heat supply of the quartier Sullivan, alternative innovative concepts are required. Since the energy provided by the sun has a primary energy factor of 0.0 by definition, the concepts shall aim for a high solar thermal fraction. A seasonal thermal energy store (STES) offers the possibility to increase further the solar thermal fraction. An integration of PV into the further investigated alternative concepts was not taken into account due to the missing concurrency between generated PV-power and heat demand. Only on a yearly bases, the energy balance of such combinations might be balanced. Furthermore also under exergetic aspects it is considered as much more appropriate rather to use PV-power directly to substitute conventional produced electricity than converting it into heat.

The following chapters present three alternative concepts with different characteristics. These concepts have been compared to the reference concept related to economics, CO_2 emissions, primary factor and solar fraction.

Concept 1: Solar district heating grid with short term thermal energy store

The first alternative concept for providing the required heat to “Sullivan” is also based on a district heating grid. But in contrast to the reference concept it is partly fed by solar thermal energy. The primary district heating grid of the city of Mannheim provides only the energy demand, which solar thermal cannot cover. The concept comprises 5,000 m² solar thermal flat plate collectors, and a 400 m³ hot water buffer store. To avoid stagnation during times without sufficient heat demand, the solar thermal collector field feeds into the return flow of the primary district heating grid. Fig. 4 shows the scheme with the separation between primary and secondary district heating grid and the hydraulics.

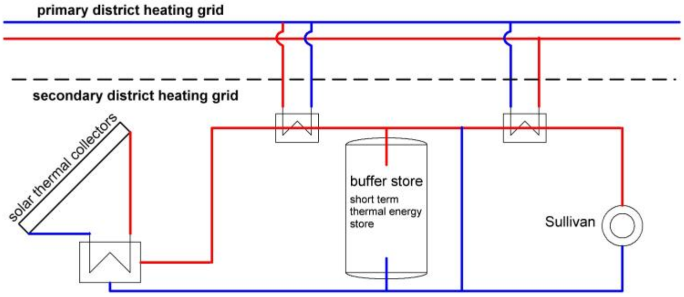

Fig. 4: Scheme of the first concept based on solar district heating grid and a short term thermal energy store

Fig. 5 shows the energy balance on a monthly basis. During summer time, the energy gains from the solar collector field covers entirely the heat demand of the quarter. The heat provide into the return flow of the primary district heating grid to avoid stagnation is not diagrammed. Due to the relatively high inclination angle of 45° of the solar thermal collector field, this heat can be neglected. No seasonal thermal energy storage is included. This approach leads to a relatively high annual solar fraction of 34 % with lowest system and investment effort.

