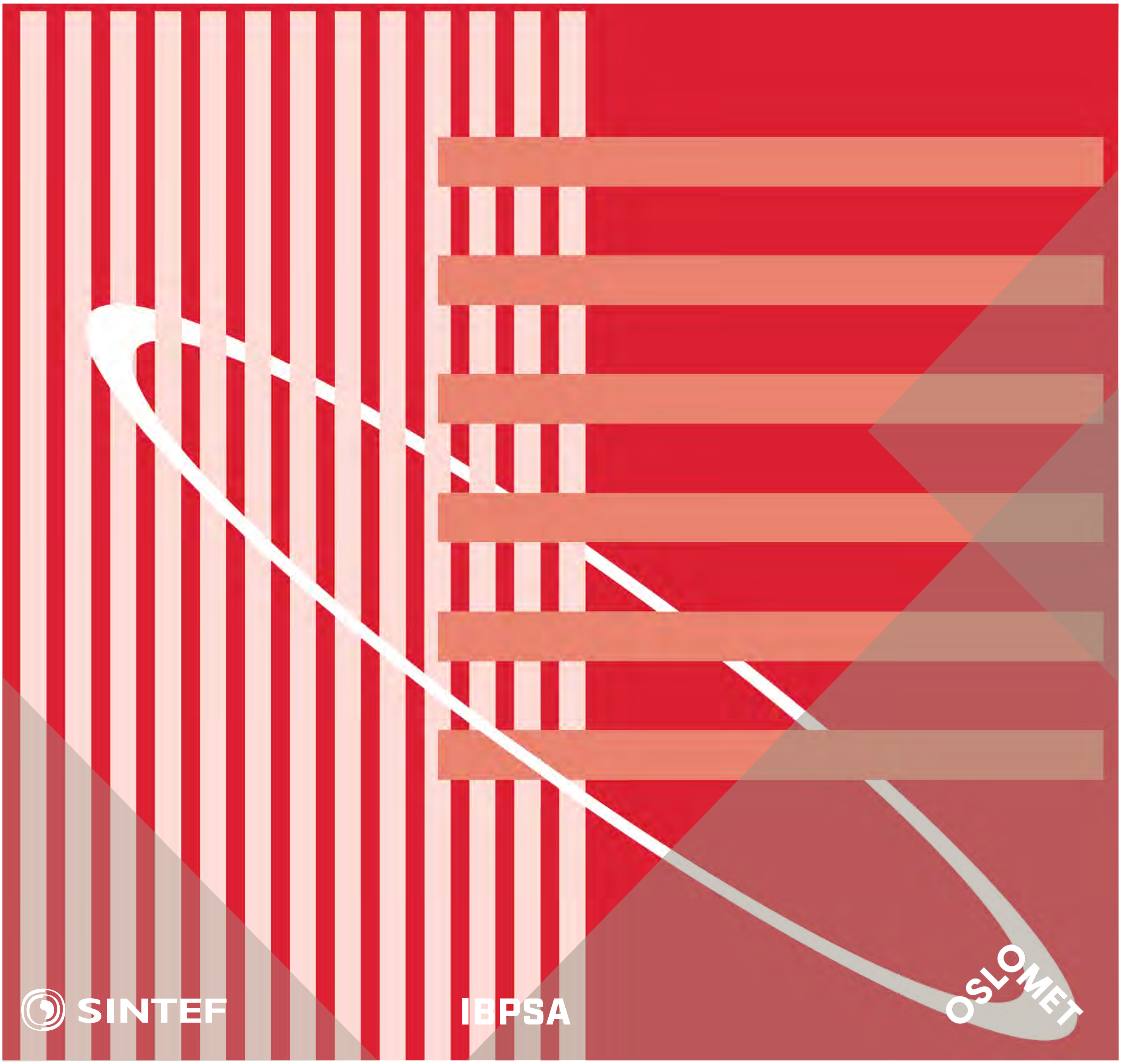
SINTEF
PROCEEDINGS
5

International Conference Organised by
IBPSA-Nordic, 13th–14th October 2020,
OsloMet

BuildSIM-Nordic 2020

Selected papers



SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

BuildSIM-Nordic 2020

Selected papers

International Conference Organised by IBPSA-Nordic,
13th–14th October 2020, OsloMet

SINTEF Academic Press

SINTEF Proceedings no 5
Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild
BuildSIM-Nordic 2020
Selected papers
International Conference Organised by IBPSA-Nordic,
13th–14th October 2020, OsloMet

Keywords:
Building acoustics, Building Information Modelling (BIM), Building physics, CFD and air flow, Commissioning and control, Daylighting and lighting, Developments in simulation, Education in building performance simulation, Energy storage, Heating, Ventilation and Air Conditioning (HVAC), Human behavior in simulation, Indoor Environmental Quality (IEQ), New software developments, Optimization, Simulation at urban scale, Simulation to support regulations, Simulation vs reality, Solar energy systems, Validation, calibration and uncertainty, Weather data & Climate adaptation, Fenestration (windows & shading), Zero Energy Buildings (ZEB), Emissions and Life Cycle Analysis

