

Analysis of monthly and daily profiles of DHW use in apartment blocks in Norway

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Abstract. Profiles of domestic hot water (DHW) use give valuable information for achieving energy saving in buildings. In this article, analysis of monthly and hourly profiles in apartment blocks in Norway was performed. The aim was firstly to identify influencing factors on DHW use and afterwards to define typical DHW use profiles. Due to availability, two different data samples were used for monthly and hourly analysis. Monthly data from 49 apartments showed that approximately 30% of DHW was used in kitchens and the rest 70% in bathrooms. The influence of apartment sizes on DHW use was tested based on monthly profiles. Monthly profiles for three categories of apartments with 33 m², 51-52 m², and 68-72 m² floor area were developed. Cluster analysis allowed us to identify profiles for three groups of apartments with a typical number of residents. In addition, for comparison purpose, DHW hourly profiles in two social housings and two housing cooperatives were investigated. These profiles indicated that there was a difference in when DHW was used in these two types of buildings, with a higher daytime DHW use in social housing. Finally, the measured DHW heat use profiles are compared with the profile in the national standard.

1 Introduction

Nowadays, domestic hot water (DHW) systems are an essential part of residential buildings. They ensure a high level of hygiene and living conditions. DHW systems contribute to approximately 20% of the total energy use in buildings [1]. The projections of energy demand for residential buildings shows that DHW heat use tends to increase in the nearest future [2].

Primarily, the share of DHW energy use in Norway is growing due to the introduction of passive house solutions and technologies. Currently, these solutions reduce the energy need for heating. However, they do not affect DHW heat use. In this regard, DHW systems still have great potential for energy savings. Therefore, improving the operation and design of DHW systems is a topical issue for attaining more efficient and sustainable energy use in buildings.

Profiles of DHW and heat use are effective instruments for analysis and improvement of DHW systems performance. Monthly and hourly profiles are commonly used for design, modelling, simulations and management of DHW systems.

Many authors emphasise the importance of using accurate and reliable profiles for various purposes [1]. Application of proper DHW energy use profiles is an essential condition for accurate prediction of energy demand in buildings. The investigation [3] shows that application of profiles obtained from standards is not sufficient for accurate DHW heat use modelling in buildings.

The research toward the development of representative DHW use profiles is conducted in many countries.

The influence of DHW profiles on simulations for DHW and space heating solar combi-system in residential building is investigated in [4]. The simulations show potential for energy savings in the DHW system by applying more realistic DHW use profiles.

Profiles suitable for analysis of solar DHW systems in Canada is presented in [5]. To take variation in user's behaviour into account, the authors propose to use profiles divided by apartments with predominantly morning use, predominantly evening use, and use dispersed throughout the day. The simulations reveal that various DHW use profiles could lead to significant differences in the prediction of DHW system operation.

In Sweden, DHW use in 1,300 apartments within six years is measured [6]. These measurements are used as input for simulations. The simulations demonstrate the influence of the apartment's sizes and locations on the heat use. In addition, the authors found a strong correlation between the number of residents and DHW use. However, even within apartments with the same number of residents, a significant variation of DHW use is observed.

Analyses of one-year DHW measurements from 86 apartments with 191 occupants in Finland is performed in [7]. Representative DHW profiles for resident groups with 1, 3, 10, 31 and 50 occupants are developed. The authors

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assume that the actual profiles closest to the mean profile for each group and with similar shape are representative.

Weekdays and weekends load profiles for DHW heat use in Norwegian buildings, which use a heat supply from district heating, is investigated in [8]. For calculations, the authors use hourly measurements obtained by regular heat meters. The analysis of the profiles indicates that the DHW system efficiency should be improved through better pipe insulation.

In residential buildings, DHW is mainly used for showering and hygienic purposes, cooking, cleaning, dishwashing and laundry. Therefore, most of the existing publications report two main peaks of DHW use that occur in the morning and evening. These peaks indicate the typical time of food preparation and showering practices [9].

