Analysis of DHW energy use profiles for energy simulations in a hotel located in Norway

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Domestic hot water (DHW) system is significant energy consumer in hotels. For this reason, energy modeling and simulations in hotels should provide an accurate and representative assessment of the energy performance of domestic hot water systems. The majority of dynamic simulation tools use DHW energy use profiles as the basic for estimating DHW energy needs. In this article, energy simulations in EnergyPlus software for a large hotel were carried out. All inputs in the EnergyPlus simulation model were adjusted according to Norwegian national regulations. Application of different DHW energy use profiles in the simulation model was explored. The profiles given in the national and international standards were compared with profiles obtained from measurements in the hotel located in Oslo, Norway. Simulations in EnergyPlus showed that application of profiles from measured data have higher accuracy then simulations based on standards. The results of the study may give indication for sizing and planning of DHW systems.

Domestic hot water (DHW) systems make a substantial contribution to the energy balance in hotels in Norway [1]. They are responsible for approximately 20–35% of the total energy use in these buildings [2]. Michopoulos, Ziogou [3] estimate that CO_2 emissions for hot-water use in the hotels remains quite high, 2.87–3.2 kg-CO_2/(person·night). Hot water usage is the second largest energy consumer in hotels after heating [4]. Recent studies emphasise that a large potential for increasing energy efficiency in buildings can be achieved by improving operation and design of DHW systems [4]. One of the aims of the simulation approach of DHW system performance is to estimate and predict the DHW volume and the energy use for hot water production in existing building, or in building at the design phase. This information is essential for sizing and optimising of DHW system and its components [5].

The DHW profiles are the basis for simulation of DHW systems performance in buildings, as well as useful instrument for understanding the process of DHW energy use in the buildings [6]. The profiles of DHW energy use show how the energy for DHW is used most of the time.

Building simulation tools may require diverse input data for DHW energy use simulation. In many simulation tools, average yearly DHW energy use profiles per m² of building area are applied as input for modelling. Other tools require three types of input data: average DHW use in l/(person·day), occupant number, and DHW usage profile. In addition, the default values for DHW supply temperature and cold-water temperature are considered for energy estimation. The so-called bottom-up approach requires a detailed information of occupant presence, profiles of occupant activities, available domestic appliance, corresponding technical details, etc. [7]. The methods based on detailed information about DHW use activities and DHW system, usually require extensive input data, which increases the complexity of obtaining this information and process of energy use estimation.

A comparative analysis of five different software calculation tools based on technical standards for predicting monthly and daily DHW consumption profiles in residential buildings are investigated in [5]. The deviation in results from measured data are −30% to +40%. Better estimations are obtained with methods based on standards specific to the country where measurements were done.

A better understanding of DHW energy use profiles and their application in simulation tools is a crucial factor in achieving energy savings in hotel buildings. Therefore, in this article DHW profiles based on measured energy use in the hotel in Oslo, Norway, were developed. The data comprises five years of hourly measurements of energy use for DHW. The obtained profiles, as well as profiles from national and international standards for heat demand calculation, were applied in simulation model of a representative hotel. The model was developed in EnergyPlus [8]. The possible benefits from using more accurate energy profiles were explained.

Methods

For modelling of the hotel, EnergyPlus model from the Department of Energy (DOE) Large Hotel model [9] was used. The model was adjusted according to Norwegian regulations and requirements.

For the analysis of DHW energy use in the hotel, it was considered few different scenarios:

1) DHW energy use was derived from profiles obtained based on measurements in the real hotel, located in Oslo.
2) DHW energy use was derived from profiles in ISO 18523-1 [10].
3) DHW energy use were derived profiles obtained from the technical specification SN/TS 3031:2016 [11].

The results of simulations based on different DHW energy use profiles were compered.

Description of the real hotel building

The parameters of the hotel are typical for Norway. The hotel reflects well the trends of DHW energy use in similar types of buildings. The building was renovated in 2007. The area of the hotel is 4 939 m². The building has eight floors with 164 guest rooms. All the guest rooms have bathrooms with toilet facilities and shower. According to the hotel management, employees use hot water for cleaning, and guests use hot water for personal hygiene.

In the DHW system, the hot water is circulated all the time to ensure fast delivery at each tap all the time. The hotel uses electric water heaters for DHW preparation. Data on energy use for DHW were collected during several years from an energy meter installed by the hotel owner. The meters measure electricity delivered to the DHW tanks. This means that both DHW needs and heat losses in the DHW system were included in the presented DHW energy use.