Cover illustration: IBPSA-logo

ISSN 2387-4295 (online)
ISBN 978-82-536-1679-7 (pdf)

Published by SINTEF Academic Press 2020

SINTEF Academic Press
Address: Børrestuveien 3
PO Box 124 Blindern
N-0314 OSLO
Tel: +47 40 00 51 00

www.sintef.no/community
www.sintefbok.no

SINTEF Proceedings
SINTEF Proceedings is a serial publication for peer-reviewed conference proceedings on a variety of scientific topics.
The processes of peer-reviewing of papers published in SINTEF Proceedings are administered by the conference organizers and proceedings editors. Detailed procedures will vary according to custom and practice in each scientific community.

Domestic hot water decomposition from measured total heat load in Norwegian buildings

Synne Krekling Lien[1*], Dmytro Ivanko[2], Igor Sartori[1]
[1]SINTEF Community, Oslo, Norway
[2]NTNU Department of Energy and Process Engineering, Trondheim, Norway

* *corresponding author: synne.lien@sintef.no*

Abstract

In Nordic climates, the energy use in buildings is dominated by space heating (SH) and domestic hot water (DHW). Heat load measurements with hourly resolution from smart meters are now becoming the standard. However, in most cases, only the total heat use in the building is metered, without separation into DHW and SH use. The analysis performed in this work is aimed at comparing and verifying different methods for estimating typical DHW load profiles by decomposition of heat load measurements into SH and DHW. Three methods have been used for the decomposition of the same set of measurements of the heat load from 78 buildings comprised of apartments and hotels: the seasonal method, the energy signature method and hybrid summer-signature method. All three methods have limitations, but in this article it is shown that the hybrid-summer signature method, which is a new method that is proposed in this article, has the closest similarity to measurements of DHW energy use from similar buildings.

Introduction

The building stock is the most energy demanding sector in Norway. According to (Abrahamsen and Bergh, 2011), it accounts for about 40% of the total energy consumption. A characteristic feature of energy use in buildings in Norway is a high demand for space heating (SH) and domestic hot water (DHW) (Unander et al., 2004). For this reason, a huge potential for increasing energy efficiency in buildings in Norway can be gained through better design and operation of SH and DHW systems.

Analysis of energy use in existing buildings is a powerful instrument for achieving energy savings in buildings, performing better design and dimensioning of the energy systems, as well as introducing energy planning and demand-side management. The European Directive 2018/844 prescribes that energy analysis for building stock should include typical energy consumption for SH, DHW, and other technical systems in a building. However, the heat meter systems in most buildings are simplified and do not allow us to perform energy analysis in a proper way, and a significant share of buildings in Norway uses only a single heat meter for the total heat use. The readings from the meter are not separated into SH and DHW heat use. Experience shows that SH and DHW systems are technically detached. The factors affecting the energy performance in these two systems and are different (Tereshchenko et al., 2019). Accordingly, it is crucial to conduct the analysis of heat use in SH and DHW systems independently (Cai et al., 2018). Despite the obvious drawback of simplified heat metering systems, the measured total heat use still contains valuable information about the DHW and SH systems performance. However, to use this information correctly, the reliable and accurate method for extracting the DHW and SH heat use profiles from the total heat use should be applied.

Currently, there are no generally accepted recommendations on how to separate the SH Acknowledgment and DHW profiles from the total heat use. The several approaches for decomposing the SH and DHW profiles from the total heat use that can be found in scientific publications are discussed in the text below.

In the article (Tereshchenko et al., 2019), the energy signature curve (ESC) was used to find temperature-dependent and temperature-independent part of the heat use in a Norwegian school. The temperature-independent part in ESC represents the DHW heat use. Based on this assumption, the DHW heat use profiles for working days and weekends were found. When the DHW heat use profiles are known, the profiles for SH can be extracted from the total heat use.

The modification of the ESC approach that takes into account the monthly variation of DHW heat use in dwelling in the United Kingdom (UK) is proposed in (Burzynski et al., 2012). The authors in (Burzynski et al., 2012) consider the days when the outdoor temperature is higher than the base temperature (Tereshchenko et al., 2019) as only the DHW heat use in the building. Hence, the DHW heat use profiles for several warm months can be found. After that, the DHW monthly variation factors from the UK national standard “The government’s standard assessment procedure for energy rating of dwellings" were used to extrapolate the DHW heat use from warm months to other months of the year (Burzynski et al., 2012).

Linear regression models were used to extract DHW heat use profiles from the total heat delivery in (Sørensen et al., 2019). A model for total heat delivery was built with using the outdoor temperature, separate hours of each day, weekdays and holidays as an input for the modelling. When estimating the DHW heat use, the authors set the outdoor temperature in the models equal to the break-point temperature, before calculating the DHW daily load profile with hourly mean values (Sorensen et al., 2019).