A number of articles propose to develop DHW profiles for apartments based on occupant activities and operating schedules for appliances (showers, baths, sinks, dishwashers etc.). Occupancy related parameters significantly affect the final energy demand in residential buildings. With the increase in the number of occupants, the relative share of DHW heat use in the total energy use for the apartment is also increasing. Mostly due to the increased DHW use, the number of occupants have a substantial impact on the heat used in residential buildings [3]. The DHW use is modelled by considering the probabilistic use of appliances in apartments in [10]. A DHW modelling approach that is coupling information about behavioural activities, energy balance models and stochastic modelling is presented in [11]. An Artificial Neural Network model for DHW energy use analysis is proposed in [12]. In this model, the occupant behaviour, appliance ownership, demographic conditions and occupancy rate are the main inputs.

Development of representative DHW profiles should be based on information gained from up-to-date data of DHW use in existing buildings. Due to the challenges in collecting and accessing statistical data about hot water and heat used in apartment blocks, the DHW use in these types of buildings in Norway is not fully investigated yet. Meanwhile, factors influencing DHW use (i.e. technical solutions, traditions, behaviour, weather condition etc.) are varying from country to country. For this reason, the profiles developed for other counties cannot be directly applied in Norway.

Investigation of both hourly and monthly data gives a deeper understanding of the process of DHW use in apartments. Traditionally, utility bills for heat and water use in residential buildings are paid monthly. Due to this fact, monthly data about DHW use could be accessed up to the apartment level. A study of monthly profiles for different apartments provides useful information on the structure of DHW use in buildings, seasonal variations, expected volumes of hot water use, and variables that have influence on DHW use. At the same time, hourly profiles are very important for system design, energy management and peak shaving. Therefore, this article aims to present an analysis of both monthly and hourly DHW use profiles in different types of apartments in Norway. For this purpose, two data samples were examined. Due to data availability, these data samples

were obtained from different sources, however for similar apartment buildings.

First data sample contained data of monthly DHW use in 49 apartments in Norway. The available data had separate information about DHW use in both kitchens and bathrooms. This data sample was used for: identifying the share of DHW use in kitchens and bathrooms, investigating the seasonal variation of DHW use, analysing the influence of apartment's sizes on DHW use and developing monthly profiles of DHW use, taking the typical number of residents in apartments into account.

The second data sample contains 2-second DHW and heat use measurements in four apartment blocks. Two of these buildings belong to social housing and the other two to a housing cooperative with privately owned apartments. The measured data was applied to develop hourly profiles of DHW use for social housing and housing cooperative. Besides, the DHW heat use profiles for these types of buildings were further compared with the national standard. The main differences in these profiles were specified.

2 Description of apartment buildings

Data in 49 apartments that were used for the monthly analysis of DHW use were obtained from a company that specialised on measurements and billing of energy use in buildings in Norway. The considered apartments have the following sizes: 16 apart. - 33 m², 5 apart. - 51 m², 20 apart. - 52 m², 4 apart. - 68 m², 4 apart. - 73 m². For each of them, one-year data with DHW use in kitchens and bathrooms were collected in 2016-2017. The data were in liters of tapped hot water.

In addition, within the research project "Energy for domestic hot water in the Norwegian low emission society" 2-second measurements were performed in four apartment blocks. Table 2 shows the main properties of the observed buildings. Apartment blocks AB1 and AB2 are both social housing, while AB3 is part of a large housing cooperative with several blocks. AB4 consists of 4 smaller blocks. The average apartment size in AB1 and AB2 is significantly smaller than in AB3 and AB4. For all the buildings, the measurements were performed at the heating plant, giving the aggregated heat use of each block. Fig. 1 shows a principle drawing of the heating plant and measurements. In Fig. 1, the symbols for the temperature and water flow show the measurement places. In our analysis, heat losses from the circulation system were removed from the use data.