Description of the simulation model

It is supposed that a reference building simulation model represents the average building stock in a Norwegian geographical area in terms of building characteristics and functionality [8]. The model for the reference hotel was selected from the U.S. DOE database. The building in EnergyPlus present 7 floors: 6 floors above the ground level and 1 basement, see **Figure 1**. The total building area is 11 348 m². Based on the geometry and shape of the real hotel in Oslo, it was estimated that the model in **Figure 1** would fit well for the analysis. The weather data for Oslo, Norway, were used as input in this study.

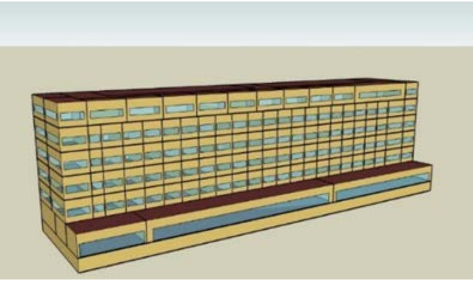

Figure 1. Reference hotel.

The modifications were done to conform the model to Norwegian national limits on building thermal properties, indoor comfort, and annual energy use. To initialise, the building parameters and schedules for human occupancy were used from the following national and international standards: ISO 18532-1, EN 15232, and NS 3031:2007 [10-12].

Results

DHW energy use profile based on measurements

Statistical data of energy use in the hotel show that DHW tap systems have significant impact on energy use in buildings. More specifically, in the observed hotel, DHW energy use constituted more than 20% of total energy use.

Since the simulation model and actual hotel have different area, energy use profiles from measurements were calculated per m² of building area. As discussed above, both DHW needs and self-use in the DHW system were included in the presented measurements. Self-use includes water leakages in the pipes, circulation losses, energy use for maintaining the required temperature of DHW in the system and other consumer-independent losses in the system. Due to these losses, a DHW system is constantly using a certain amount of heat, even if there are no visitors in a hotel. Reducing self-use is an essential task in achieving efficient energy use in the buildings. Statistical data for the hotel showed that information about self-use could be obtained based on profiles of the DHW energy use in public holidays. From **Figure 2**, we can see that hourly average and variation of DHW energy use during the holidays is very small. This phenomenon could be explained by the fact that on holidays, the hotel was closed for visitors. Consequently, the DHW energy use in the hotel in these days mostly caused by self-use in the system.

Accordingly, it was proposed to consider the average profiles of DHW energy use during the public holidays as a way to assess self-use in DHW system of the hotel. Average profiles of energy use on holidays evaluate the share of energy use for self-use of DHW system. The identified percentage of the energy use for self-use in the hotel constituted 39.15% of the average DHW annual energy use.

Comparison of DHW energy use in the standards and measurement data in the real hotel

"ISO 18523-1:2016: Energy performance of buildings" provides reference domestic hot water usage for different types of rooms. Based on ISO 18523 and EnergyPlus model, DHW energy use profiles for the typical hotel were obtained. "SN/TS 3031:2016: Energy performance of buildings. Calculation of energy needs and energy supply" is a national standard in Norway. Calculation of energy needs and energy supply gives recommendation on DHW profiles that should be used as input for energy demand calculation [11].

In this study, the profiles of the actual DHW energy use in the real hotel, see **Figure 2**, and the profile for the same type of building based on the standards ISO 18523, see **Figure 3**, and SN/TS 3031, see **Figure 4**, were compared. The analysis indicates the big difference between these tree types of profiles.

Compered to profiles in real hotel, **Figure 2**, the profile based on ISO 18523, see **Figure 3**, significantly overestimates the DHW energy use in the hotel. ISO 18523 shows morning and evening peaks of the DHW energy use, which occur from 6 a.m. to 10 a.m. and from 6 p.m. to 11 p.m. The peak energy use modelled based on ISO 18523 are about three times higher than those measured in the real hotel. Besides, evening peak of DHW energy use in a real hotel is not expressed as obvious as in the ISO 18523.

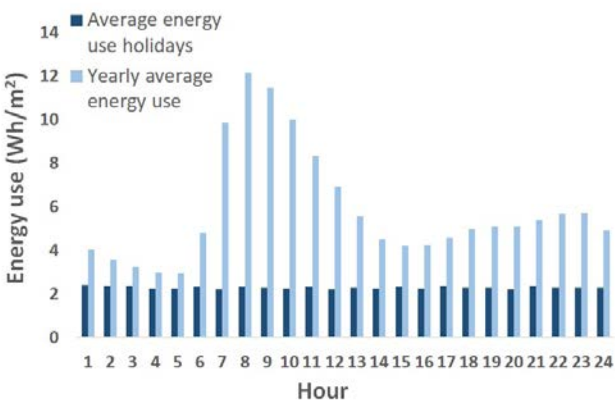

Figure 2. Profiles of hourly DHW energy use on holidays and all days in the year in the hotel.

