DERIVATION OF HEATING LOAD PROFILES ON THE BASIS OF DEMAND-CONSUMPTION ANALYSES

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Abstract

Without having extensive measurement equipment installed, only annual or monthly values of the energy consumption of existing buildings are usually available. The same applies to demand analyses, for which usually monthly and annual values for net, final and primary energy requirements are calculated. However, a higher temporal resolution of the consumption/demand data can be an important decision-making assistance both in the design of new buildings and in the planning of renovation and reconstruction measures. However, the determination of the time-resolved energetic behavior of buildings with the help of dynamic simulation models is very complex. As an alternative, a method was developed that allows hourly heating load and final energy profiles to be derived on the basis of comparatively simple approaches. The method was tested using an existing building in the local heating network of Kassel University, on a new building of the university campus being in the planning phase as well on the new institute building of Fraunhofer IEE being recently completed.

Keywords: space heating load, building heating load, energy balancing, thermal-dynamic simulation, demand-consumption balancing, DIN V 18599, DIN/TS 12831-1, method development

1. Introduction

Without extensive monitoring equipment, usually only annual or monthly values of the electrical and thermal energy consumption of buildings exist. In the case that demand analyses have been carried out, e.g. on the basis of DIN V 18599, only monthly and annual values for net, final and primary energy demands were evaluated. The procedure for calculating the space heating load according to DIN/TS 12831-1 also does not consider thermal dynamics of the buildings.

Both in the design of new buildings and in the planning of renovation and conversion measures, a higher temporal resolution of consumption/demand data can be important in various contexts. This applies, for example, to the planning of thermal and electrical storage systems, to possibilities for optimizing local heating networks in the provision and transfer of heating and cooling, or to the integration of load shifting strategies and measures for sector coupling.

For the investigation of the thermal dynamics of buildings and supply systems, the use of simulation environments such as TRNSYS, Modelica or IDA ICE is a good choice. The creation of dynamic simulation models quickly becomes very time-consuming, both for complex buildings or if a larger number of buildings is to be considered. With the complexity, the error sensibility of the numerical modelling increases at the same time, so that a validation on alternative data, e.g. from a consumption measurement or a normative demand calculation, is essential. In addition, the necessary building and plant engineering data is in many cases not fully available in order to parameterize detailed simulation models in a suitable way. For existing buildings, construction plans are often insufficiently available or inaccurate, if, for example, conversion measures have taken place or supply systems have been adapted. Parameterization in the above-mentioned simulation environments is therefore extremely difficult or does not adequately represent the existing situation. In case of new building projects, especially in the early planning stage, only limited information is available or for many aspects, no specification has been be made

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yet. If not even the cubature or orientation of the building has been determined during preliminary investigations, the application of detailed simulation tools would be of limited use. Nevertheless, for many conceptual investigations it is necessary to consider results with a higher temporal resolution, for which simplified mapping methods could represent good compromises.

2. Methodical Approach

Based on these basic considerations, a mapping method for buildings was developed in the CampusKassel2030 research project funded by the BMWK. With this method, which is further described in (Stricker 2022), the modeling and calculation effort for the required hourly profiles, e.g. for heating load or final energy demand, can be kept as low as possible. The method is based on the calculation rules of DIN V 18599 and is supported by the procedure for calculating the space heating load according to DIN/TS 12831-1 as well as by a demand-consumption comparison. The variables to be calculated within the method, using for the climate consideration test reference year data of the DWD, are:

$$\Phi_{HL,zone} = \Phi_{T,zone} + \Phi_{V,zone} - \Phi_{I,zone} - \Phi_{S,zone} + \Phi_{SpAufh,zone} - \Phi_{SpAus,zone}$$

With being:

$\Phi_{HL,zone}$	W	Heat Load of the respective zone
$\Phi_{T,zone}$	W	Transmission heat loss of the zone
$\Phi_{V,zone}$	W	Ventilation heat loss of the zone
$\Phi_{I,zone}$	W	Internal heat gains of the zone
$\Phi_{S,zone}$	W	Solar heat gains of the zone
$\Phi_{SpAufh,zone}$	W	Power for preheating the zone and its thermal mass
$\Phi_{SpAus,zone}$	W	Power taken from the thermal mass to the zone

In principle, the methodology can also be applied to weather-adjusted consumption data. For this, the availability of monthly consumption data would be desirable. However, annual consumption data are also sufficient.