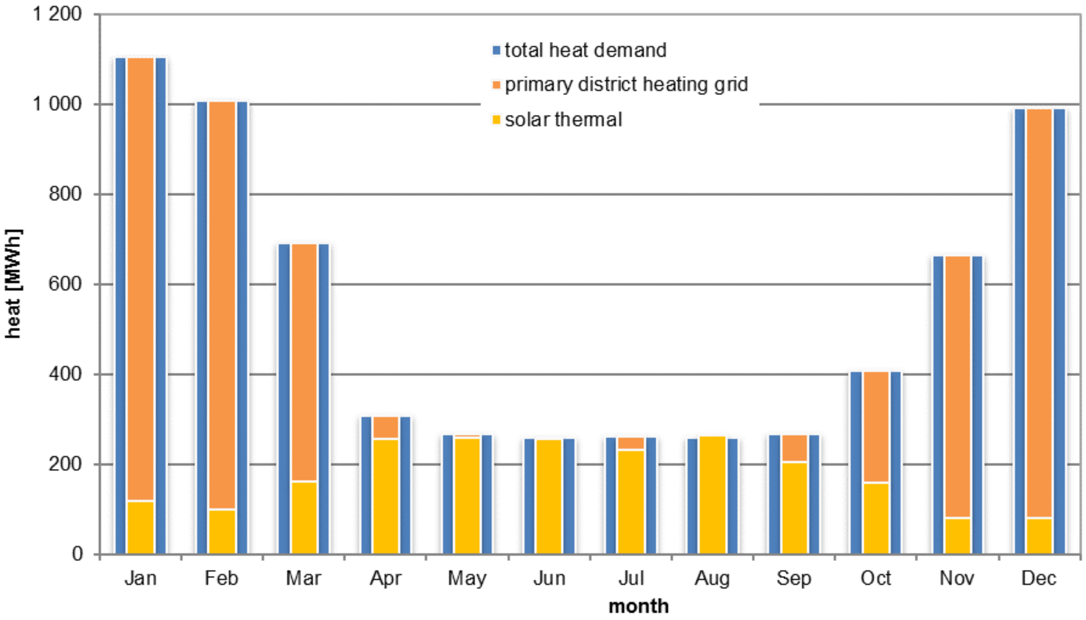

Fig. 5: Monthly energy balance of concept 1, comprising solar district heating grid and a short term thermal energy store

Concept 2: Solar district heating grid with seasonal thermal energy store and compression heat pump

The second concept aims for a solar fraction of 50 % and a separated district heating grid. No heat exchange between the primary and the secondary heating grid takes place. To reach a solar fraction of 50 %, a solar thermal collector field of 7 600 m² is required, which is about 50 % larger than in concept 1. A seasonal thermal energy store with a volume of 7 200 m³ stores the additional heat from the solar collector field, Due to this large store, the volume of the short term buffer store is reduced by half, compared to concept 1, to 200 m³. A heat pump (HP) decreases the temperature in the seasonal thermal energy store and therefore increases the effective usable storage capacity. Additionally, the efficiency of the solar thermal collectors increase with decreasing operation temperature. The heat pump only operates in winter times and decreases the temperature in the seasonal thermal energy store down to 18 °C. A further temperature decrease in the seasonal thermal energy store is not efficient any more. Due to available groundwater at a temperature level of 18 °C, the heat source of the heat pump is changed at 18 °C from the seasonal thermal energy store to the groundwater. The heat pump has a nominal electrical power of 400 kW, the highest monthly thermal power occurs in February with 1.27 MW. The buffer store covers the peak power demands that rises up to 2.8 MW_{th}. Therefore, no auxiliary heating system additionally to the heat pump is required. Fig. 6 shows the hydraulics of this concept.

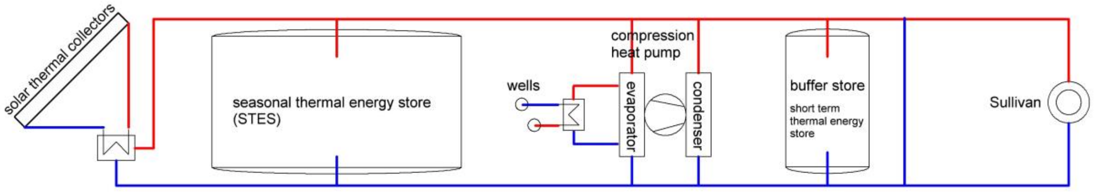

Fig. 6: Scheme of the second concept based on a solar district heating grid, a seasonal thermal energy store and compression heat pump

Fig. 7 shows the monthly energy balance of concept 2. The solar thermal collector charges during the months April to September the seasonal thermal energy store. During October and November, this heat is discharged and supplied directly into the district heating grid (light blue). Eventually in November, the temperature level of the heat discharged from the seasonal thermal energy store is not sufficient any more. With the help of the heat pump, the seasonal thermal energy store is discharged further and delivers into the grid (green). After reaching a temperature level of 18 °C in the seasonal thermal energy store, the heat pump uses the available groundwater as heat source and provides the energy demand for the district heating grid (violet) Although, the seasonal thermal energy store feeds only in total 560 MWh/a heat into the grid, its implementation increases the efficiency of the heat pump and the solar thermal collector significantly, [8].