A time series method for extracting DHW heat use spikes from the total heat use is presented in (Bacher et al., 2016). The method uses the fact that the SH heat use changes gradually during the day due to changes in outdoor temperature and user behaviour. DHW heat use does on the other hand create short-lived spikes in the total heat use time series. In order to identify the slow changes of SH heat use, the authors in (Bacher et al., 2016) propose to apply a non-parametric kernel smoother. All heat use values which lie above the kernel smoother are considered to be DHW heat use spikes.

Another method for detecting the SH and DHW heat use profile is proposed in (Marszal et al., 2019). The method consists of the following steps: 1) the daily profile for the total heat use in an average summer day is identified; 2) the non-DHW use is calculated as a minimum of total heat use profile for an average summer day or average for hours from 0:00–04:00 o'clock; 3) the DHW profiles are calculated by deducting the non-DHW heat use from the value of the heat use at each hour of the day.

An investigation of SH and DHW heat load measurements is shown in (Riachi et al., 2014). Here, the authors propose to model the DHW heat use based on the volumetric DHW use, the building activity, and the type of DHW system within the building. The SH loads are estimated according to the changes in outdoor temperatures, the building setpoint temperature, the night setbacks, and days of the week.

An alternative modelling approach that couples of the behavioural, stochastic, and energy balance models is proposed in (Fischer et al., 2016). The SH model in this approach uses a simplified physical method with a behavioural model for standardised buildings. The characteristics of the DHW heat use is found as a result of the SH model.

The literature review shows that the issue of extracting the SH and DHW profiles from the total heat use is not solved yet. The methods described above require extensive knowledge about the characteristics of the DHW and SH systems, the monthly variation factors for DHW heat use and/or users behaviour in buildings. Usually, when an energy analysis is conducted on a group of buildings, this information is not available. Several of the methods described are not verified with actual measurements (Bacher et al., 2016). For this reason, the comparison and further investigation of methods for identifying DHW and SH profiles from the total heat use in buildings are required.

Methodology

The analysis performed in this work is aimed at comparing and verifying different methods for estimating typical DHW load profiles for different building types by decomposition of heat load measurements into SH and DHW. Three methods have been tested for the decomposition of the same total heat use data from measurements: measurements: the seasonal method, the energy signature method and the hybrid summer-signature method. The seasonal method and the energy signature method are classical methods. Meantime, the hybrid summer-signature is a new method proposed in this article The results from the decomposition with each method have then been compared against each other and against measurement of DHW heat loads, profiles from the national standard, as well as other studies conducted on decomposition and measurements of DHW in Norwegian buildings.

Measurements

DHW use is significantly influenced by user behaviour and the number of occupants in a building. For this reason, the analysis was performed on measurement data from a large number of buildings. In total, data from 78 Norwegian buildings have been used in this analysis. The buildings are comprised apartments and hotels. None of the buildings are considered to be passive houses or low energy buildings (very energy efficient). The measurements gathered for each building contain between 1-3 years of hourly data on the outdoor temperature and the total heat load (HtTot) in each building. The total heat load is assumed to be the sum of energy use for SH and DHW. The HtTot is covered by district heating in all buildings. The buildings are not registered with secondary heating and/or heat storage inside the buildings, however it is uncertain whether this is actually true for all of them. Table 1 shows an overview of the number of buildings within each building category that were analysed in this paper.

Table 1: Number of buildings sorted by building category.

Building category	**Number of buildings**
Apartment blocks	58
Hotels	20
Total	**78**

Decomposition method 1: Seasonal method (SM)

The seasonal method – which is sometimes referred to as the summer method - assumes that there is no demand for SH during the summer time (between June 1st and August 31st) in any of the buildings, and that the HtTot during the summer months is used only for DHW purposes. For each building, a typical DHW profile for workdays and weekends is created by extracting the average value for HtTot for every hour of the day during the summer period. SH is assumed to be zero in the summer. SH energy use for the rest of the year is identified as a difference between the measured heat load in the building and typical DHW profiles.

There are two approaches to treat holidays in seasonal method. The first approach ignores holidays when creating the typical DHW profile with the seasonal method. The second approach assumes that for a building there will be at least 30 days within each year when there will be little-to-no operation of SH and DHW systems due to the residents/users being away during the holidays. Most of these days will occur during the summer months.

Therefore, the way of identifying holidays is to mark the 30 days with the lowest heat load out of the warmest days within each year. These data should be eliminated from analysis to take effect of holidays into consideration.

Decomposition method 2: Energy signature method (ES)

In the energy signature method, an energy signature curve (ESC) is created for each building. The ESC shows the relationship between the total heat load in an observed building and the outdoor temperature, as shown in Figure 1. For a typical building, the ESC consists of two parts, divided by the change point temperature (CPT). The CPT is a critical temperature that indicates when the heating season ends. It is assumed that when the outdoor temperature is higher than the CPT, the SH system does not work and the heat use in the building is mainly related to the DHW use.