The transmission heat sinks are evaluated by determining the heat transfer coefficient H_T via an indirect determination from the calculation methodology according to DIN V 18599-2. With regard to the determination of the ventilation heat sinks, infiltration and ventilation air exchanges have to consider times of building use and non-use and as well as the heat recovery efficiency. Internal heat sources are taken into account according to the specifications of DIN V 18599-10 and are integrated in the calculation methodology. The evaluation of solar heat sources requires a conversion of the hourly values of direct and diffuse horizontal radiation of the test reference year data into radiation intensities on planes of other orientations. The solar heat inputs are then calculated by multiplication with the transmission coefficients of the transparent building components and the reduction factors and shading ratios, e.g. by a manual shading control, according to DIN V 18599-2.

Especially for questions of load smoothing or load shifting as well as for the evaluation of the impact of temperature reduction during nights and heating times, the correct mapping of the building inertia is essential. Without the possibility of transient consideration of the thermal storage behavior of a room or the whole building, an hourly steady-state storage model is used within the developed method. For this purpose, the thermal mass of the building is assumed like a kind of battery storage. For this purpose, the definition of the heat storage capacity C_{wirk} within DIN V 18599-2 is used. Furthermore, a maximum transfer capacity between storage tank and room has been defined. For this purpose, the basic heating value from DIN/TS 12831-1 was used as an approximation of the maximum heat flow. Following this, the necessary storage limits are defined and the effective charging and discharging capacities can be calculated. For evaluating final and primary energy demand of buildings, the consideration of building systems is necessary. For thermal storages like e.g. ice storage systems, the charging and discharging processes are again integrated in the calculation method according to battery storages with maximum and minimum charging capacities.

In addition to thermal aspects of buildings, the determination of the electrical power demand is an important target value, particularly for questions of sector coupling, especially if the building has its own power generation systems. In contrast to DIN V 18599, it is not sufficient to limit the calculation to the electricity demand of the building systems so that an estimation of the user consumption is necessary for the calculation procedure. In this context, it is important to distinguish between periods of use and periods of non-use. To avoid overly regular profiles, the stochastic smoothing of utilization profiles and thus of internal gains and electrical consumption is integrated in the developed method. The degree of stochastic variations is a parameterization variable and can be selected individually in the procedure.

3. Use Cases

The developed method has been applied to three different use cases. In a first step, the method was tested for the determination of possible temperature reductions within the heating network of Kassel University. For this, the existing building of the headquarter of Kassel University was investigated in detail. In addition, the new building for the natural sciences at Kassel University currently being in the design phase was modeled with the developed method in order to give conceptual support to the planning team. Finally, the new institute building of Fraunhofer IEE being recently completed has been investigated for evaluating and optimizing the energy supply system based on an ice-storage heat pump system.

3.1. Headquarter of Kassel University

Fig. 1 shows the investigated headquarter of Kassel University. The building has been analyzed by means of two approaches. On the one hand, the overall energy balance is calculated using the static calculation method of DIN V 18599, and on the other hand, thermal-dynamic simulations are carried out for the building using the IDA ICE application from EQUA. The calibration of both the time series calculation and the IDA ICE simulation is carried out in the present case with consumption data of the building.

Fig. 1: Digital twin of the headquarter of Kassel University (https://kassel.virtualcitymap.de)

As can be seen in Fig. 2, the static calculation method according to DIN V 18599, in this case performed with the software ZUB Helena from ZUB Systems, overestimates the measured final energy consumption (district heat) by roughly a factor of two. When adjusting the monthly balancing method to the real user behavior, the deviation reduces. However, a significant deviation remains both to the measured consumption as well as to the simulated demand. A further reduction seems only possible with more in deep adjustments of the building parameters and the user behavior.

