Identification of Characteristic Heat Load Profiles of Different Usage Units in Non-Residential Buildings

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Abstract. For energy-efficient design of district heating networks and their components, knowledge about load profiles and the peak simultaneity are of crucial importance. Heating load profiles are needed in high temporal and spatial resolution as well as information about their composition. Due to high computational and temporal effort for transient calculations of a whole district heating network a less complex method is needed. For this reason different areas of use of non-residential buildings are analyzed separately to identify their characteristical variations and main influences on their individual load profiles to finally superpose their load profile in one overall building /district heat load profile. In a first step similar use areas in four buildings are calculated transiently and the deviation of the results were analyzed. Additionally, the building age and the associated structural-physical parameters are varied to get results for different building age classes. In a second step the profiles are superposed up to the district scale by using the area as scale factor. The gained district heat load profile is compared to time series of the observed consumption in order to assess the reliability of the method. The first results show promising conformity of modelled and measured energy demand. So the method will be applied to several buildings with varying structural-physical parameters and geometries.

1. Introduction
Worldwide, much of the total energy demand and emissions of greenhouse gases are attributable to the building sector. In EU its partition of the building sector is estimated to account for 40 % of total energy demand and for about 36 % of greenhouse gas emission [1]. In the United States, the share of energy demand used for the building sector is 38.9 %, whereat already 34.8 % are attributable to heating, cooling and ventilating buildings [2].

These facts reveal the great potential for saving energy and greenhouse gases in the building sector. To utilize this potential, a deliberate establishment of technical building facilities besides an energetically optimized building envelope and an optimization of the energy production and transmission system technology are necessary, as globally local and district heating grids are being expanded more and more. Most of research work on optimization of local and district heating networks still is based on energy generation so far and only a few consider the consumer side. [3]

However, an appropriate prediction of the load behavior on the load decrease side is a fundamental prerequisite for development and optimization of local and district heating networks. In particular, for an energy-efficient design of the grids and their components, knowledge about the temporally high-resolution course of the load as well as the simultaneity of the heat demand is of central importance.
These parameters, the coincidence factor and the heat load course, are currently determined by static methods and are substantiated by safety factors due to the resulting uncertainties. [4]

As a result, systems do not operate in the point of optimal energetic efficiency. In practice, local and district heating networks are designed and optimized based on former insights. In this case, historical data of other local and of district networks are transferred to predict load behavior of a supplied district. Since different districts might differ strongly in their distinct settings, the inherent data characteristics have to be adapted for the new district. How good this transfer fits, strongly depends on the experiences of the planner. [5]

To provide a sophisticated and quantitative prediction of the heat load demand for planning and optimization of local and district heating networks, some research has been done in the last few years. On the one hand, so-called top-down models, have been developed, which are based on historical data from existing local and district networks. However, these models have proven to be crude and too general for the planning and optimization of networks. On the other hand, bottom-up models, which e.g. account for individual nodes in detail as a base of operations, can be subdivided into the four categories of empirical models, statistical models, physical-statistical hybrid models, and engineering models. While the models of the first three categories are highly detailed compared to top-down models, they still exhibit drawbacks particularly in the initial state of planning, as they are based on historical data as well and thus lack in transferability. It is not possible to comprise effects, which have not been in the observed data within these models. The engineering models allow the implementation of all physical and user behavior effects which are needed and are based on thermal building simulations. Thus, they are highly adaptive and moreover quite accurate in the heat demand forecast. However, this approach is very elaborate and thus expensive to build, since each unit of a district to be supplied has to be simulated individually. To ease this, general load profiles for specific building types, e.g. office buildings, residential buildings, etc., can be developed. While this simplification accelerates the development of the thermal load profiles, it is at the expense of the accuracy, since it refers on average building data. For a closer review on modelling heat load profiles the reader is kindly referred to [3], where the authors provide a comprehensive survey of current assessment techniques.

Following generally the last mentioned approach, the aim of this research work is to create heat demand profiles with appropriate accuracy likewise to methods where all units are assessed individually, but with the advantage of a less time-consuming set up. For this purpose, heat demand load profiles were created for characteristic usage units. By scaling and superposing these load profiles we aim to predict the heat demand load behaviour of any building or district.

