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Analysis of heating load diversity in German residential districts and implications for the application in district heating systems

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ABSTRACT

In recent years, the application of district heating systems for the heat supply of residential districts has been increasing in Germany. Central supply systems can be very efficient due to diverse energy demand profiles which may lead to reduced installed equipment capacity. Load diversity in buildings has been investigated in former studies, especially for the electricity demand. However, little is known about the influence of single building characteristics (such as building envelope or hot water demand) on the overall heating peak load of a residential district. For measuring the diversity, the peak load ratio (PLR) index is used to represent the percentage reduction of peak load of a district system from a simple sum of individual peak loads of buildings. A total of 144 residential building load profiles have been created with the dynamic building simulation software IDA ICE for a theoretical analysis in which the PLR reaches 15%. Within this study, certain district features are identified which lead to higher diversity. Furthermore, these results are used in a district heating simulation model which confronts the possible advantage of reduced installed capacity with the practical disadvantage of heat distribution losses. Likewise, the influence of load density and the districtís building structure can be analyzed. This study shows that especially in districts with high load density, which consist of newly constructed buildings with low supply temperature and high influence of the hot water demand, the advantages of load diversity can be exploited.

1. Introduction

Traditionally, energy supply systems for residential buildings are being designed individually, treating each building as a stand-alone system. However, as buildings are integrated into an urban context, such as a district or a neighborhood, designing the energy supply on the district scale with one central plant may lead to advantages in energy efficiency as well as economic benefits.

From the technical perspective, a major advantage can be achieved concerning the design installed capacity. Regarding heat supply of buildings, the installed capacity of the heat source depends on the maximum requested heat load in one time step. In German residential buildings, heat for space heating and hot water is traditionally produced by the same boiler. Likewise, the maximum heat load is influenced either by the space heating demand or the hot water demand. It is assumed that the time step in which this maximum load appears varies within a certain range for different buildings. Consequently, if one central plant is designed for several buildings, the maximum heat demand of the supplied group is likely to be less than the sum of the individual building peak load (Fig. 1).

This benefit is dependent on the variability of residential building heat demand profiles, in the following designated as load diversity. It is assumed, that the diversity of heat demand profiles for residential buildings has increased in recent years as buildings are better insulated which extends the influence of the occupantís hot water demand on the total heat demand profile. The aim of this paper is to identify building and occupant related characteristics that influence the heat demand profile of residential buildings and to quantify their influence on the heating load diversity within a residential district.

The heat produced by a central plant can be distributed to the district's buildings via a district heating system. District heating systems are an established technology for the heat supply of residential districts in Germany. Moreover, innovative systems that

Abbreviations: PLR, peak load ratio; SFH, single-family house; MFH, multi-family house; PPH, people per household; AIS, aggregated individual supply; CS, central supply; DH, district heating.

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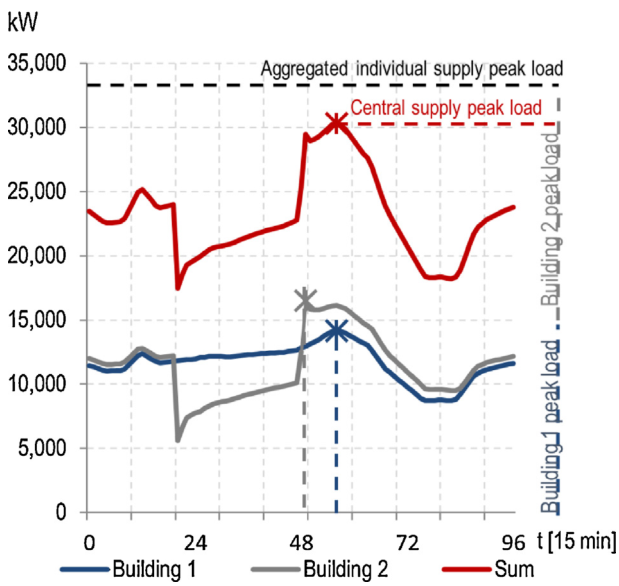

Fig. 1. Aggregated individual supply (AIS) peak load and central supply (CS) peak load.