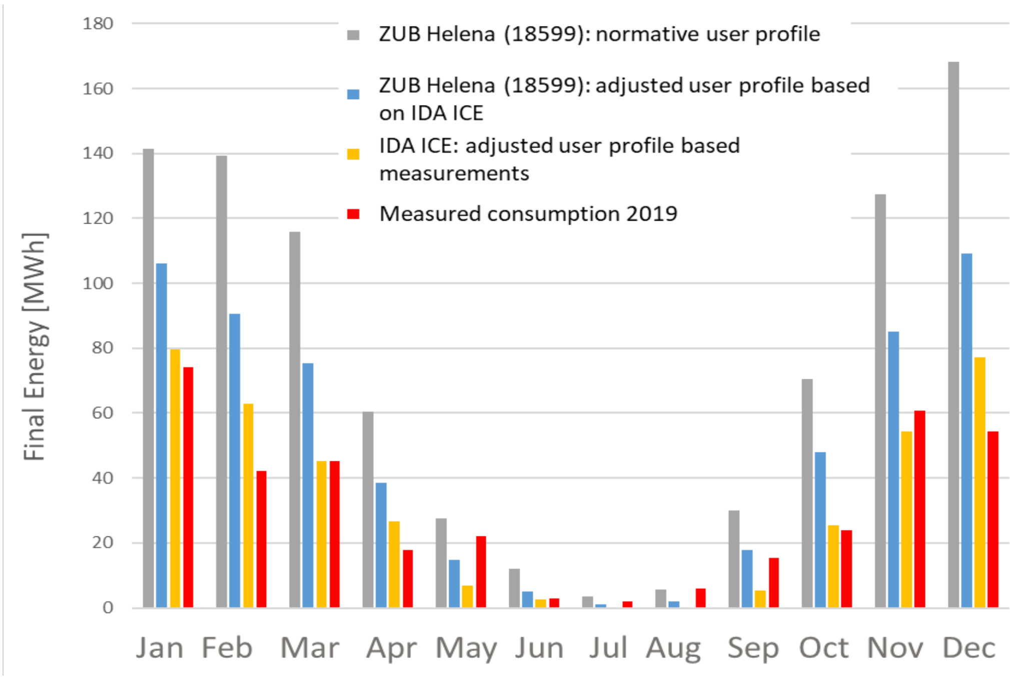

Fig. 2: Comparison of the calculation methods ZUB Helena and IDA-ICE with the measured values of district heat supply.

Fig. 3 shows the determined heat load profiles of the head quarter of Kassel University determined with the static method developed in the research project CampusKassel2030 using the approaches of DIN/TS 12831-1. As can be seen, the static calculation method using energy balances according to the method of DIN V 18599 follows the simulated load profiles with a good tendency, however, the method overestimates the simulated values by approximately 30 %. Hereby, the deviations are in the same range as shown in Fig. 2. Nevertheless, considering the systematic deviations, the load profile generation represents a smart method for determining time serials, especially in cases when a static model according to DIN V 18599 is available. Taking into account the systematic deviations, the method still serves as a good basis for optimizing the local heating network of the Campus Holländischer Platz of Kassel University.

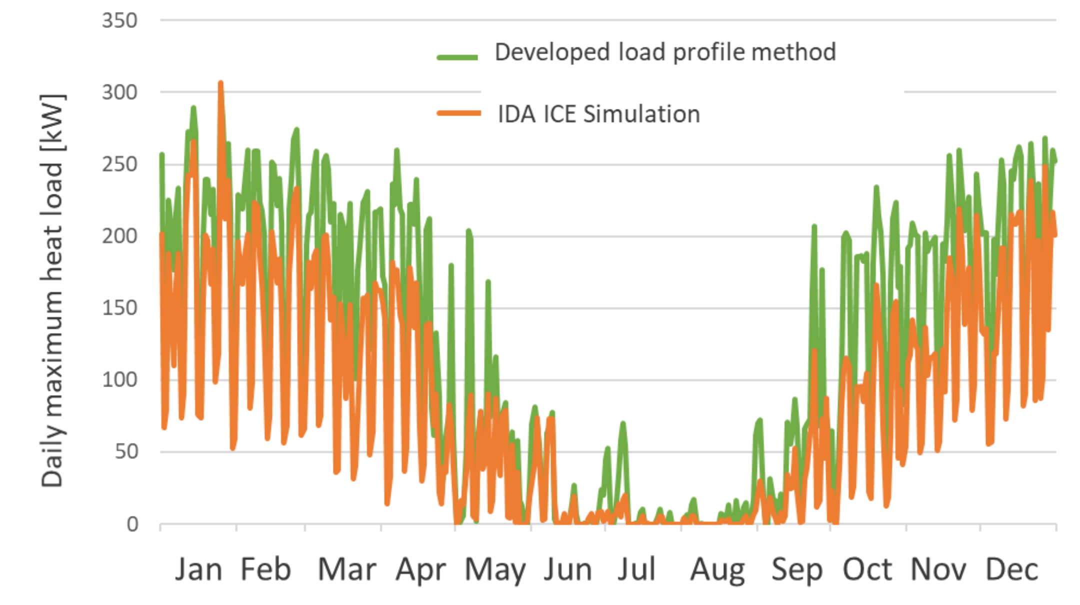

Fig. 3: Determination of hourly heat load profiles and comparison to IDA ICE Simulation

3.2. Building for natural sciences at Kassel University

The new building complex for natural science to be developed at the Campus Holländischer Platz at Kassel University is currently within the design phase cf. Fig. 4. In order to support the design process, the method of heat load derivation of existing buildings was extended to the evaluation of new buildings. For this, a zone-based exemplary geometry of the main building of the natural science complex was developed considering the space requirement of the different faculties as well as the planning specifications of the laboratory planner. The building was modelled according to the parameterization within DIN V 18599.