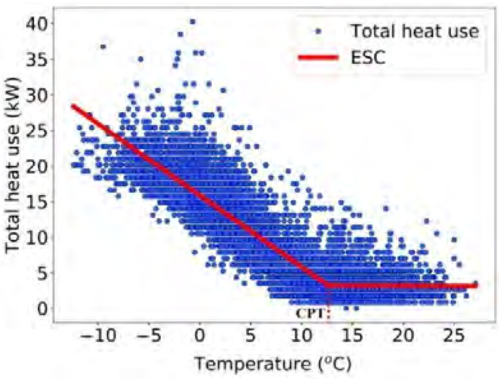


Figure 1: An example of the energy signature curve for the considered apartment building (Csoknyai et al., 2019).

The CPT can be identified by using the piecewise regression method. This method allowed us to find the CPT and construct separate models for the two parts of the ESC, as shown in Equation 1:

$$f(x) = \begin{cases} \beta_0 + \beta_1(x - CPT) + \varepsilon & If\ x < CPT \\ \beta_0 + \beta_2(x - CPT) + \varepsilon & If\ x > CPT \end{cases} \quad (1)$$

where $f(x)$ is a model for the ESC, x is the outdoor temperature, $\beta_0, \beta_1, \beta_2$ are the coefficients of the piecewise model, and ε is the residual error.

Using Equation (1), the CPT values were determined for the considered buildings. After, based on the ESD, the heat use when SH system is not operating, and DHW is the main energy consumer in the buildings was identified. Finally, the DHW heat use profiles for each building and building categories were calculated.

Decomposition method 3: Hybrid summer signature method (Hybrid SM-ES)

In order to improve the existing methods for HtTot decomposition, the authors propose a hybrid SM-ES method that takes aadditional features of SH and DHW systems performance into account. Buildings with ventilation systems might have a heating demand for heating of ventilation air during the summertime in the hours when the outdoor temperature is low – such as in the night time, in the early morning hours and on particularly cold days. By simply extracting the average value for heat load for every hour of the day during the summer (as is done in the seasonal method and to a certain extent in energy signature method), heating of ventilation air may be faulty interpreted as heating of DHW.

When using the hybrid summer signature method, the summer values for the heat load (HtTot) and outdoor temperature (Tout) for every hour of the day are plotted with the Temperature at the X-axis and the heat load on the Y-axis (in an so-called Energy-Temperature-/ET-curve). Linear regression is then used to calculate the expected value for HtTot for the given hour at a given temperature, as shown in Figure 2. When the interpolation is done at higher temperatures it can be assumed that there will be no space heating in the building, and that the interpolated value for the heat load is used solely for DHW heating purposes. In Norwegian buildings, the heating of ventilation air stops at above 16°C. Therefore, the typical DHW profiles created with the hybrid summer signature method has been tested at 16°C, 18°C and 20°C.

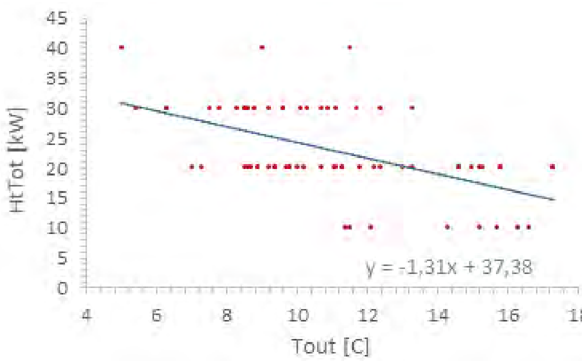


Figure 2 Tout and HtTot in one of the considered apartments on weekdays at 07:00.

In some buildings, the obtained value from the SM-ES method will become negative in some hours when the heat load is interpolated at higher temperatures, such as 20°C. When this occurs, the heat load is set to zero. In order to reduce the number of hours that get negative values for heating, whilst still aiming to reduce the effects of ventilation heating, the linear regression is performed at 18°C in this analysis.

Results

The test data (measurements of HtTot from the 78 apartments and hotels) have been decomposed into DHW and SH using three methods: the seasonal method (SM), the energy signature method (ES-1) and the hybrid seasonal signature method (Hybrid SM-ES).

The results have been compared to different reference data:

- An application of the energy signature method on a different set of measurements of HtTot (Lindberg, 2017) (ES-2)
- Actual measurements of DHW use from three different sources (REF-1 from (Walnum et al., 2019), REF-2 from (Bagge et al., 2015) and REF-3 from (ElDek, 2020)).
- Normative inout data for DHW energy use for building modelling from the national standard "SN-NSPEK 3031:2020: Energy performance of buildings. Calculation of energy needs and energy supply".

The reference data is collected from different sources with differences in methodologies, system boundaries and building types. An overview of the modelling and the reference data sources is given in Table 2.

Table 2 Overview of simulation and reference data.