Table 1. Main properties of measured apartment blocks

ID	Area (m ²)	Number of flats	Heat source	Period of data collection
AB1	4400	96	Electric water heaters and heat pump	Oct. - Nov. 2018
AB2	2700	56	Electric water heaters	Oct. - Nov. 2018
AB3	3752	56	Electric water heaters and heat pump	Jan. – Mar. 2019
AB4	5100	86	Electric water heaters and heat pump	Mar.-Aug. 2019

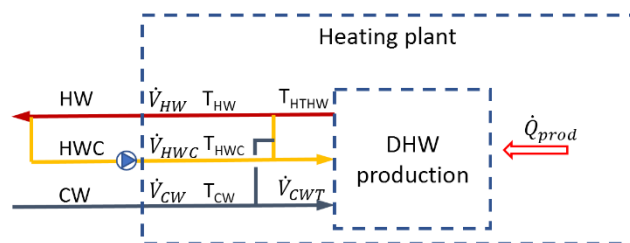


Fig. 1. Principle drawing of DHW heating plants with typical measuring points

3 Method

In this article, the analysis was primarily based on an investigation of monthly and hourly DHW use in apartment blocks. The entire approach in this study consisted of two parts: 1) identifying influencing factors of the total DHW use in apartments and analysis of monthly DHW use profiles 2) defining hourly profiles of the DHW use. Due to the availability of data and measurements, a different group of apartments were used for each of the above-mentioned analysis parts.

To identify influencing factors of the total DHW use in apartments, the DHW use data in 49 apartments were used to calculate the share of DHW used in bathrooms and kitchens for each month. In order to examine the influence of apartment size on DHW use, the monthly profiles for specific DHW use in three types of apartments with 33 m², 51-52 m², and 68-72 m² living areas were developed. Even though the sizes of apartments give essential information about DHW use, they do not take into account the number of people who lives there. In order to cover this drawback, hierarchical cluster analysis based on the K-means method was applied. By using this method, the groups of apartments with similar monthly DHW use were found. The applied clustering method is well known and presented in detail in [13]. The clustering was performed in Scikit-learn machine learning library for the Python programming language [14]. The number of residents in each obtained cluster was estimated based on the reference DHW use in apartment blocks per person in European standard “NS-EN 12831-3:2017: Energy performance of buildings” [15] and recommendations in [16]. In such a way, apartments with three different levels of occupancy were identified. Further, seasonal variations of DHW use were studied, taking into account apartment sizes and estimated number of people.

To define hourly profiles of the DHW use, the 2-second measurements in four apartment blocks were used. These apartments are used by social housing and housing cooperatives. The variation of DHW in different days of the week was studied through weekly profiles. Finally, the heat used for DHW in these building was compared with the Norwegian standard, “SN/TS 3031:2016: Energy performance of buildings. Calculation of energy needs and energy supply” [17], and the main differences were specified.

4 Results and discussion

This section is divided into two subsections. Section 4.1 investigates monthly DHW use in apartments of different sizes. Section 4.2 is dedicated to the analysis of hourly DHW use in social housing and housing cooperative.

4.1. Analysis of monthly DHW use in apartments

The average daily specific DHW use for different months for 49 apartments in Norway is shown in Fig. 2. The results were divided in DHW use in kitchens and bathrooms. The data showed that approximately 70% of hot water in these apartments was consumed in the bathrooms and 30% in the kitchens.

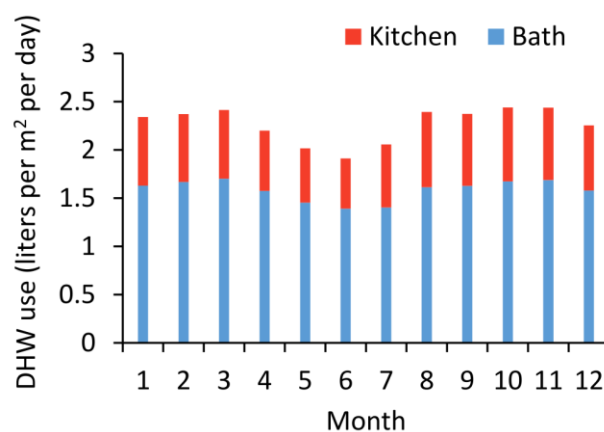


Fig. 2. Average monthly DHW use in 49 apartments

Monthly profiles in Fig. 2 display some seasonal variation of DHW use, with lower consumption from April to July, and higher in the remaining months. The decrease in DHW use in the spring/summer months may be related to the vacation time in Norway. Traditionally, the majority of Norwegian workers prefer to have vacations in July. In addition, April, May and June contain several holidays.