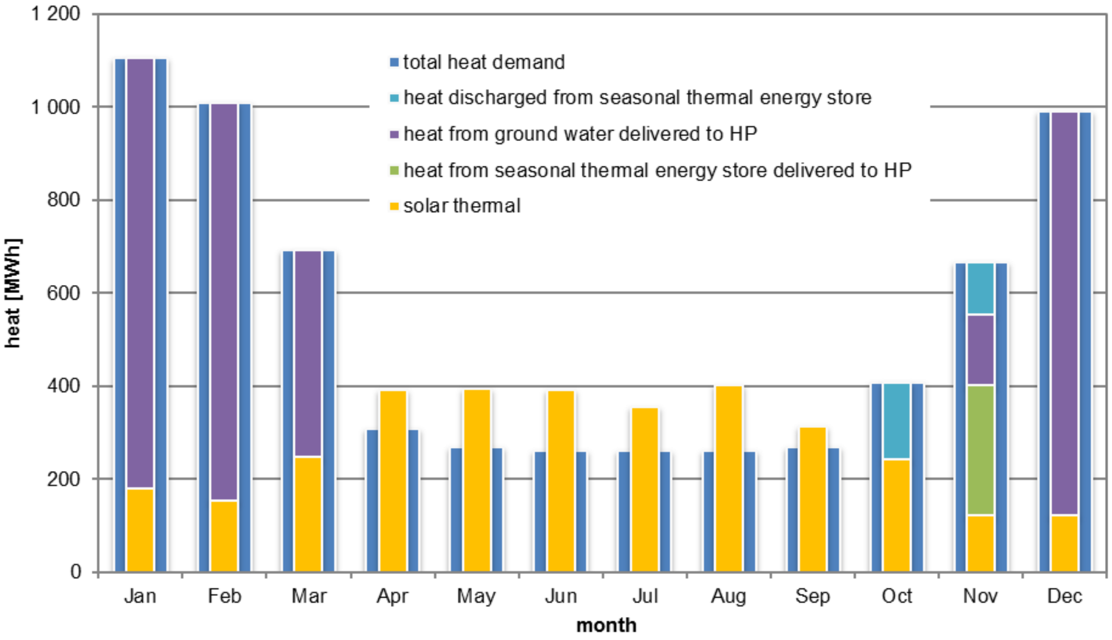

Fig. 7: Monthly energy balance of concept 2, based on a solar district heating grid, a seasonal thermal energy store and a compression heat pump

Concept 3: Solar district heating grid with seasonal thermal energy store and absorption heat pump

The third concept bases on the second concept, but an absorption heat pump replaces the compression heat pump. The collector area with 7,600 m², the size of the seasonal thermal energy store with 7,200 m³ and of the buffer store with 200 m³ stay the same. The difference is the integration of the heat provided by the primary district heating grid. The primary grid feeds on the on hand directly into the secondary grid and on the other hand indirectly via the generator of the absorption heat pump. The implementation of an absorption heat pump allows for an efficient use of the heat of the primary district heating grid. Simultaneously, the solar thermal collectors and the seasonal thermal energy store operate more efficiently compared to a system without heat pump. The absorption heat pump has a nominal output power of 700 kW. The primary district heating grid covers the additional heat demand directly.

This concept is similar to a solar district heating grid realized in the project “Ackermannbogen” in the city of Munich, Germany. Only the size of the concept here exceeds the system in Munich by a factor of three. Fig. 8 shows the scheme of the concept three.

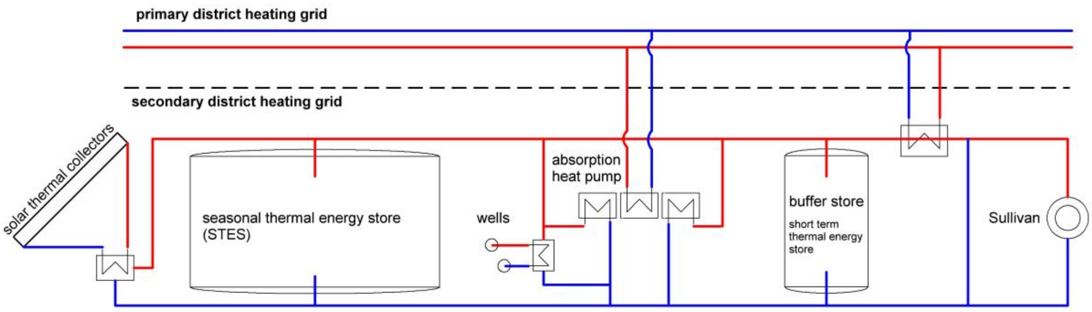

Fig. 8: Scheme of the third concept based on a solar district heating grid and the already available district heating grid, a seasonal thermal energy store and an absorption heat pump

The solar collector field charges the seasonal thermal energy store during summer. The absorption heat pump uses the seasonal thermal energy store and the groundwater as heat source. Additionally in the core winter months December, January, February the primary district heating grid provides the remaining heat demand, as the absorption heat pump cannot cover the total demand due to its limited size.