2. Method

According to the need to provide insights into the buildings load performance without a complex transient simulation the method aims to reduce the building analysis to the crucial parameters of the heat load profiles. In contrary to a rough simulation for the whole building using only one node this work tries to keep accuracy by simulating representative parts of the building to subsequently scale and superpose them up to the building level. The approach is induced by the task to deliver profiles for a long-time simulation and a linear optimization of a district heating network and its heat generators and the development of its future-oriented-energy-concept. Since the geometrical differences of the buildings are of lower significance the main emphasis is placed on an overview to the load profiles during the whole building life-cycle which for example also include major changes after refurbishment.

In order to be able to define characteristic heat load profiles of different usage units, typical influencing factors, like structural-physical parameters, user behavior and usage-dependent factors (e.g. ventilation rate, room temperature, etc.), are identified and defined within this work, which were used to determine typical characteristic usage units.
2.1. Principle procedure

The basis for the description of representative building parts is created by a transient simulation of the four largest buildings of the quarter (here Campus Garching TU-Munich), which approximately account for ¾ of the total energy consumption of the quarter. Due to the large number of buildings in the quarter and a project-related time restriction, not all buildings can be calculated. Therefore, the calculated buildings have to include a preferably broad variety of building types given in the quarter.

In order to identify significant differences in the building performance first a crosscheck of the heat demand of the buildings and their parts is done. Therefore the buildings are zoned and the user characteristics of all zones \( j = 1, \ldots, J \), whereat \( J = 10 \), are defined according to the guidelines in DIN V 18599 [6]. On the comparability all simulation parameters like boundary conditions and building characteristics are set for all buildings equally. Previously to the simulation, a room-by-room heating load calculation according to DIN 12831 [7] has been carried out. Its results set up the maximum heat load which will be applied to the rooms during the simulation. The calculation of the buildings and all different building zones is done in three different building age classes. These building age classes (\( BA_k \)) are chosen intentionally to comprise a deliberate variability of structural-physical parameters on the one side and to maintain generally the building age classes of the buildings in our case study on the other side.

As a first result the transient simulation delivers results for the whole building and each zone alike. This leads to the opportunity to combine the heat demand of identical zones like office, library, sanitary etc. to mean (identical) zones with a mean heat demand. The mean values of the different zones are used as specific heat demand in (Wh/m²a) different usage units.

In the next step the dynamic heat load profiles of the previously identified and computed usage units is investigated in order to identify differences in the temporarily high-resolved building behavior. Afterwards the heat load profiles of each zone of the four buildings, which are results of the transient whole building simulation, are combined to mean heat load profiles. This leads to a specific mean heat load profiles (MH) in (W/m²a) for each usage unit.

The determination of heat load profiles for the individual buildings and their composition to characteristic heat load profiles (CHP) of the different usage units lead to the opportunity to superpose and scale (Eq.1) the profiles to one heat load profile of the whole quarter. The superposing and scaling is done by combining and multiplying the heat load profiles of each usage unit regarding its share of area (A) in the quarter and its associated building age class.

\[
CHP = \sum_{k,j}(MH_{k,j} * A_j)
\]

In a further step, it is tested whether this method accomplishes a sufficiently accurate prediction of the heat load demand of the local and district heating network of the whole quarter.

2.2. Modell set up

All simulations are performed with the software “AX3000”, based on the four buildings on the Campus (i.e. the faculty buildings mechanical engineering (ME), physics (PH), chemistry (CH), mathematics and informatics (MI)).

The software "AX 3000" of the software producer ESS is BIM capable and thus combines the numeric simulation as well as CAD modelling. Thus, with comparatively simple steps, very large buildings with a high number of rooms (i.e. zones in underlying study) can be simulated. Due to the integrated EnergyPlus calculation engine, it is possible to thermally-dynamically calculate each zone of the buildings in hourly time steps. For further information the reader is kindly referred to the software user manual [8].

Simulation parameters like boundary conditions and building characteristics are implemented for all buildings and are alternated for three different building age classes with associated structural-physical parameters. The first building age class (BA1) includes all buildings which were built between 1956 and 1968 (which holds for chemistry), the second building age class (BA2) contains all buildings which were built between 1969 and 1994 (physics), whereat the third building age class (BA3) is valid for all buildings of the period from 1995 to 2018 (mechanical engineering and mathematics/informatics). The
The average component structure of the thermal active layers of the buildings at the Campus is implemented as followed:

- **External Walls:** 2 cm mineral interior plaster; 20 cm concrete; Insulation mineral wool of quality 0.04 W/mK BA1 2 cm, BA2 4 cm, BA3 8 cm; 2 cm mineral exterior plaster
- **Roof:** 2 cm mineral interior plaster; 20 cm concrete; quality insulation XPS 0.04 W/mK BA1 1 cm; BA2 6 cm, BA3 16 cm; gravel
- **Base Plate:** 2 cm flooring; screed 6 cm; third-party sound insulation of the quality 0.045 W/mK 2 cm, concrete 25 cm; quality insulation 0.045 W/mK BA1 0.0 cm, BA2 0.0 cm, BA3 4 cm
- **False ceilings:** 2 cm flooring; screed 6 cm; third-party sound insulation of the quality 0.045 W/mK 2 cm, concrete 20 cm; 2 cm mineral interior plaster
- **Internal Walls:** 2.5 cm plasterboard; 1.5 cm of air; 6 cm insulation quality mineral wool 0.04 W/mK; 2.5 cm plasterboard

The U-values of the walls, ceilings, roofs, base plates and windows are taken from the work of Thiel and Riedel [9] and shown in Table 2.

Climate data for the Campus Garching are based on "Climate Design Data 2009 ASHRAE Handbook" with climate coordinates 48.13 Latitude; 11.70 longitude; +1.00 Time Zone Relative to GMT; 529.00 elevation These climate data were stored in the software “AX3000” and provide weather data for one year.

| Table 2. U-Value [W/m²K] and g-Value [-] of the Envelope |
|----------------------------------------------------------|
| **Roof** | **Base Plate** | **External Wall** | **Window** |
| BA1     | 2.1            | 1.0              | 1.4        | 4.3 | 0.78 |
| BA2     | 0.5            | 1.0              | 0.8        | 4.0 | 0.78 |
| BA3     | 0.25           | 0.5              | 0.45       | 1.6 | 0.6  |
3. Results
The following Section presents the results for identifying characteristic heat load profiles. The differences between the usage units within a building age class and the differences of the different building age classes within a usage unit are shown and interpreted.

3.1. Heat load profiles of identified building usage units
Table 3 shows the 10 usage units which were identified and utilized in the transient simulations. For this, the scaling method (as described in 2.1) is applied and the yearly load sums are depicted per m² for each usage unit and BA.

| Usage Unit            | BA1      | BA2      | BA3      |
|-----------------------|----------|----------|----------|
| Seminar               | 207.68   | 171.04   | 152.77   |
| Sanitary              | 168.66   | 140.05   | 123.60   |
| Storage, Plant Room   | 86.62    | 56.16    | 31.85    |
| Laboratory            | 347.65   | 279.76   | 289.55   |
| Kitchen               | 247.94   | 194.24   | 173.05   |
| Auditorium            | 275.21   | 254.31   | 239.88   |
| Office                | 103.50   | 61.91    | 43.69    |
| Workshop Shed         | 9.35     | 3.63     | 1.19     |
| Library               | 152.39   | 115.50   | 89.54    |
| Traffic Area          | 20.63    | 13.72    | 7.34     |

As one can see in Table 3, the characteristic energy demand differs greatly between the individual usage units as well as between the building age classes within a usage unit. This indicates that a redistribution of area between the individual usage units strongly affects the result of the building energy demand.

3.2. Differences between the identified usage units within a building age class
Figure 1 and Figure 2 show the absolute deviation of the heat demand load of the different usage units, which is derived from its yearly profile. The usage unit Office was chosen as reference.

![Figure 1](image1.png) ![Figure 2](image2.png)

**Figure 1.** Mean of differences and standard deviation of differences of usage units to office unit within BA1 over one year

**Figure 2.** Heat load differences of the individual units to office unit over one year within BA1
In Figure 1 it can be seen that the mean, the spread and the standard deviation of the heat load demand vary among the individual usage units. For this purpose each unit is set into relation to the usage unit Office. As can be seen, for example, the usage unit Auditorium has partly a higher and partly a lower heat load demand than the usage unit Office. The usage unit Traffic Area generally has a lower and the usage unit Laboratory has a higher heat load demand. In Figure 2 it can be seen that the differences of the individual heat load demands to the usage unit Office are not only very large but also vary greatly over the course of one year. This shows that not only the heat load demand varies greatly between the usage unit profiles but also their temporal relation to each other. So it can be seen that each usage unit has its own characteristic heat load profile.

3.3. Differences within building age classes

Figure 3 illustrates the relative deviation of the heat load demand of the Office usage unit for different building age classes. As can be seen, BA2 generally has a higher heat load demand than BA3. However, it becomes evident that the quantity of the deviation of the profiles has no constant linear offset and varies over the course of a year. This shows the individual reaction of the different structural-physical parameters to the equal conditions of climate and usage. So it can be seen that each building age class has its own heat load characteristic within one usage unit.