A more detailed investigation of monthly DHW use in the apartments showed that in some individual apartments, the DHW use decreased during the period of vacations, see June and July, while in others it increased, see Fig. 3. The two apartments in Fig. 3 with similar sizes were considered. The DHW use in Apartment 2 was higher than in Apartment 1, which can be explained by the different number of people living there.

This research indicated that a certain group of the apartment users left their apartments and travel during the holidays. Thus, these users reduced the DHW use in buildings, see Fig. 3, Apartment 1. Opposite, some people were at home during vacation time, which has the opposite effect on DHW use, see Fig. 3, Apartment 2). For this reason, the DHW use in summer months in the residential buildings in Norway were relatively uncertain and depended on how people intended to spend their vacations.

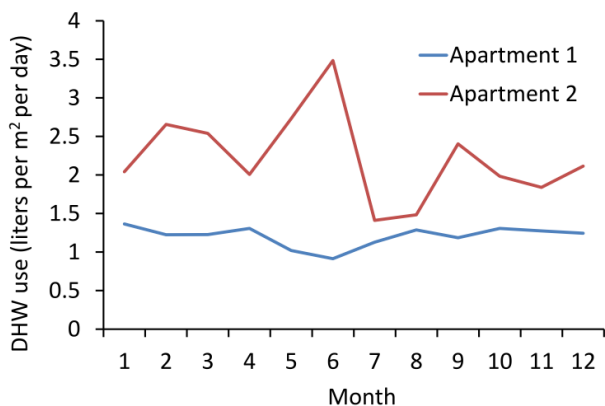


Fig. 3. Comparison of monthly DHW use of two apartments with 52 m² floor area

In order to estimate the influence of apartment sizes on the DHW use, the box plots [13] of average DHW use for apartments with 33 m² (Fig. 4), 51-52 m² (Fig. 5), and 68-72 m² (Fig. 6) floor areas were developed. Box plot is widely used method in descriptive statistics. It shows in a compact form, the median, first quartile and third quartiles, minimum and maximum, and outliers.

Apartments with 33 m² area show the highest average DHW use equal to 2.76 liters per m² per day, while the average in the 51-52 m² apartments is 1.78 liters per m², and the average in the 68-73 m² apartments is 2.5 liters per m², see Fig. 7.