As shown in **Figure 4**, the DHW energy use from 1 a.m. to 5 a.m. in the standard SN/TS 3031 is equal to zero. This fact means that the standard does not take in account the so-called self-use of the system. On the contrary, the actual data obtained with the help of energy meters usually contain both the system's self-use and DHW energy use by visitors. It should be noticed, that self-use of the system is responsible for the significant share of energy use in DHW tap systems (up to 40% during the year) and therefore cannot be neglected.

From the standard SN/TS 3031 profile (see **Figure 4**), we can assume that morning peak of energy use occurs from 7 a.m. to 8 p.m., and evening peak from 6 p.m. to 7 p.m. The maximum heat demand during the day is approximately 8 W/m². Meantime, from the profiles of energy use obtained from the statistical data, it was possible to notice that morning peak usually occurs from 7 a.m. to 11 a.m., and a small increase in energy use can be observed from 10 p.m. to 11 p.m. The maximum energy use during the day was approximately 12 W/m². The difference in the values of maximum energy use in considered profiles was 6 W/m², which was 30% of the total DHW use. This difference could be explained by self-use of DHW system that the standard SN/TS 3031 does not take into account. However, it could be noticed from **Figure 4**, the timing of actual peaks of energy use also does not match the information presented in the standards.

Monthly and annual DHW energy use

The simulation results from EnergyPlus with different DHW profiles as inputs were compared with the actual energy use in the hotel. Monthly energy use is given in **Figure 5** and annual energy use is given in **Figure 6**. The simulation results for the DHW energy use revealed the drawbacks of the considered standards.

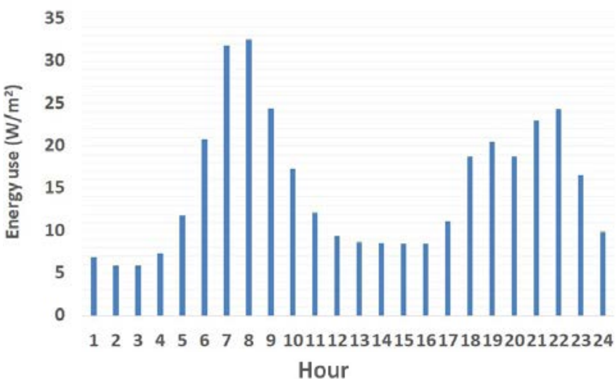

Figure 3. Hourly profile of DHW energy use of the hotel obtained based on "ISO 18523-1:2016: Energy performance of buildings".

For example, the difference between the annual DHW energy use simulated by profiles obtained from the measurements and the real total DHW energy use was approximately 10%. Meantime, the national standard, SN/TS 3031:2016, underestimated annual DHW energy use for 32% and ISO 18523-1:2016 overestimated for 2.3 times.

Simulation results indicated that the DHW energy use was responsible for significant share of the total energy use of the hotel see **Figure 7**.

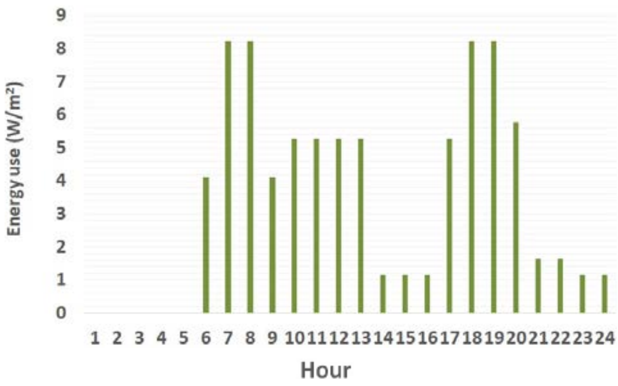

Figure 4. Hourly profile of DHW energy use according to the standard "SN/TS 3031:2016: Energy performance of buildings. Calculation of energy needs and energy supply".

