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Potential analysis of heat sharing at different temperature levels in a district

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Abstract

The present decentralized heat production in urban areas is characterized by a wide spectrum of consistently fossil fuel based equipment. The integration of renewable energy and cogeneration technologies require increased flexibility from both sides of production and consumption. This study explores the potential primary energy savings achievable by connecting existing buildings and energy systems by means of a multi-temperature level district heating system. For this purpose, a district in Berlin with single and multiple family dwellings, a school and a commercial building has been modelled and simulated with the existing heat supply systems. Furthermore, a potential analysis for the installation of solar thermal collectors has been conducted with the focus on the temperature levels of heat production during an entire year. The results show that since the installed capacity of heat generation is often higher than the required heat demand, the systems efficiency may be enhanced by extending the supply to neighboring buildings and turning off the less efficient boilers. The results also suggest that the operating period of the cogeneration system, initially designed to cover the heating demand of non-residential building, could be extended through the whole year by providing domestic hot water to neighboring dwellings. Furthermore, the total energy efficiency of the oil/gas boilers can be increased by connecting them, which allows a more selective and prioritised operation. In summary, this paper indicates that heat sharing between buildings with different consumption profiles and different energy systems is advantageous from the energy efficiency standpoint, but requires further development of the infrastructure and control systems.

Keywords – District heating; Heat sharing; Primary energy saving

1. Introduction

The European Council has adopted ambitious energy and climate objectives for 2020: reduce gas emissions by at least 20%, increase the share of renewable energy to at least 20% of consumption and make an at least 20% improvement in energy efficiency. In order to attain these targets several measures should be enacted. One of the priorities of the 2020 Energy Strategy is to promote the high-efficiency district heating and cooling due to its significant potential for saving energy [1]. Accordingly several innovative research programs and projects have been developed across the EU and beyond [2]. All of the research studies contribute to increase the overall efficiency of the heat and cold supply in the building sector and increase the share of renewable resources by smart district heating and cooling systems. This case study investigates the potential to achieve these goals in a part of the Pankow district of Berlin by connecting the heat supply systems of different buildings through a multi-temperature-level district heating system. Such a district heating network can help to enhance the overall efficiency and maximize the utilization of renewable energy sources by removing the drawbacks of systems based around a single energy heat supply such as differences in scale, temperature and peak time between supply and demand sides.

2. Buildings model

Generally the building simulation models differ in the accuracy of calculations for different study purposes. For the calculation of dynamic heat demand profiles for different types of buildings on a district scale an equation-based model was developed in Modelica. This model calculates the heat losses and gains in analogy to the DIN V 18599 considering the zonings and the usage time for different building types. In order to achieve higher accuracies the model will be improved regarding heat capacitance of the building and environmental effects in future works.

The residential buildings were categorized according to the TABULA concept of residential building typologies [3]. Accordingly they have been divided into two groups of detached buildings and multi-family buildings. Each group has been then categorized according to their year of construction in three groups of before 1960, between 1960 and 1990 and after 1990. The categories represent the typical energetic and geometric properties of their group. This classification was applied for this case study on the 93 residential buildings of the chosen district in Pankow.

The building model takes the building type, the zones surface areas and the building envelope data as input. More over three operating modes have been defined for the buildings to distinguish between continuous operation, reduced night-time or weekend time heating operation and heating with timer control.

Regarding to the buildings classification of the Pankow quarter the demand for both domestic hot water (DHW) and space heating were simulated dynamically. The blue line in Figure 2 shows the total heating demand during the one-year-test-period. In Table 1 the classification, the total annual heat demand and the heat load of all simulated buildings are shown.