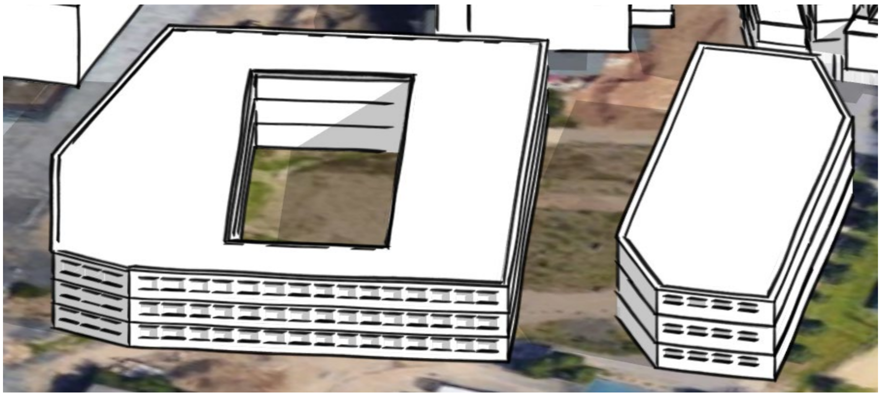

Fig. 4: Selected architectural design for the new Natural Sciences Building complex consisting of a main building (left) and a cleanroom building (right).

With the help of the developed static procedure, conceptual investigations of the heating and cooling supply were then carried out. Hereby, the investigations especially focussed on was heating and cooling concepts based on heat pump technology supported by photovoltaic systems as well as thermal storage systems. In order to estimate the resulting final energy demand profile of the building, the time serial method has been extended among the electricity consumption caused by light, technical systems as well as the electricity consumption of building users (e.g. computers, laboratories, etc.). For this, measured consumption data from (Biechele 2015) have been used for parametrization. In addition, a randomize function has been integrated to consider simultaneity. As shown in Fig. 5, the method serves as a good indication for electricity consumption and generation and helps to dimension heat pumps and PV-systems.

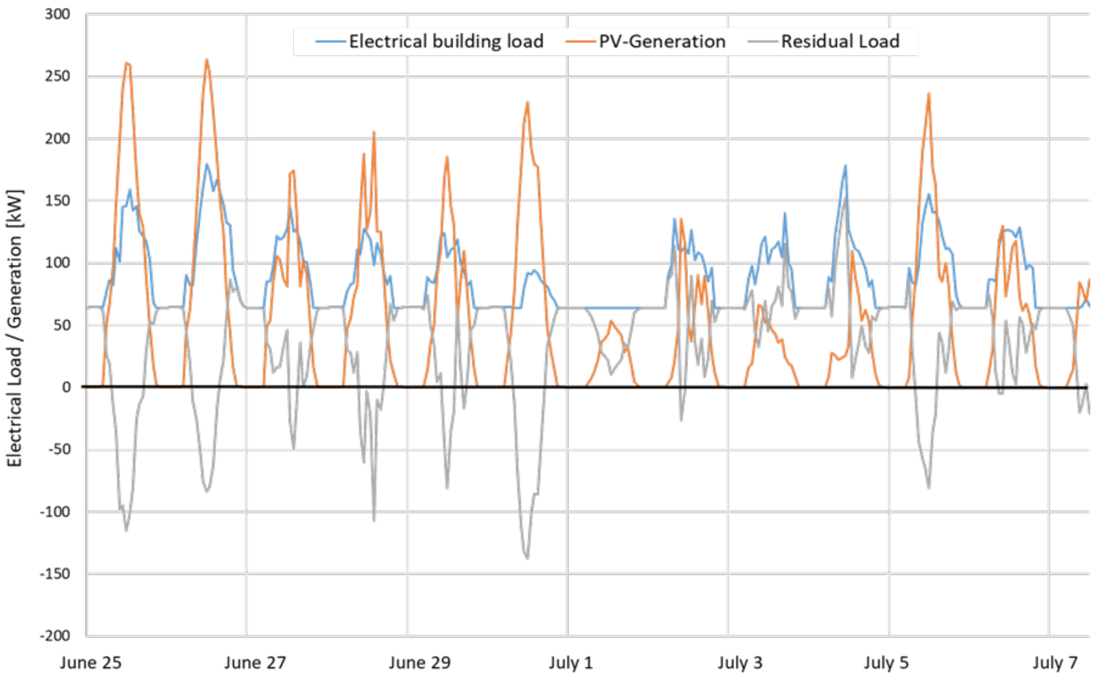

Fig. 5: Resulting electricity balance for a summer period within the new Natural Science Building at Kassel University