		Description	#	Sirc. losses	Energy supply
Test data	SM-1	Seasonal method without (1) and with marking (2) of holidays.	58 apartment blocks, 20 Htl	Yes	DH
	SM-2				
	Hybrid SM-ES 18	Seasonal method with linear regression at 18°C			
	ES-1	Energy signature 1			
References	ES-2	Reference Energy signature values for apartments (Pedersen, 2007) and for hotels (Lindberg et al., 2019).	53 dwellings, 7 hotels	Yes	DH
	REF-1	Reference 1 from measurements. Flow and energy measurements on pipes in Norwegian hotels and apartments. (Walnum et al., 2019)	2 Apt. blocks 3 hotels.	Yes No	DH and EL
	REF-2	Reference 2 from measurements. Flow measurements on pipes in Swedish apartments, later converted into energy with a fix conversion factor. Individual metering for each unit. (Bagge et al., 2015)	4 apt. blocks with 1000 units.	No	NA
	REF-3	Reference 3, measurements of DHW energy use in single family houses. Energy measurement on socket (ElDek, 2020)	Unknown.	Yes	EL
	NORM	SN-NSPEK 3031:2020. Normative values of net energy demand for heating of DHW used in building modelling	-	No	-

Daily profiles

To evaluate the different decomposition methods, the typical daily profiles for DHW energy use in hotels and apartments have been created based on the test data. These daily profiles have been compared to the daily reference profiles for DHW energy use in apartments and hotels.

The reference daily profiles on DHW energy use from measurements in apartments are shown in Figure 3 (Weekdays) and Figure 4 (weekends). The reference measurements have been gathered from three different sources: REF-1 and REF-3 come from measurements of DHW energy use in Norwegian apartment buildings, while REF-2 is gathered from the measurement of DHW use in 1000 Swedish apartments. REF-2 is plotted in the figures with a spread from the lowest 10^{th} percentile to the highest 10^{th} percentile of DHW energy use from all of the apartment units, indicating a large spread in DHW energy use between different users. The apartment references indicate that usually during weekdays, apartment blocks will have a high morning peak and evening peak for DHW energy use, with a significant reduction in DHW energy use during the night time. On weekends, the references indicate that apartments typically will have a higher morning peak at a later time of day (compared to workdays), with higher consumption of DHW energy use throughout the day, but still with a low consumption during the night time.

Figure 5 and Figure 6 show the typical profiles for apartments created from the test data with the different decomposition methods, plotted against REF-2, the reference energy signature profiles (ES-2) and normative values for DHW energy consumption (NORM). The seasonal-method profiles (SM-1 and SM-2) and the energy signature profiles (ES-1 and ES-2) show higher values for most hours compared to the typical profiles obtained from measurements, with little reduction in energy consumption during the night time. The hybrid SM-ES 18 profiles are closer to the average profile from REF-2, and show a more significant reduction in the energy consumption during the night time, although the typical daily profile from the Hybrid SM-ES method creates a "flatter" daily profile for the apartments with less significant morning and evening peaks, compared to the other decomposition methods.

The typical daily profile for hotels (regardless of weekdays/weekends) from the test data and from the references is shown in Figure 7. All of the daily profiles for DHW energy consumption in hotels indicate a high morning peak, and a slight increase in DHW consumption towards the evening/night, with a decrease in energy use during the night. The Hybrid SM-ES method has a bigger decrease in energy use during the night compared to the other decomposition methods. The weekend and weekday DHW profiles are not plotted individually for hotels, as the reference values don't separate between different days in the typical profile. The test data does however indicate a later morning peak in hotels on weekends compared to weekends regardless of the decomposition method used.

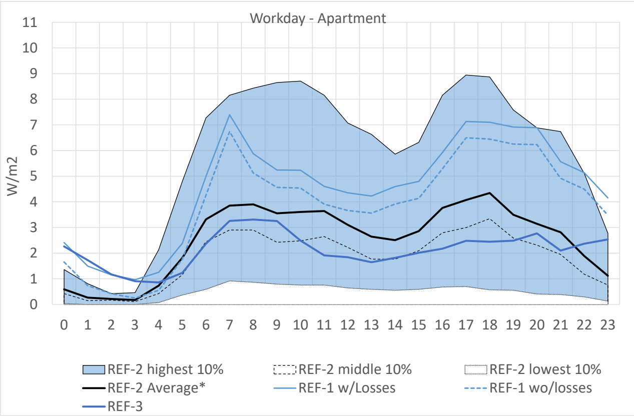


Figure 3 Reference measurements of DHW energy on weekdays in apartments.

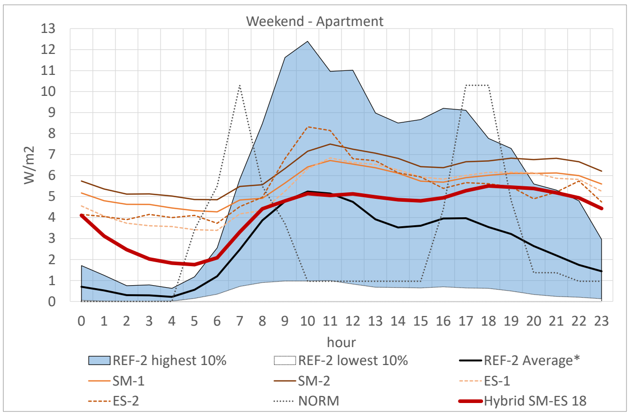


Figure 6 Average weekend profiles for DHW energy use in apartments created for the test buildings with different methods compared against REF-2 and NORM.