Table 1: Overview of the building classes and the calculated heating demands

Type/ Year of const-ruction	Operation mode	No. of Build.	Heat demand [kWh/a]	Heating load [kW]	Type of heat generator
Residential/ Before 1960	continuous	13	1699554	753.3	EU-standard gas boiler
	night setback	19	2397575	1131.2	
	Time-controlled	9	1027944	520.8	Condensing gas boilers
Residential/ 1960 - 1990	Night setback	27	2076890	908.8	EU-standard gas boiler
	Time-controlled	9	578187	283.5	Condensing gas boilers
Residential/ After 1990	Time-controlled	16	617839	230.9	
School/ 1911	Base load	1	4509145	2092.8	CHP
	Peak load				DHS
Shopping Center/ 2007	Heat demand	1	4240973	2271.8	Condensing gas boilers
	DHW			276.4	Electrical heating station

3. Primary energy savings potential

The reduction of the primary energy consumption for heating purposes of the Pankow district was studied comparing two scenarios. The primary energy consumption calculations are according to the DIN V 18599-1. In Scenario-1, the actual state scenario, heat of all consumers is produced locally by its own heat generator. Scenario-2, the heat sharing scenario, considers cases were all consumers and heat generators are connected by an idealized district heating grid. Idealized means no heat losses and no power consumption of subsystems e.g. pumps and controlling systems are considered.

To compare the primary energy consumption of both scenarios information about the installed heat generators are needed. The heat generators in the non-residential buildings could be determined by a direct inquiry. The heat demand of the school is covered by a 680 kW CHP for base load. The pike load is covered by a 1420 kW district heating connection (DHC). In the shopping center the heat demand is covered by five condensing boilers. Three have a power of 730 kW each and two the power of 400 kW each. The domestic hot water (DHW) is covered by a 300 kW electrical heating station.

To determine the type of heat generators of the residential buildings some assumptions has been made. Regarding to [4] gas is the dominant fuel type in the Pankow district. Therefore only gas boilers without buffer storage were considered in this paper. Moreover we distinguished between standard and condensing gas boilers. The distribution is related to the operation mode of the heat generator. We assume that all buildings which are operated in time controlled modes have a condensing gas boiler as heat generator. All other building types use standard gas boilers respectively. The maximum size of the boilers Φ_{Boi} is estimated by the heat load of the building Φ_{HL} and the over-dimensioning factor f_s (1). The over-dimensioning factor is usually 1.2 [5] and takes the oversizing of existing gas boilers into account.

$$\Phi_{Boi} = \Phi_{HL}\ f_s \tag{1}$$

Moreover, boilers are dimensioned for the coldest 2-day period of a year in respect to DIN EN 12831. Therefore, and due to the over-dimensioning factor, boilers run on low part load rates during most days of the year. Regarding DIN 18599-1 the lower heating value related primary energy QP is calculated in relation to (2).

$$Q_P = \Sigma_j\ (Q_{f,j} \times f_{p,j}) \tag{2}$$

Were $Q_{f,j}$ is the final energy related to the lower heating value of each producer j and $f_{p,j}$ the primary energy factor. The final energy of each heat generator is calculated regarding to (3) and takes the thermal efficiency $\eta_{th,j}$ and the heat load into account.

$$Q_{f,j} = \int (\Phi_{HL,j} / \eta_{th,j})\ dt \tag{3}$$

For part load rates (f_{PL}) lower than 0.5 efficiency curves regarding to Figure 1 were used.

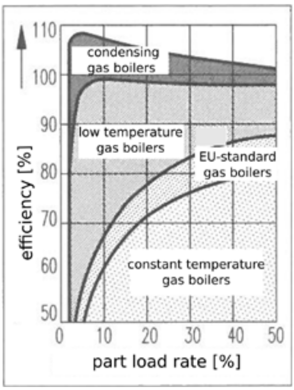

Figure 1: Characteristic curve of different gas boilers types related to lower heating value, [6]

The curve of condensing gas boilers is approximated by (4a) and the efficiency curve of an EU-Standard gas boiler by (4b). For coefficients see

Table 1. For part load rates higher than 0.5 constant efficiency values of 1.012 for condensing and 0.874 for standard gas boilers were used.