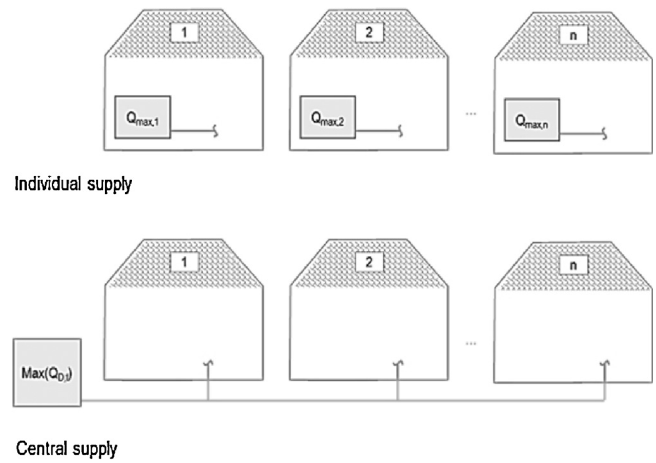

Fig. 2. Illustration of individual supply and the central supply system.

include solar thermal power plants or geothermal storages and likewise reduce carbon emissions have been tested [1]. According to the German Renewable Energy Heat Act (EEWärmeG), district heat is considered equal to heat from a renewable energy source if at least 50% of the total heat outcome is gained from industrial waste heat or produced by a combined heat and power plant [2]. Hence, there is a lot of potential for the further establishment of district heating systems in Germany in the context of the turnaround in the national energy policy [3]. Apart from that, the reduction in installed capacity leads to smaller investment costs. At the same time, the overall operating costs of the whole district might be reduced as only one central plant has to be maintained and individual buildings can save the plant room space for another usage. Furthermore, due to scaling effects, the economic benefit is enhanced with an increasing amount of supplied buildings by the central plant.

However, disadvantages appear regarding the distribution of heat from the central plant to the final recipient. Depending on the pipe length, insulation, and supply temperature, distribution heat losses may increase the minimum installed capacity of the central plant. Likewise, high-pressure losses cause additional electricity consumption because of the pump power. Therefore, a further objective of this paper is to confront identified diversity advantages of central heat supply systems with their practical disadvantage regarding heat distribution.

1.1. *Existing diversity studies related to energy supply*

In energy research, the term “diversity” is used for different purposes and applications. Former studies refer to energy diversity for describing optional energy sources (coal, gas, biomass) or a variety of energy suppliers for energy portfolios in the context of energy supply security. Stirling lists several indices for describing energy diversity in the form of variety, balance or disparity such as the Shannon, Simpson, Herfindahl-Hirschman, Solow-Polasky or Weitzman index and illustrates that these are also applicable in the context of energy transition and sustainability [4]. Furthermore, Skea analyzed how political incentives may increase the diversity of an energy system in this context [5].

In the framework of ASHRAE RP-1093, “diversity factors” have been developed to create various individual load profiles based on measured data that can be applied in energy simulations [6]. Yang et al. analyzed the influence of diversity in occupancy behavior on the energy efficiency of HVAC systems by using the Minkowski distance for occupancy profile clustering [7]. Likewise, Zhou et al. aimed to increase the efficiency of centralized HVAC systems by identifying differences of load curves in separate zones with the Gini coefficient [8].

Instead of analyzing the whole load profile other studies focused simply on peak loads for detecting diversity effects. The “diversity factor” in the context of electrical engineering is defined as “the ratio of the sum of the maximum power demands of the subdivisions of any electric power system to the maximum demand of the whole system measured at the point of supply” [9]. Guan et al. apply this definition of diversity not only for assessing electricity load but also the heating load and water supply of a university campus. They define a “coincidence factor” which is the total maximum load of the campus divided by the sum of the individual building load maxima. Moreover, they measured the contribution of each singular building to the maximum campus load peak [10]. Yarbrough et al. also focused on the relationship between total campus peak load and individual building peak load by applying the coincidence factor. For this purpose, they also developed a pivot table tool for visualizing the loads of all buildings [11].

Based on the same principle, Winter et al. defined a “simultaneity factor” for comparing the district peak load with the aggregated individual building peak load for two district heating systems with overall 558 buildings in Austria. They furthermore developed a formula for estimating the simultaneity depending on the number of buildings in the district [12,13].

In this paper, the basic principle of the peak load methodology used in the campus studies and by Winter will be adopted for measuring diversity as it leads to direct conclusions regarding the reduction of minimum installed capacity.

1.2. *Definition of the peak load ratio (PLR) index*

In a district in which every building is supplied with heat individually, the overall installed capacity is described by the aggregated individual supply (AIS) peak load $Q_{AISpeakload}$ (see Fig. 2)

$$Q_{\mathrm{AISpeakload}} = \sum_{i=1}^{n} Q_{max,i} \tag{1}$$

With $Q_{max,i}$ as the maximum heat demand of a single building i at a certain time step within the investigated period.

In a district with a central heating supply system, the minimum installed capacity is only defined after aggregating the demand