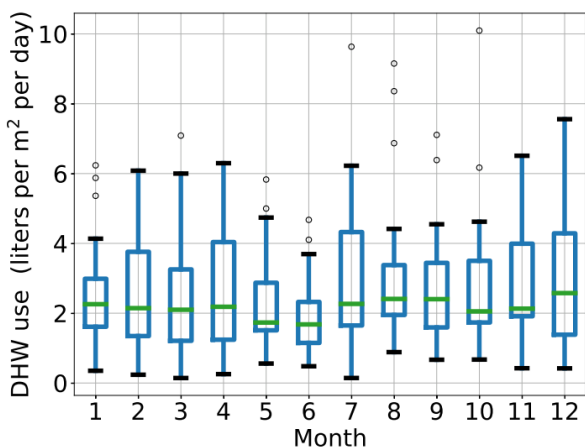


Fig. 4. Box plot of monthly DHW use in 33 m² apartment

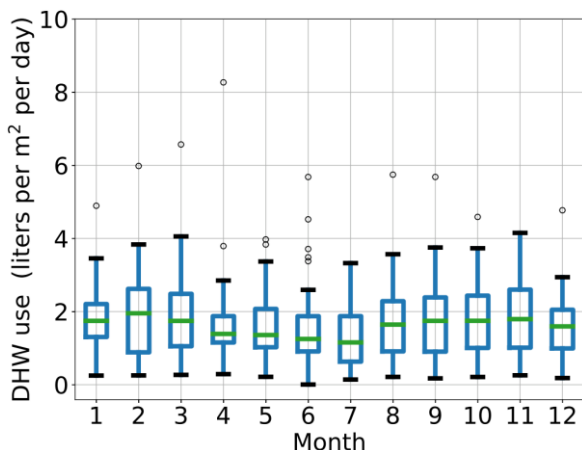


Fig. 5. Box plot of monthly DHW use in 51-52 m² apartments

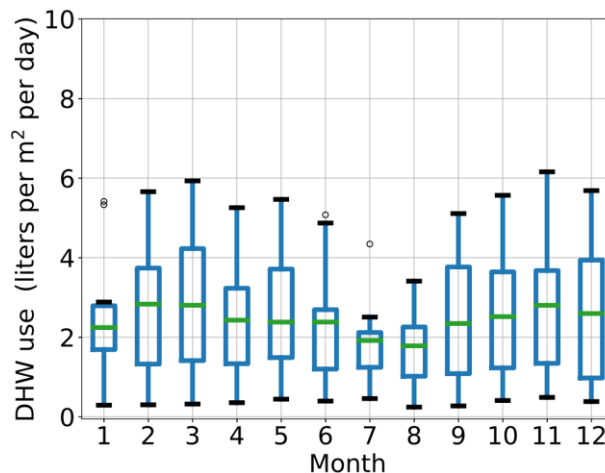


Fig. 6. Box plot of monthly DHW use in 68-73 m² apartments

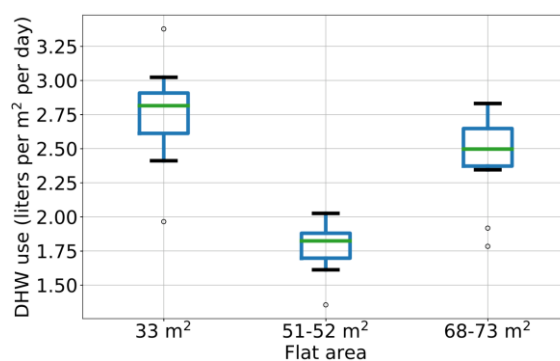


Fig. 7. Box plot of average monthly DHW use for different apartment sizes

The number of inhabitants was the main factor affecting the DHW use in apartments. However, information about this parameter was usually not disclosed. Therefore, it was proposed to find groups of apartments that have similar levels of DHW use based on cluster analysis. The assumption was that each of these clusters should represent DHW use in a group of apartments with a similar amount of people.

The clustering method showed three main clusters of the DHW use, see Fig. 8. Cluster 1 and Cluster 2 mainly contained apartments with 33 m² and 51-52 m², see Fig. 9. Fig. 9 shows that Cluster 3 included all types of apartments. Average DHW use in apartments within Cluster 1 was equal to 31 liters per day, while Cluster 2 – 76 liters per day and Cluster 3 – 167 liters per day.