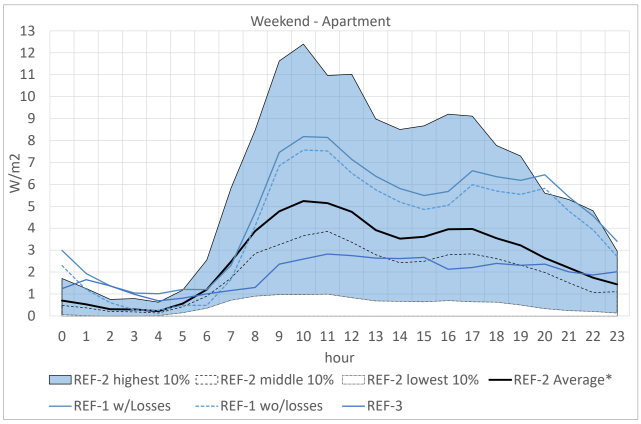


Figure 4 Reference measurements of DHW energy on weekends in apartment buildings.

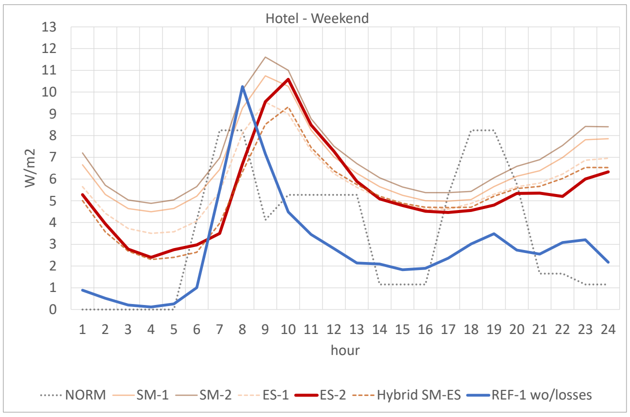


Figure 7 Average daily profiles for DHW energy use in hotels created for the test data with different methods compared against REF-1 and NORM.

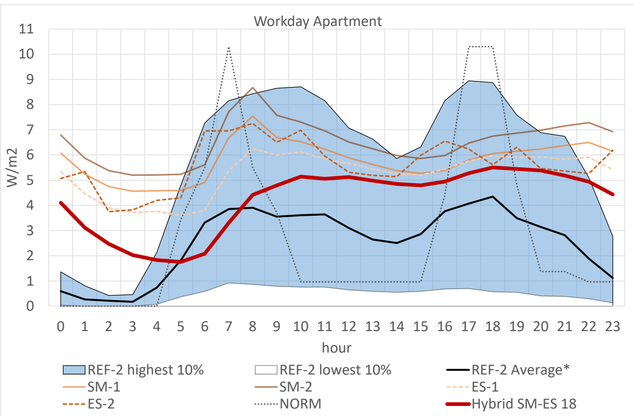


Figure 5 Average weekday profiles for DHW energy use in apartments created for the test buildings with different methods compared against REF-2 and NORM.

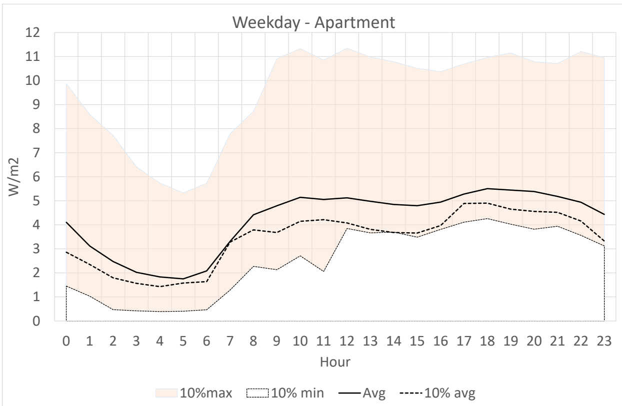


Figure 8 Variation in daily profiles for the apartment test data on weekdays created with Hybrid SM-ES method at 18°C.