For $0 \leq f_{PL} < 0.5$:

$$\eta_{CGB} = A_0 + A_1 \exp(-f_{PL}/A_2) + A_3 \exp(-f_{PL}/A_3) \quad (4a)$$

$$\eta_{EU\text{-}GB} = \Sigma B_i \times f_{PL}^{\,i} \quad (4b)$$

Table 2: Coefficients of boiler efficiency curves

i	A_i	B_i
0	1.01E+02	3.26E+01
1	1.20E+01	6.87E+00
2	1.67E+01	-5.21E-01
3	-3.72E+03	2.40E-02
4	3.50E-01	-6.27E-04
5	-	8.54E-06
6	-	-4.71E-08

While considering the primary energy consumption of Scenario-1 all heat generators are controlled regarding to their local heat demand. In opposite to that all heat generators are controlled centralized in respect to the overall heat demand of all consumers and to a prioritization in Scenario-2. The prioritization was chosen in respect to the primary energy factor and the thermal efficiency of each heat generator. Therefor the use of DHS has the highest and the electrical heating station the lowest priority (see Table 2). Furthermore, it is assumed that all boilers of Scenario-2 run within a part load rates higher than 0.5 and therefore in a region of constant efficiencies. This assumption can be made because we assumed the all boilers are controlled centralized and therefore low part load rates of single producers can be neglected.

In Figure 2 the total heat demand of the considered district and the installed capacity of all heat generators are shown. You can see that all high efficiency heat generators (DHC, CHP and condensing boilers (CGB)) provides almost enough heat to supply all consumers during the whole year. EU-standard gas boilers (EU-GB) and the electrical power station are used only for backup purposes. Just during a few days in February the heat provided by the EU-standard gas boilers is needed. During the summer period the heat demand for DHW is covered by the DHC.

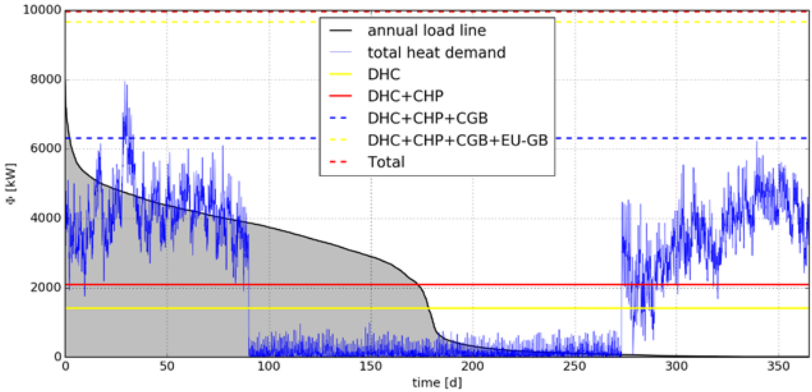

Figure 2: Simulation results of the total heat demand and the installed heating power

In Figure 3 the overall primary energy consumption of both scenarios are compared. In Scenario-2 29.3% less primary energy is consumed in comparison to Scenario-1. This is affected by two main effects. The dominant effect is related to the prioritization of heat generators. Therefore high primary energy consumptive heat generators are substituted by low primary energy consumptive ones.

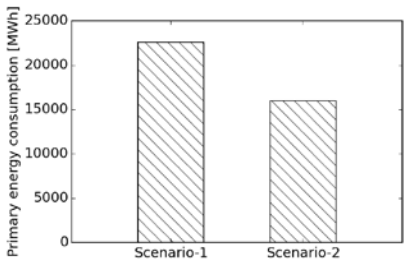

Figure 3: Comparison of primary energy consumption of Scenario-1 and Scenario-2

Moreover, low part load rates of single heat generators in Scenario-2 are avoided. This yield in higher efficiency rates for EU-Standard gas boilers and in slightly lower efficiency rates for condensing boilers in comparison to Scenario-1. The installed supply capacity is almost twice as high as the installed supply capacity of condensing boilers. Therefore the effect of increased efficiencies due to low part load rats of condensing gas boilers of Scenario-2 is small in comparison to the decrease of the efficiencies of EU-Standard gas boilers.