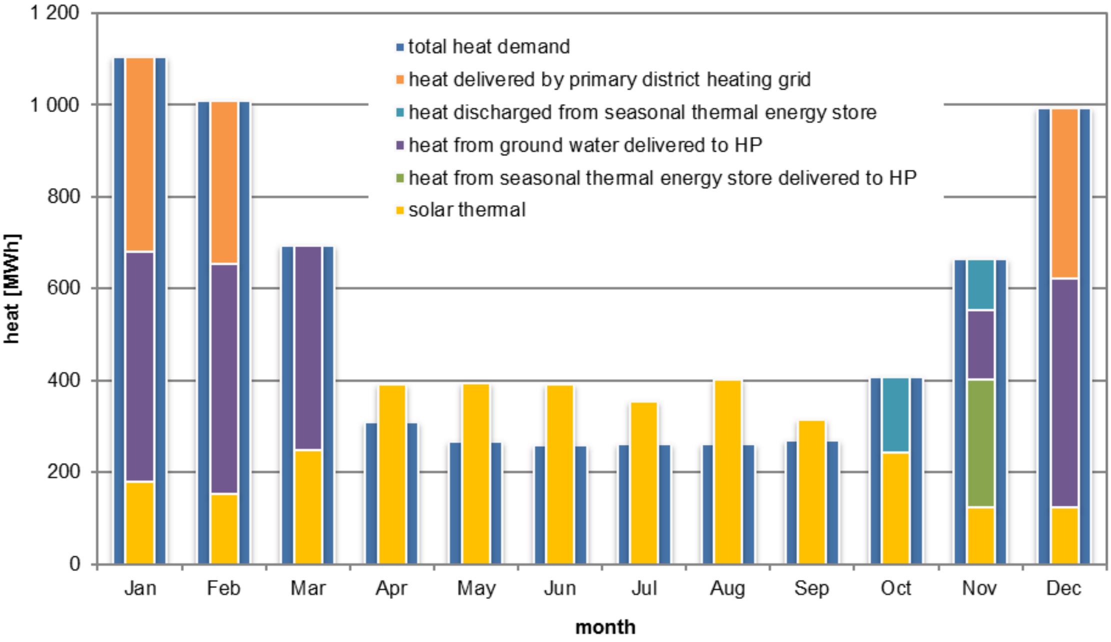

Fig. 9: Monthly energy balance concept 3, based on a solar district heating grid and the already available district heating grid, a seasonal thermal energy store and a absorption heat pump

4. Evaluation of concepts

The evaluation of the reference concepts and the three developed alternative concepts bases on four performance figures:

- Primary energy factor
- CO_2 emission in kg per MWh heat
- Solar fraction
- Specific costs in € per MWh heat

The primary energy factor fp [-] serves in several standards and directives in the building sector as performance figure. The primary energy factor puts all efforts and losses, occurring during generating, treatment, storage, transportation and distribution, into relation to the delivered usable energy. In contrast to the cumulative energy demand, the primary energy factor only takes into account the energy carrier. Hence it omits the required raw materials, semi-finished products and services, such as a power plant. Table 1 shows the primary energy factor used for the evaluations.