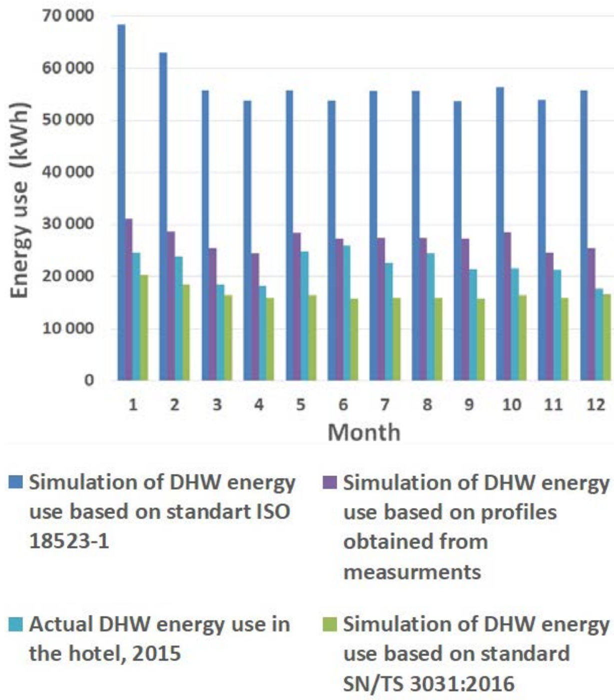

Figure 5. Simulated and actual monthly DHW energy use in the hotel.

Comparison with the DHW energy use in the real hotel revealed that simulations based on profiles obtained by measurements gave better explanation of the DHW energy use than the standards. The standard ISO 18523-1:2016 significantly overestimated the DHW energy use in the hotel in Norway. Meantime, for annual and monthly simulations of the DHW energy use, the technical specification SN/TS 3031:2016 demonstrated quite reasonable result. However, in addition to using the technical specification SN/TS 3031:2016, the assumption about self-use in DHW system should be included in calculations. Making this assumption for a real building can be problematic.

The factors that introduce uncertainty to simulations are number and types of DHW use facilities in the hotels. The presence of a restaurant, swimming pool, sauna, and gym increase DHW energy use at the hotel. The profiles given in the standards are usually too simplified. These profiles were created for certain categories of buildings such as hotel, offices, school, etc. However, even within one type of buildings, DHW energy use can behave differently. For example, studies showed that specific DHW use in large and luxury hotels is much higher than in a regular one [4]. Therefore, there is a need to develop more aggregated profiles, which will take into account the main factors that influence DHW energy use. It should be emphasized that these profiles should be based on accurate and up-date statistical data from real buildings and reliable methods of processing available information.

Conclusion

DHW systems play essential role in achieving efficient energy use in buildings. For this reason, evaluation of DHW energy during simulations should be representative and corresponds to real energy use in buildings. The DHW profiles are the basis for simulation of DHW systems performance. Moreover, analysis of DHW energy use profiles is a powerful instrument for gaining knowledge about DHW system operation.

In this article, the EnergyPlus model from the DOE Large Hotel model was adjusted according to Norwegian regulations and requirements. For analysis of the DHW energy use in the hotel, it was considered few different scenarios with various profiles used as input. Profiles obtained based on measured DHW energy use in the real hotel, profiles derived from international standard ISO 18523-1, and the national standard SN/TS 3031:2016 were used in this study. The comparison of the standards revealed the significant difference between hourly DHW energy use obtained by measurement and standards. Besides, the timing of actual peaks of energy use does not match the information presented in the standards. Implementation of the EnergyPlus model indicated that simulations based on profiles obtained by measurements gave better explanation of the DHW energy use than using the standards. Simulations based on ISO 18523-1:2016 overestimated the annual DHW energy use approximately two time and peak energy use three times. Meantime, the national standard SN/TS 3031:2016 showed better result. However, the standard SN/TS 3031:2016 does