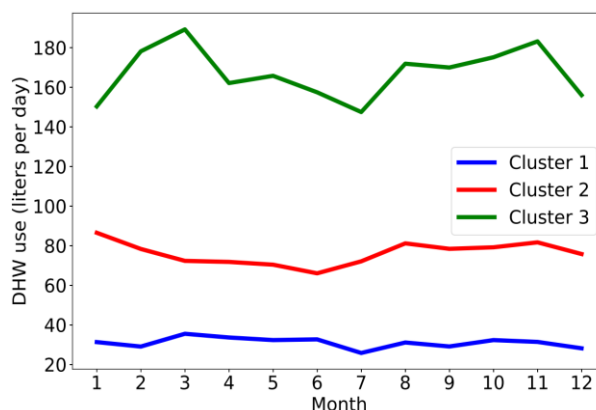


Fig. 8. Average DHW use within clusters of apartments

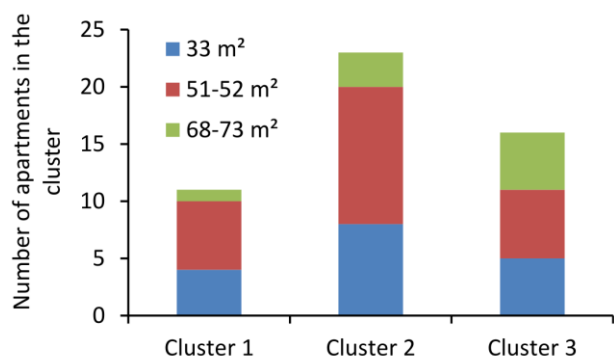


Fig. 9. Number of apartments of different sizes for each cluster

According to the European standard NS-EN 12831-3:2017: Energy performance of buildings [15], the average daily individual DHW use for residential buildings equals approximately 30 liters per person per day. This parameter is higher for Norway and reaches 40 liters per person as shown in [16]. By using this value to estimate the number of residents in the apartments, Cluster 1 might consist of apartments with only one resident, Cluster 2 apartments with two residents, and Cluster 3 families with three or more residents. However, this estimation did not take into account individual variation in DHW use, as observed in [6].

From Fig. 8, it may be noted that for all the clusters, DHW use in the cold season was higher than in the warm season. DHW use in the apartments within Cluster 3 was more uneven and showed bigger variations in DHW use. For Cluster 3, the highest DHW use was observed in November and March. There is observed significant drops in DHW use in months, which include long holidays and typical vocational time. To be able to draw further conclusions, it would be valuable to analyse DHW use in a higher number of apartments in a similar way, compared with holiday periods. This would increase the knowledge regarding seasonal variations in hot water use.

4.2 Analysis of hourly DHW use in apartment blocks

To recall, due to data availability, to identify hourly profiles of the DHW use, the other apartment buildings were used. However, building type and DHW heat use in these buildings were similar. In Fig. 10-13, the hourly DHW use for the four apartment blocks is represented as box plots. As was mentioned above, AB1 and AB2 are social housing buildings. These types of buildings are owned and managed by the state to provide affordable housing for people who need it. AB3 and AB4 are a housing cooperative, where residents normally own their apartment, representing a regular type of ownership in Norway. Fig. 10-13 display certain differences in DHW use profiles for social housing and the housing cooperatives.

In the housing cooperatives, the DHW use is mainly used from 7:00 to 22 o'clock. The increased DHW use occurs in the morning from 8:00 o'clock and lasted until 11:00 o'clock, see Fig. 12 and 13. From 13:00 o'clock to 16:00 o'clock, the reduction of DHW use could be

observed. Evening peak occurred from 18:00 o'clock until 21.00 o'clock. The minimum DHW use arose at night time from 1:00 o'clock to 6:00 o'clock.

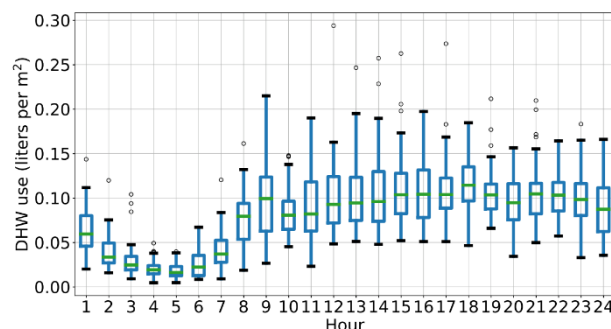


Fig. 10. Box plot of hourly DHW use in AB1 (social housing)