Tab 1: Primary energy factor for different energy carriers

Energy carrier	Primary energy factor	source
Solar thermal	0	EnEV [11]
Photovoltaic	0	EnEV [11]
District heating, Mannheim	0.65	certificate power plant, city of Mannheim
Electricity mix, Germany	1.8	EnEV [11]

Since the primary energy factor only indicates one aspect of the environmental stress, the **CO_2 emissions** are introduced as a further evaluation criteria. The CO_2 emissions [kg/MWh] represents the amount of climate-damaging CO_2 equivalents emitted per MWh final energy. The used data represent not only the energy carrier, but also the production, use and disposal of the energy conversion systems. Bases of the calculation is the database GEMIS, Version 4.93, see table 2 [12]

Tab 2: CO_2 emissions of different energy carrier

Energy carrier	equivalent CO_2 emissions [kg/MWh]
Solar thermal, flat plate collector	13
Photovoltaic, multi crystalline	62
District heating mix, Mannheim	295
Electricity mix, Germany	617

The **solar fraction** [-] is the ratio between the useful, solar generated heat supplied to the system and the total heat demand. The solar fraction is a common and wide spread performance figure to classify and compare solar thermal systems.

The **specific heat costs** [€/MWh] is the ratio between the annual total costs and the generated heat based on VDI 2067 [13]. The solar heat costs enable an economic comparison between different concepts and technologies.

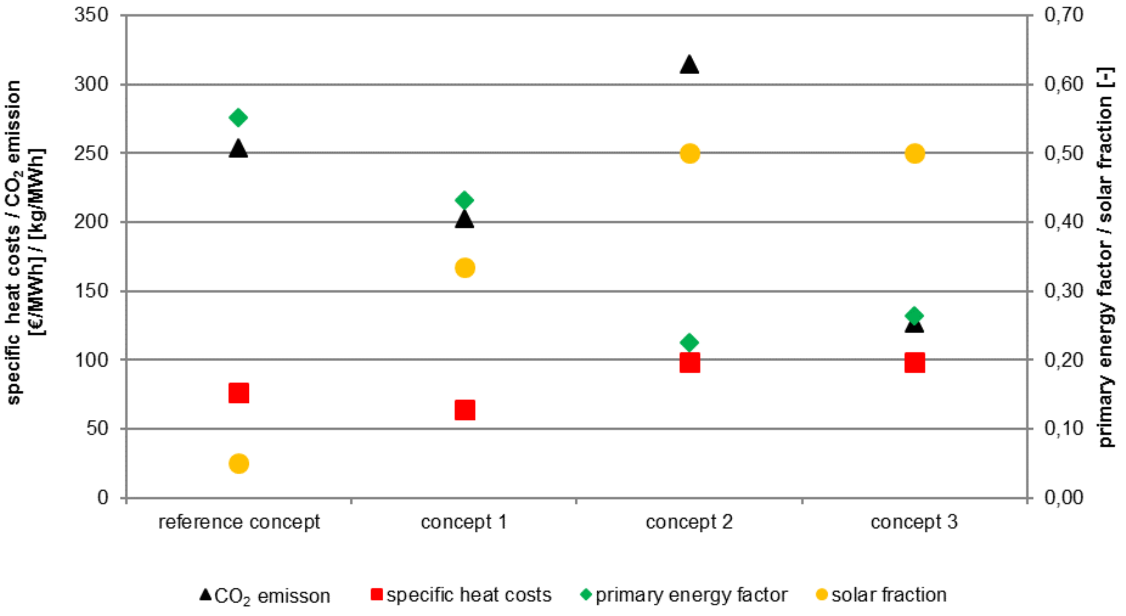

Fig 10: Comparison of the performance figures of the different concepts

Fig. 10 shows the comparison between the reference concept and the three alternative concepts. Concept one has the lowest specific cost, even lower than the reference concept. The primary energy factor of all three alternative concepts are lower than the one of the reference concept. Related to the CO_2 emissions concept one and three have lower emissions than the reference concepts, although concept two has the highest CO_2 emissions. This is due to the high share of heat generated by the compression heat pump and therefore the high electricity demand. If an additional installation of a PV system is considered (as it is within the reference system), the CO_2 emissions would be reduced significantly.

5. Conclusions

The evaluations of the three alternative concepts show a significant potential for improvements related to the primary energy demand and the solar fraction. Further, concept one and three have reduced CO_2 emissions compared to the reference concept. Only concept two has higher CO_2 emissions due to the implementation of a compression heat pump. Even for systems with 50 % solar fraction the specific heat costs are in the same range of the reference concept.

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