3.2. New Institute Building of Fraunhofer IEE

The new institute building of Fraunhofer IEE as shown in Fig. 6 started its operation in 2022 having first staff moving in in May 2022. The building can host approximately 350 people and has a very ambitious energy supply concept based on an ice-storage heat pump system. The heat system uses waste heat from the data center of the office building. Only in peak load times, the heating generation is supported by a cascade of gas burners. Regarding room comfort and indoor air quality, decentral ventilation units with high heat recovery are supplying fresh air to the respective rooms of the building.

Fig. 6: New institute building of the Fraunhofer IEE in Kassel

For the evaluation of the building performance, the developed tool for time serials investigation has been applied to the building and its heating and cooling concept. For this, a storage model for the ice storage has been integrated in the time serial model, considering sensible and latent storage capacities. Since the energy efficiency of the building concept depends on the available of the waste heat from the data center, the energy performance has been evaluated with different electrical load assumptions as well as different scenarios for regenerating the ice storage. In order to remain the availability to cool the office rooms of the building during the summer period, both waste heat and heat from solar thermal collectors were not used for the regeneration of the ice-storage in early/mid-summer within the parametrization of the model. As can be seen in Fig. 7, with low waste heat being available from the data center, the proportion of heat pump supplying heat to the building is very limited. With an average server activity of about 150 kW, the heat pump system can serve the majority of the heat demand of the building reaching the planned value of final energy demand estimated within the building energy certificate.

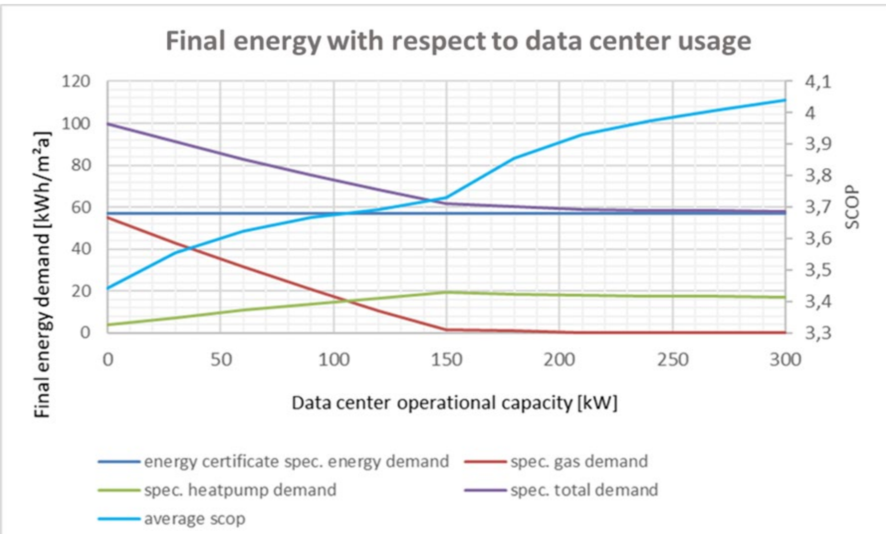

Fig. 7: Final energy performance of the heating supply concept of the new building of Fraunhofer IEE depending on the electrical consumption of the data center.

4. Conclusion

With the developed simplified method of determining time serials for heat load as well as final energy demands based on the method of DIN V 18599, useful investigations to evaluate and optimize buildings and their energy supply systems can be carried out. Typical use cases are for example the determination of load profiles, the evaluation of load shifting options especially regarding electricity generation and consumption scenarios as well scenarios including thermal and electrical storages. However, the investigation showed that the simplified method cannot easily reach the accuracy of dynamic thermal simulations like TRNSYS or IDA ICE. However, the effort of developing a validated numerical simulation model of a building, it´s technical system and their corresponding control systems is significantly higher than for the presented static time serial approach. In addition, simulation models are often not very flexible in terms of changing specific system designs or operation modes. Following this, the method can be recommended for first guess investigations of specific aspects like the examples given in this paper. Further investigations to improve the method should focus on an improved consideration of the building inertia, especially to predict cooling load profiles as well as the passive use of solar irradiance with higher accuracy.

5. Acknowledgments

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