Individual Domestic Hot Water Profiles for Building Simulation at Urban Scale

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Abstract

Many urban simulation tools focus mainly on the calculation of space heating (SH) demand and not on the domestic hot water (DHW) demand. Instead, DHW is often assumed as an always constant value that does not change during the day or year. In this paper, the importance of differentiated, hourly domestic hot water profiles for residential buildings in urban energy demand simulations is shown. The comparison between the use of DHW profiles and the use of a constant value for the DHW demand shows a high underestimation of the DHW demand during the morning peaks on weekdays and in the afternoon on weekends, as well as a high overestimation of the demand during the night. There is also a notable difference between summer and winter days, which is not represented when using a constant value.

Introduction

In general, urban energy demand simulations focus on the energy requirements for space heating. For domestic hot water (DHW) mostly very simplified assumptions are taken, for example a constant specific demand depending on the building area or the number of people (Li, Quan, Augenbroe, Yang, & Brown., 2015; Agugiario, 2015) or even left out entirely (Reinhard & Cerezo Davila, 2016, Bahu, Koch, Kremers, & Mushed, 2013).

The energy demand for the preparation of DHW, however, usually has the second largest share of the total energy demand for buildings and is therefore a relevant factor in the simulation of building energy demand. Especially since the share of the energy demand for DHW of the total energy demand of a building rises due to the improved performance of newly constructed buildings and their reduced space heating (SH) demand (Frijns, Hofman, & Nederlof, 2013). In regions with low space heating demand due to their geographical location and climatic conditions, the demand for DHW in buildings even plays a dominating role (Eicker, Harter, & Weiler, 2017).

Various studies, for example Fuentes, Arce, & Salom (2017), Ahmed, Pylsy, & Kurnitski, (2016) and de Santiago, Rodriguez-Villalon, & Sicre (2017) as well as the tool DHWcalc, developed within the framework of the IEA Task 26 (Jordan & Vajen, 2005), identify hot water profiles, which show clear morning and evening peaks for the domestic hot water demand. Additionally, seasonal variations and differences between weekdays and

weekends are generally observed in studies concerning the measured DHW demands of residential buildings.

Methods

With the tool DHWcalc, different load profiles for single-family, multi-family and large multi-family buildings are created to represent the DHW demand. A DHW consumption of 160 l / d per household is assumed. This value represents the average daily hot water demand of a household in Germany according to the final report of Annex 42 of the International Energy Agency IEA (Beausoleil-Morrison, 2008).

Several studies found a significant deviation in temporal distribution as well as amount of DHW between weekdays and weekends (Ahmed, Pylsy, & Kurnitski, 2015; Agence de l'Environnement et de la Maitrise de l'Energie, 2016; George, Pearre, & Swan, 2015; Krippelova & Perackova, 2014; Masiello & Parker, 1992). Both effects can be explained by different usage patterns of occupants, e.g. a less pronounced peak in the morning hours because people get up later. In general, the amount of DHW used on the weekends is assumed with a ratio of 120% compared to the weekdays.

In DHWcalc, these observations can be represented by probabilities for certain tapping events in specific time spans of the day (see Figure 1).

Figure 1: Probabilities of events in time spans of the day for weekdays and weekends in DHWcalc

The different seasons and therefore the outside temperature are taken into account with a sine function. With the assumptions made by Jordan and Vajen (2005) and also presented by Fuentes, Arce and Salom (2017), a slight reduction of the DHW demand in summer times is taken into account.

The draw-off incidents are distributed over the year according to the cumulated frequency method in

DHWcalc, which takes into account that not all tapping points in their respective households generate a DHW demand at the same time.

Since the profiles are in litres, a conversion into kWh needs to be made to know the energy needed for the preparation of the amount of hot water from the DHWcalc output. This is calculated with the assumption of a temperature increase from drinking water inlet to outlet of $\Delta T = 30$ K. Assuming an inlet temperature of 15°C , the outlet temperature is 45°C .

As the total heating demand of a building consists of both the domestic hot water (DHW) demand and the space heating (SH) demand, the SH demand needs to be calculated. To analyse the influence of the different DHW demand representations on the total heating demand, they are added to the SH demand and then compared.