Table 3: Thermal efficiencies of het generators related to lower heating value, primary energy factor related to DIN V 18599-1 and chosen priority

Heat generator	η_{th}	f_p	Priority
Condensing gas boilers	(4a) and (5a)	1.11	3
EU-standard gas boilers	(4b) and (5b)	1.11	4
DHS	1.0	0.56 [8]	1
electrical heating station	1.0	2.4	5
CHP	0.51 [7]	0.7	2

4. Solar potential analysis

The current technology provides mainly three different sustainable solutions for decentralized thermal energy production in district areas: using solar thermal energy, ground heat (trough ground water, soil or underground air) and transforming power to heat, with electricity from renewable sources from decentralized energy systems or from the excess power of conventional power stations.

The exergetically less expensive solution corresponds to the direct use of environmental energy and therefore the solar thermal energy production in district scale represents a practical and cheap solution for the decentralized and renewable energy production in the city [9] and [10].

In order to determine the potential of effective solar production of the city block in Pankow it had been necessary to identify the suitable roofs and surfaces for the installation of standard solar panels. For this purpose the 3D map of all the buildings of Berlin, the “Berlin Solar Atlas”, has been used [11]. The main criteria for the selection of the installation roofs have been: orientation, inclination and free available area. According to the specific latitude and the climatic area, the most eligible buildings for the installation of solar thermal panels are buildings with flat roof, buildings with roof maximum inclination of 60° and south oriented with a maximum deviation of ± 5°. Vertical installations of solar panels on the exterior walls of the building have been excluded, because of the high density of buildings and vegetation in this specific part of the city. In this way it simplifies the calculation of the effective shading and the simulation time diminish.

Observing the specific district the roof with the best condition for solar thermal energy production is the roof of the shopping mall. Flat roof, squared shape and large surface (17257 m²), it represents the highest potential for solar thermal generation, even if the feasible area for the panel installation is about 30% of the total roof area, so the installable collector surface results 4659 m².

The second biggest roof area available in the district is represented by the school with 4571 m². However, the shape and orientation of the building is not optimal and due to the numerous skylights the maximum installable (south facing) collector area is about 686 m².

The installation of solar collectors on the detached houses is more complicated because of the smaller surfaces and the variety of different architecture types of the district, but according to the calculation the total roof area which can be covered with solar panels is about 3709 m².

In the apartment buildings the ratio between the roof area and the net floor area is much lower compared with the ones of detached houses. Moreover, the roof surface is often occupied and the potential of solar thermal panel is low.

The maximum installable surface of solar panels on the whole apartment buildings of the district corresponds to 1398 m².

Finally the maximal installable solar panels area on the district is 10452 m² which corresponds to the 52% of the total walkable roof area of all the residential and non-residential buildings.

The simulation of solar thermal systems has been conducted using a model from the Building Library (Berkley University). The model for the solar collector is based on the EN12975 test protocol and respects the models for solar gain, heat loss of the European standards. This model reduces the heat gain rate to 0 W when the fluid temperature is within 1 K of the maximum temperature of the medium model.

The modeled panels have an optical efficiency of 72%, the nominal mass flow rate is 0.104 kg/s and the heat transfer medium is water. All the panels are exposed to the south and the medium incidence angle has been calculated to be 45°C. The solar panel model reads the same weather data used in the building simulation model.

Temperature analysis of the solar heat production has been conducted for the period of one year. Due to the high latitude of Berlin and the cold temperatures of the winters months the highest temperature produced in the coldest day of the year ($T_{environment}$= -9°C), the produced solar temperature out of the panel is 31°C. The most productive period is in the months between April and August, with a maximum temperature production of 77°C.

The temperature levels of the heat production have been distinguished in four main categories, as shown in Figure 4.