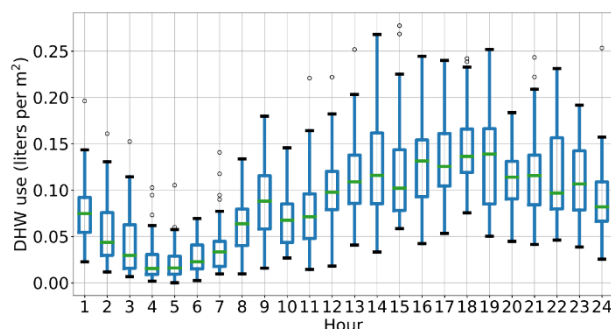


Fig. 11. Box plot of hourly DHW use in AB2 (social housing)

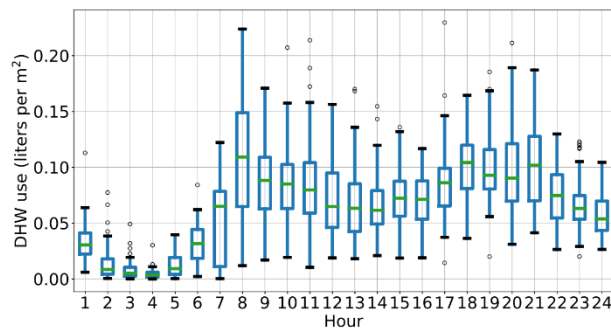


Fig. 12. Box plot of hourly DHW use in AB3 (housing cooperative)

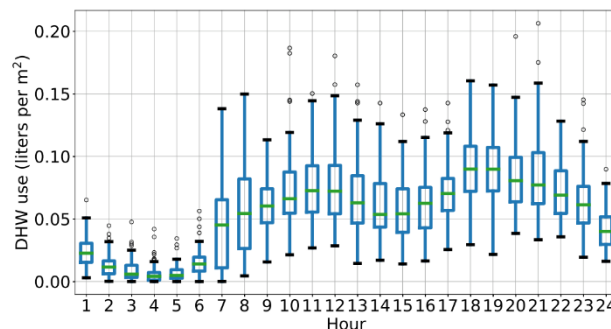


Fig. 13. Box plot of hourly DHW use in AB4 (housing cooperative)

The DHW use profiles for social housing are more even through the day and with a morning peak, about one hour later than in the housing cooperative. Evening peak in social housing took place before 20:00 o'clock. Unlike a housing cooperative, social housing profiles had increased DHW use in the daytime, from 13:00 to 16:00

o'clock. An explanation of this might be that a larger share of the residents in social housing was staying home during the day-time.

Both social housing and housing cooperative showed a weekly variation of DHW use, see Fig. 14. From Fig. 14, it is clear that the DHW use at the weekends in apartment blocks is higher than during the working days.

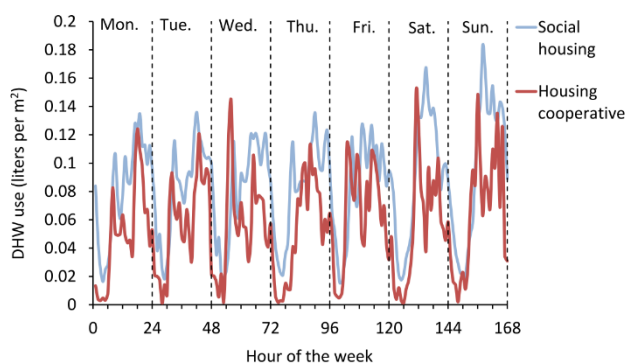


Fig. 14. Weekly average DHW for apartments in social housing and housing cooperative

The profiles of the DHW heat use for social housing and housing cooperative is shown in Fig. 15. The reference profile presented in the Norwegian technical specification, SN/TS 3031:2016: Energy performance of buildings. Calculation of energy needs and energy supply are shown in Fig. 16 [17]. The shape of the average hourly DHW heat use corresponds to the DHW use profiles in Fig. 10-13. A comparison of the measured DHW heat use profiles with the SN/TS 3031:2016 standard showed a significant difference between them. Especially, this difference was noticeable for social housing.