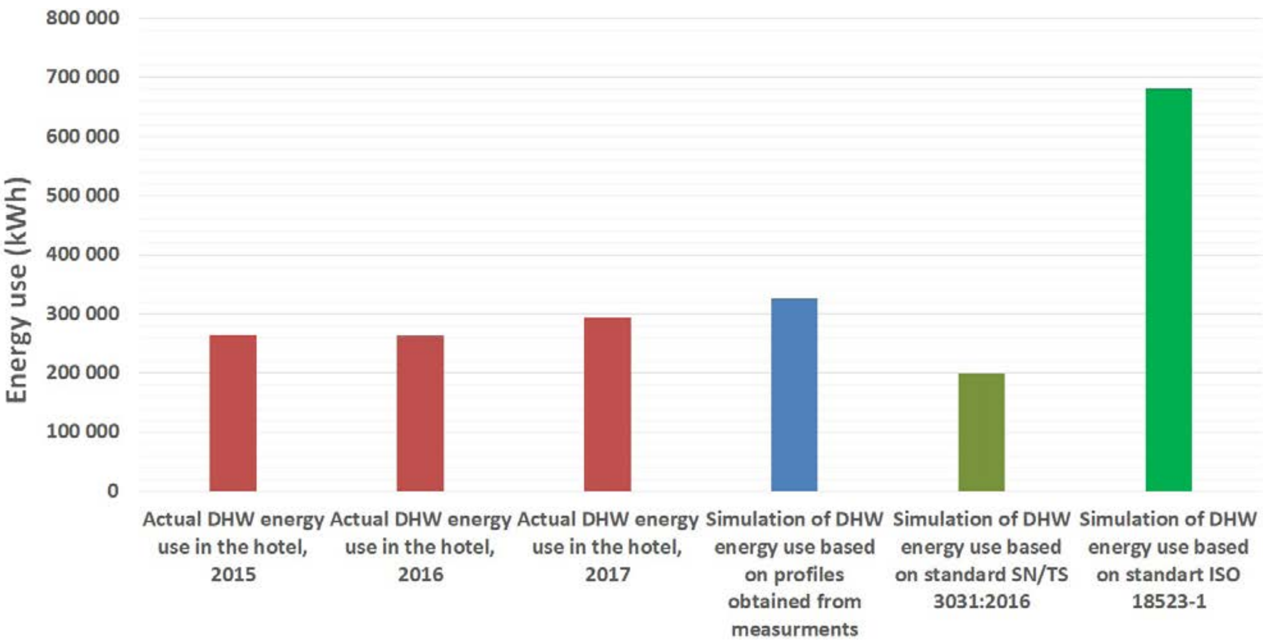

Figure 6. Simulated and real yearly DHW energy use in the hotel.

not take in account self-use of DHW system. Therefore, information given in this standard should be supplemented by estimation of self-use of DHW system in the building. At the same time, profiles which are based on actual measurements, allowed us to obtain the most reliable results. The difference between yearly DHW energy use simulated by profiles obtained from measurements was approximately 10%. ■

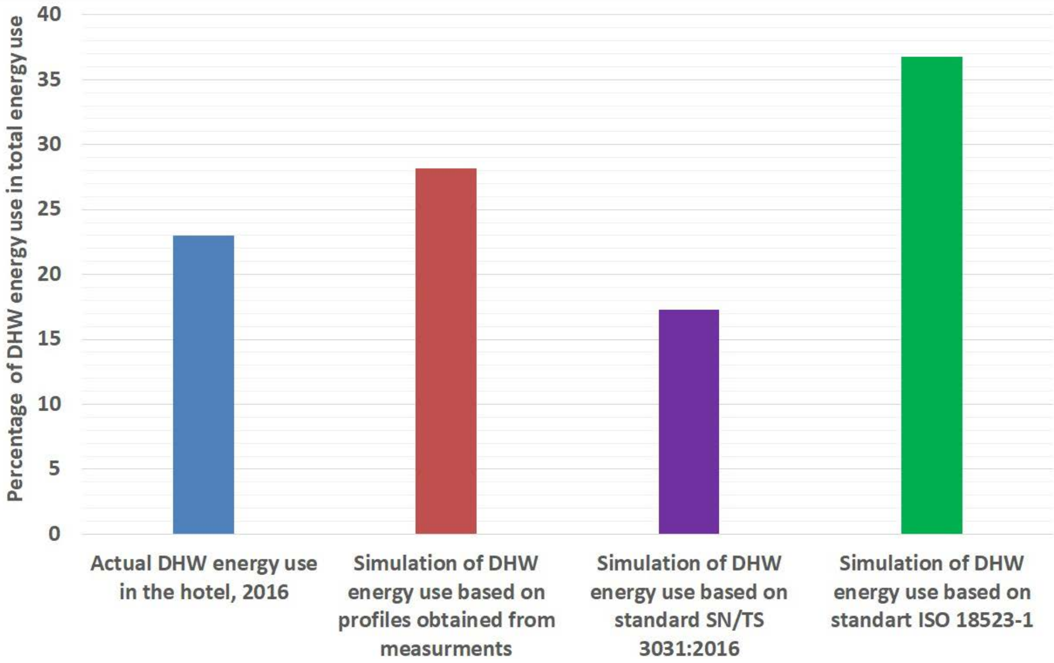

Figure 7. Percentage of DHW energy use in total energy use of the hotel.

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