The SH demand of the buildings in this study is calculated using the urban energy simulation platform SimStadt (Eicker, Nouvel, Schulte, Schumacher, & Coors, 2012). SimStadt uses the building geometry of each individual building from the CityGML model and links it to different libraries to calculate the monthly heating energy demand according to the German norm DIN V 18599 (2016). The libraries are a building physics library and a usage library, that are based on several German norms and studies, like e.g. the building typology for Germany described in Loga, Stein, Diefenbach, & Born, (2015).

The calculated monthly values are then transferred into hourly values using the German standard VDI 4710 (2007). This method depends on the hourly outside temperature and the desired inside temperature. It takes into account the heating season (here from October up to April) and a night setback to 15°C from 0 to 6 am. The heating set point is set to 20°C .

Results

The created profiles are first applied to one multi-family building to see the difference to a constant value and the influence of using them. Then, the different profiles are used for a complete heating demand simulation of an urban district in Stuttgart, Germany.

One building

The building used for the comparison of the different calculation methods of the DHW demand is a multi-family, four-storey building with a footprint area of 214 m^2 . Based on this information, it can be assumed that the building has eight households with an average living area per household of 91.8 m^2 (Statistisches Bundesamt, n.d.) and an average of 2.49 people per household (GESIS, n.d.), which is the German average.

The comparison of the different calculation methods on building level (constant value and building type specific profile) for a multi-family building with eight households and 16 persons shows a significant difference in demand pattern during the day. With a constant value for the DHW demand for every hour of the year, the demand is highly underestimated during the peak consumption times in the morning on weekdays (deviation up to -537 %) and midday (-125 %) on weekdays (see Figure 2). The

difference in the weekends is not as significant due to less pronounced peaks compared to weekdays, but there are still periods of high deviation between the two methods, especially in the evenings the demand is highly underestimated (up to -253 %) with the constant value. For all days, the demand is very much overestimated during the night (up to 95 %).

Figure 2: Comparison of DHW demand with constant value and profile for a multi-family building

The next step is to compare the two methods for the energy demand calculation for both DHW and SH combined (see Figure 3) to see the influence of the different DHW profiles on the total heating demand.

Figure 3: Comparison of DHW and SH demand with constant value and profile for DHW for a multi-family building

In this comparison, the average daily SH demand over a year (purple line) is used. This comparison also shows a pronounced morning peak for the total heating demand with DHW profile for the weekdays (blue), and an increased total demand during the afternoon on weekends (green). The heating demand for SH and DHW with a constant value (red) follows the same slope as the average SH demand. To sum up, the course of the DHW profile is also visible in the total heating demand calculation in Figure 3, albeit less pronounced than the DHW profile alone in Figure 2.

Furthermore, daily total heating demand profiles, either with a constant DHW demand or a DHW demand with a profile, for different temperatures are compared. Profiles for different outside temperatures are compared. In Figure 4, two specific daily profiles for a winter day with an average outside temperature of -5°C and a summer day with an average outside temperature of 20°C are compared. The absolute deviations between the two

calculation methods are especially pronounced with cold temperatures, while the highest percentage deviations are found with the highest temperatures. This is due to the fact that there is no SH with an outside temperature of 20 °C.

Figure 4: Influence of outside temperature on total energy demand, average daily profiles with hourly values

Urban city quarter

For the application of the different DHW profiles to an urban area, a case study area in the City of Stuttgart in Southern Germany is chosen. In this stage, only residential buildings are considered, therefore 10 buildings from one building block are chosen and their respective DHW profiles applied.

The CityGML model of this city quarter as well as an aerial view from Google Earth can be seen in Figure 5. Only the residential buildings of this building block are chosen for analysis and therefore less buildings are represented in the CityGML model than in the aerial view. The 10 considered buildings are of different age and size, ranging from 1-20 households per building and a year of construction between 1953 and 2006 (see Table 1).

Each of the buildings is attributed with a DHW profile created with DHWcalc and converted into kWh according to their number of households. The SH demand is simulated with SimStadt and added to the DHW demand. The total heating demand (SH + DHW) is the same in both calculation methods, since the sum of the hourly DHW demand of the profiles is distributed evenly over the 8760

hours of the year for the constant method. Like this, the influence of the two different methods can be clearly evaluated.