The highest rate (48.50%) of the hot water heated though the solar collectors during the winter months (form September to March) shows a temperature range of 28-35°C, which could be used to preheat the hot water demand or be integrated in heating circuits. In the same months 32.81% of winter solar heat shows a range of temperature between 35°C and 45°C and could be used for heating purpose in underfloor heating systems. Only a few hours in the winter the hot water production rises over the 45°C, representing the 18.57% of the total heat collected during the winter; this heat could be used for the production of domestic hot water or could be integrated into conventional heating systems with higher operating temperatures.

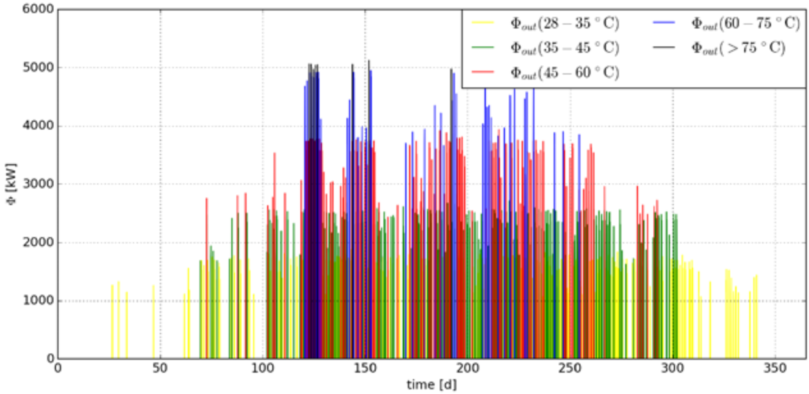

Figure 4: Solar heat production of different temperature levels: 28-35°C; 35-45°C; 45-60°C; 60-75°C, >75°C.

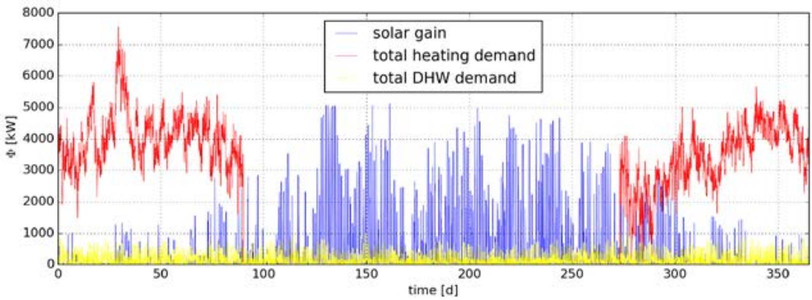

Figure 5: Simulation results for heating and domestic hot water demand compared to the solar heat production of one year for the city block in Pankow.

The total solar heat collected from the solar panels during the whole year is 1.9 GWh which corresponds to 11.13 % of total heat demand of the district (Figure 5). During the winter months the solar production could cover 1.04% of the heat demand or 30.80% of the winter domestic hot water demand of the domestic heat demand of the whole residential and non-residential buildings.

In summer when the heat demand is zero, the solar heat production increases and from April to August the solar panels collect a total amount of heat corresponding to 1.7GWh, which is 2.89 times bigger than the domestic hot water demand of the whole district, as shown in Figure 5.

5. Conclusion

It could be indicated that heat sharing between buildings in an urban area with different consumption profiles and heat generators is advantageous if it comes to primary energy savings. In this investigation a potential of almost 30 % primary energy savings could be observed if heat losses and the energy consumption of secondary systems are not considered.

In addition, the results of the solar potential analysis show that the heat produced in one year form all the solar panels installed on the roofs of the district buildings covers about 11% of the total heat demand of the district. During the winter months the solar production covers only 1% of the heating demand and this heat could be integrated only into specific heating systems with low operative temperatures, or could be used to cover about 30% of the domestic hot water demand. In the summer period the solar heat production increases and since the heat demand is reduced to the only domestic hot water request, thermal storage for the cold season should be foreseen in order to increase the share of renewable energy for heating supply.

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