3.4. Super-positioned heat load profiles for the District

Figure 4 shows the superposed heat load profile for the Campus. In order to generate this heat load profile, heat load profiles of the individual use units are scaled and aggregated (as described in paragraph 2.1) according to the existing areas of the individual usage units and their distribution at the Campus. For the simulation of the individual usage units, a reduction of the room temperatures at the weekend is taken into account, according to the information of the operator of the local and district heating network at the Campus thus following closely to real heating operation. This becomes also evident in heat load profile in Figure 4. During weekend the heat load profile has very low values. Thus, the load peaks represent the reheating phase. The heating demand in the summer months probably can be

![Figure 3](image3.png)

**Figure 3.** Deviation [%] of heat load profiles between the building age classes of the usage unit Office over one year

![Figure 4](image4.png)

**Figure 4** Super positioned load profile for the Campus
ascribed to characteristic shortcomings in leakage and insulation characteristics of relatively old buildings already evoking heating at an ambient temperature of 17 °C or during intermittent colder periods in this region. This superposed heat load profile reflects the heat demand for space heating. Losses in the local and district heating network or heat demand for hot water are not included. In the next Section, this heat load profile will be compared to a measured heat load profile of the Campus.

The Section at hand shows that there are partly huge differences between the different usage units regarding yearly heat load profiles, BAs and different types of usage units. Finally a superposed yearly heat load profile is given for the aggregated Campus.

4. First validation

In this Section a first validation will be presented to test how well the method described in Section 2 leading to the results of Section 3 is working. In order to check how well the superposed heat load profile (Figure 4) copes reality, this heat load profile was compared with the real heat load behavior of the Campus. This real heat load behaviour was developed by the project partner ZAE Bayern which also is responsible for the analysis and simulation of the district heating network in this project, called “CleanTechCampus”. To assess for the real load behaviour of the whole district, accompanied with a former intention to expand the Campus, the ZAE took into account the heat demand of the absorption of cooling machines, grid losses and further demand of hot water. For this undertaking a climate adjustment has been applied. This so-called real heat load resulted in the orange, called "Measured", heat load profile shown in Figure 5. The blue curve shown in Figure 5 reflects the superposed, called “Simulated” heat load profile from Figure 4. As can be seen from the superposition of the two heat load profiles in Figure 5, the fundamental load behavior, particularly considering the seasonal cycle the spread and peak distributions, is very similar. Except of the exact matching of temporal highly frequent peaks, the two heat load profiles fit quite well. Particularly the aggregated heat load profiles (Figure 6) show an acceptable accuracy of the deducted results compared to the overall measured data.

![Figure 5. Super positioned heat load profile and measured head load profile of the heat generator at the Campus](image)

![Figure 6. Compared annual load duration curves](image)

Overall, the results from the first validation indicate that this method can be utilized to provide first guesses and future predictions of load behavior of a district by a bottom-up approach by utilizing an engineering model as it is discussed in paragraph 1.

5. Discussion

By applying a dynamical engineering model the results from Section 3 and Section 4 indicate that it is inevitable to identify and define different characteristic usage units, as they exhibit different heat load profiles, which are dependent on user behavior. Furthermore specific heat load profiles emerge from varying ages of buildings and the accompanied physical types of structure. With the knowledge of the
individual partitions of these usage units within a greater district a feasible scaling and aggregation of the accompanied heat load profiles can be conducted. It is shown, that this method leads to a comprehensive estimation of the total heat load profile of the whole district performing quite well in fitting an observed heat load profile. Regarding its facile utilization the underlying bottom-up approach offers a powerful tool for estimating future or real time heat load profiles of whole districts with respect of its individual partitions.

In a next step, for future buildings, a fourth building age class will be introduced, which takes into account the specifications of the draft law for the Building Energy Law “Gebäude Energien Gesetz” (GEG). This draft law intends that new buildings should have a close to zero energy balance. Particularly for this the underlying approach provides benefits.

For further specifications of this method, further investigations at the building level must be carried out. In particular, influencing factors such as storage mass, window area proportion, building geometry and user behavior must be analyzed separately and implemented in the heat load profiles of the individual usage units. Subsequently, the superposed heat load profiles on building level need to be validated by measured heat load profiles of singular buildings. Afterwards transient simulations have to be accomplished for usage units like class rooms, shop, residential use, etc. to expand the range of application of this method to any other district.

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