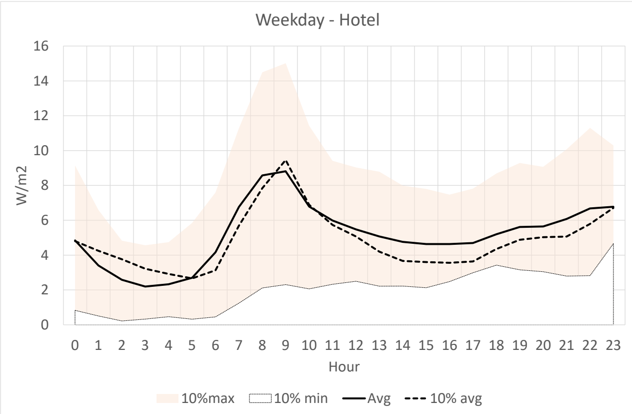


Figure 9 Variation in daily profiles for the hotel test data on weekdays created with Hybrid SM-ES method at 18°C.

The average daily profiles for DHW energy use in apartments and hotels created with the hybrid SM-ES-method has the resulting profile which is the most similar to the typical profiles obtained from actual measurements on the building category level. However, there is a large variation in the typical DHW energy consumption between all the buildings in the test data. Figure 8 and Figure 9 show the variation between the typical profiles created with the hybrid SM-ES method for the 78 apartments and hotels respectively, from the lowest 10th percentile to the highest 10th percentile.

Annual energy use for DHW

The different methods for extracting the DHW energy use give different results on the annual consumption of energy use for DHW. The spread of the resulting annual energy use for DHW in the 78 test data is shown in the boxplots in Figure 10 and Figure 11 for apartments and hotels respectively.

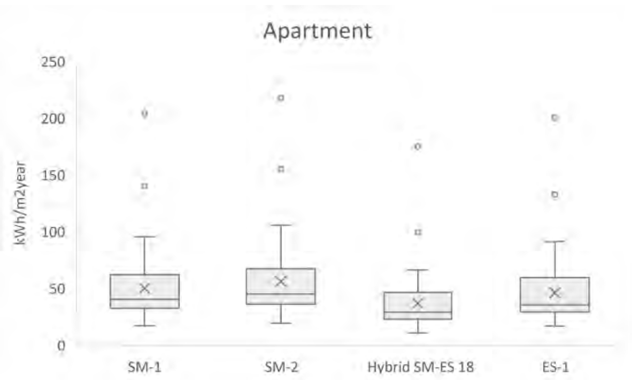


Figure 10 Boxplots of annual specific energy use for DHW decomposed with different methods in 58 apartment blocks.

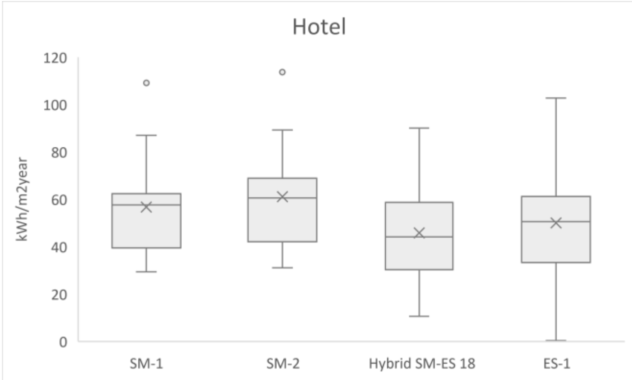


Figure 11 Boxplots of annual specific energy use for DHW decomposed with different methods in 20 hotels.

The mean annual energy consumption is the lowest when the hybrid SM-ES method at 18°C is used, and highest when the SM-2 method is used.

The mean annual specific energy use for DHW created for the test data with the different methods, as well as the mean energy use from the references is listed in Table 3. The results show that all the decomposition methods used on the test data have resulted in higher annual energy use for DHW in both apartments and hotels compared to most of the references. The exception is REF-1 with circulation losses which have higher annual consumption than the resulting mean created with SM-ES-18 for apartments.

Table 3 Mean annual energy use DHW Heating.

	Method	Apartment [kWh/m²year]	Hotel [kWh/m²year]
Test data	SM-1	50.2	56.9
	SM-2	56.3	61.3
	Hybrid SM-ES 16	42.4	50.5
	Hybrid SM-ES 18	37.0	46.0
	Hybrid SM-ES 20	31.8	41.9
	ES-1	45.9	50.0
Reference data	ES-2	48.8	46.9
	NORM	25.1	30.1
	REF-1 w/Losses	40.2	24.5
	REF-1 wo/losses	34.3	-
	REF-2	22.7	-
	REF-3	18.2	-

Discussion

The comparison of decomposition methods is nescessary in order to create realistic energy profiles for achiving energy efficiency in buildings. The proposed Hybrid SM-ES method has showed good results and can be applied in practice.