The standard SN/TS 3031:2016 assumes that the DHW heat use from 1:00 o'clock until 6:00 o'clock equals to zero. In considered apartment blocks, a certain amount of heat use was measured even during the night. In addition, the standard profile significantly underestimated DHW heat use during the day time, especially for the social housing.

It should be mentioned that the standard SN/TS 3031:2016 shows precisely the morning and the evening hours with the highest DHW heat use for a housing cooperative. In addition, the peak values of DHW heat use presented in the standard quite well corresponds with the measured values. Thus, we could conclude that standard SN/TS 3031:2016 gives useful information about the peak values of DHW heat use. However, the timing of heat use in the standard does not explain DHW heat use in actual apartment blocks. This reference profile is especially inaccurate for social housing.

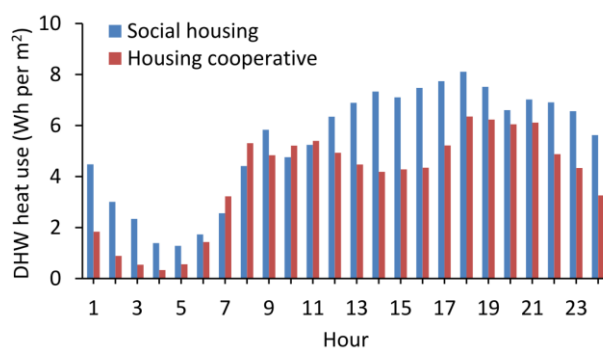


Fig. 15. Average hourly DHW heat use for social housing and housing cooperative

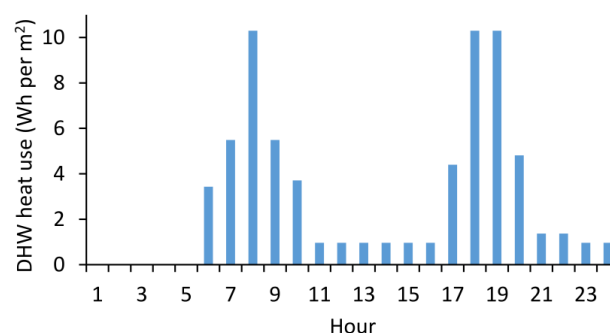


Fig. 16. Hourly profiles of DHW heat use according to the standards SN/TS 3031

3 Conclusions

Improving the performance of DHW systems is a critical issue for achieving further energy savings in buildings. Using accurate and representative profiles is essential for the design, modelling, simulations and improving the operation of DHW systems. In this article, both monthly and daily profiles for apartment blocks in Norway were investigated.

Examination of monthly profiles for 49 apartments revealed that kitchens contributed to approximately 30% of the DHW use in Norwegian apartments and the remaining 70% were used in bathrooms. The analysis of monthly data from three types of apartments with 33 m², 51-52 m², and 68-72 m² living area indicated that the highest specific DHW occurred in 33 m² apartments.

Well known, that the main influencing factor on DHW use is the number of people who live in apartments. Despite this fact, quite often, this information is not available. Apartment sizes did not allow us to estimate the number of inheritance in a particular apartment. For this reason, hierarchical cluster analysis based on the K-mean method was used to identify three clusters of apartments with different levels of DHW use. It was assumed that these clusters represented the apartments with one resident, two residents and families with three or more residents. Obtained in such a way, profiles within each cluster were studied on seasonality.

At the next step of our research, the hourly profiles of DHW and heat use for social housing and housing cooperative apartment blocks were examined. The profiles showed differences in the timing of DHW use in these types of buildings. Compared to the housing

cooperatives, the social housing buildings had an increased DHW use during the daytime and not a pronounced evening peak.

The profiles of the DHW heat use for social housing and housing cooperative were compared with the reference profile presented in the national technical specification SN/TS 3031:2016 [17]. SN/TS 3031:2016 provides valuable information about the peak values of DHW heat use. However, compared to the four apartment buildings analysed, the reference profile is not accurate enough and should be considered modified. In addition, it may be relevant to take into account the difference between social and regular housing.

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