Figure 5: Case study city quarter (above: own representation in the FZK viewer by the Institute for Automation and Applied Informatics, Karlsruhe Institute of Technology), CityGML model by the Stuttgart City Surveying Office and State Agency for Spatial Information and Rural Development Baden-Württemberg; right: aerial view in Google Earth)

Table 1: Specification of case study buildings and simulation results

Households	Year of construction	Footprint area [m ²]	Heated area [m ²]	Total SH demand [kWh]	Total DHW demand [kWh]	Ratio of SH and DHW	Total heating demand (SH + DHW) [kWh]
1	2006	71	101	10,945	2,031	5:1	12,976
3	2006	79	312	13,868	6,094	2:1	19,962
4	1953	172	390	63,585	8,124	8:1	71,710
4	1955	92	393	56,347	8,124	7:1	64,472
7	2006	210	629	29,531	14,218	2:1	43,749
8	1965	161	748	96,339	16,248	6:1	112,587
11	1955	193	992	116,809	22,343	5:1	139,152
12	1977	217	1143	115,829	24,374	5:1	140,203
13	2006	346	1195	43,896	26,405	2:1	70,301
20	2006	396	1845	125,726	40,623	3:1	166,349

Table 1 also shows that the share of the DHW demand rises with newer buildings. The buildings of the case study that were built in 2006 have a much smaller ratio of SH to DHW than the older buildings. This shows the growing importance for detailed DHW modelling.

SH plus constant DHW demand

Table 1 compares the aforementioned two methods of calculating the total energy demand (SH demand plus DHW demand based on individual profiles and SH demand plus DHW demand with a constant value). SH plus DHW demand from constant values

The peak load in this calculation method reaches 406 kWh, then the curve declines, however the load is never zero, because of the always constant demand for DHW of 19 kWh. In the winter months, the curve of the total hourly heating demand follows the same slope as the SH

demand, just with the addition of the constant DHW demand in every hour. Figure 7 shows this in greater detail.

In the summer months, only the flat line of the constant DHW demand is visible.

SH plus DHW demand from profiles

The peak demand with 612 kW is considerably higher in this calculation method with the use of DHW profiles compared to the method with a constant DHW demand. The sorted annual load curve declines and reaches zero after 8279 hours, which means that there are 481 hours in the year that have no heating demand at all.

Each daily peak on weekdays (usually between 6 and 8 AM) is clearly visible even on a yearly scale, especially in the summer months when there is no SH demand.

Figure 6: Comparison of annual total heating demand and heating load with different calculation methods, hourly values

Figure 7: Comparison of total heating demand with different calculation methods for one week, hourly values

Conclusion and outlook

The difference of the results from the two different calculation methods for an hourly time resolution is clearly visible on a daily, weekly and annual basis, both on an individual building level and on a district level. A considerable difference of the hourly heating demand, depending on which calculation method is used for the DHW demand can be noticed (up to 537 % deviation for peak consumption hours in the morning between the constant method and application of profiles). The annual energy values remain the same.

The DHW load profiles for different residential building types depending on the number of households in the building are of practical importance for detailed urban energy planning, especially for assessing peak hot water consumption periods. If the energy generation system in a building has to provide both SH and DHW, the installed power of the energy generation and storage system should

be chosen according to the combined peak of SH and DHW demand.

Renewable energy generation is important for urban energy simulation, since the global goals to decrease greenhouse gas emissions need to be met. In order to provide renewable energy for the DHW generation, the possibility of using PV electricity is promising. Since DHW is needed almost only during the day, the simultaneity of PV electricity generation and DHW demand is given. With a sensible combination of PV and hot water storage size, this could be a way to increase the own-consumption of PV electricity and provide CO₂-neutral DHW.

For the use of these profiles in simulations for large urban areas with several hundred or more buildings at the same time, the profile generation for each building needs to be done automatically. Therefore, the number of households depending on building type and building size needs to be determined from the CityGML file used for energy simulation first. Then DHWcalc can create a DHW profile for each building fitting these parameters. The profiles should be different for each individual building to represent the difference in use patterns for each building. This avoids unreasonable peaks at the exact same time if the same profiles were used and leads to a representation of each building with a different load curve for each day.

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