The simple seasonal method assumes that there is no SH energy use during the summer, however this may not be true for all buildings, especially the buildings with ventilation systems, where the ventilation air is heated before being supplied in the building. By following traditional methods, heating of ventilation air may be faulty interpreted as heating of DHW, resulting in an overestimated total annual demand for heating of DHW, as well as overestimating the hourly energy demand for DHW, especially at night and in the early morning hours when the outdoor temperature is lower, and the heating of ventilation air is higher. An alternative to the simple seasonal method would be to sort the heat load data by outdoor temperature, and look at the warmest days/hours instead of the summer dates. For buildings in colder climates, there may not be enough data points for higher temperatures (above 16°C) at all hours of the day. The hybrid seasonal-signature method offers an alternative approach where the expected value for the heat load is interpolated at higher temperatures. The hybrid summer-signature method shares similarities with (Burzynski et al., 2012), however, it doesn't identify the CPT/break point temperature for each building, and only measurements from the summer season are collected before the linear regression is applied. In some buildings, the interpolated value results in negative values when the SM-ES method is applied, especially when the heat load is interpreted at higher temperatures (20°C). When this occurs, the heat load is set to zero. Negative values suggest that the values should be low – and close to zero, however this is an underestimation as in reality, the circulation losses will be above 0. If the heat load is interpolated at too high temperatures, the resulting DHW value can get too low. Establishing the most suitable temperature for the interpolation must be balanced between reducing the effects of ventilation heating during the night, whilst not underestimating the heat load for DHW energy use during the day.

The energy signature method is a widely used method for extracting the DHW energy use from heat load measurements. The ES-method is based on Piecewise Regression and optimization. If the ES-method is applied to a dataset without a classical shape, where there for instance is little dependence between the heat load and the outdoor temperatures, where there are a significant amount of data points, or where there heat is being turned off at different times (e.g. due to heat storages being used, load controls or other factors), the ES-algorithm will not work normally. Due to this, the ES-method will not be applicable to all datasets, and has not been possible to apply to all files in the test data set.

All typical profiles created from the test data with the different decomposition method show a time-shift compared to the measurements. This could be due to a difference in the registration of data, or different user behaviour in the different data sets.

In all three methods, it is assumed that there is no seasonal variation in the DHW consumption, however (Bagge et al., 2015) has found a seasonal dependence of DHW consumption in apartment blocks, with higher consumption in the winter months. One could also assume that tourist oriented hotels have higher consumption in the summer months, while congress and business oriented hotels have higher consumption outside the summer months. Seasonal variation in DHW is also supported by (Gerin et al., 2014). The methods could be improved by combining the typical DHW-profiles with seasonal coefficients for DHW from (Gerin et al., 2014) or create coefficients based on (Bagge et al., 2015).

The comparison of the DHW energy use in the test data created with the different methods and the measurements indicate that all methods for decomposition likely overestimates the energy use for DHW purposes in apartments and hotels. As the modelled DHW energy use might be used for dimensioning purposes, this is considered to be preferred compared to underestimation of DHW energy use.

Conclusion

Analysis of energy use in existing buildings is a powerful instrument for achieving energy savings in buildings, performing better design and dimensioning of the energy systems, as well as introducing energy planning and demand-side management. Currently, there are no generally accepted recommendations on how to separate the SH and DHW profiles from the total heat use. The aim of the analysis performed in this work has been to compare and verify different methods for estimating typical DHW load profiles by decomposition of heat load measurements into SH and DHW. Three methods have been used for the decomposition of the heat load from 78 apartments and hotels: the seasonal method, the energy signature method and hybrid summer-signature method. All methods have limitations in creating the typical DHW-profile for a building. The hybrid-summer signature method with linear regression at 18°C gave the best results for the decomposition of DHW compared to the measurements for the test data used in this analysis. A similar comparison of the resulting SH energy use profiles with verification against SH measurements should be conducted in further work in order to further evaluate this method.

Acknowledgment

The authors gratefully acknowledge the support from the Research Council of Norway and several partners through the "Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN)", grant nr. 257660, and the project " Energy for domestic hot water in the Norwegian low emission society (VarmtVann 2030) ", grant nr. 267635.

References

Abrahamsen, A. S., & Bergh, M. (2011). Energibruk i bygninger for tjenesteytende virksomhet. 2008.

Bacher, P., de Saint-Aubain, P. A., Christiansen, L. E., & Madsen, H. (2016). Non-parametric method for separating domestic hot water heating spikes and space heating. *Energy and Buildings, 130*, 107-112.

Bagge, H., Johansson, D., & Lindstrii, L. (2015). BRUKARRELATERAD ENERGIANVÄNDNING Mätning och analys av hushållsel och tappvarmvatten. *LÅGAN - För Energieffektiva Byggnader*.

Burzynski, R., Crane, M., Yao, R., & Becerra, V. (2012). Space heating and hot water demand analysis of dwellings connected to district heating scheme in UK. *Journal of Central South University, 19*(6), 1629-1638.

Cai, H., Ziras, C., You, S., Li, R., Honore, K., & Bindner, H. W. (2018). Demand side management in urban district heating networks. *Applied Energy, 230*, 506-518.

Csoknyai, T., Legardeur, J., Akle, A. A., & Horvath, M. (2019). Analysis of energy consumption profiles in residential buildings and impact assessment of a serious game on occupants' behavior. *Energy and Buildings, 196*, 1-20.

ElDek. (2020). Data obtain from personal communication with Hanne Sæle [or Project Leader, or Contact Person] in April 2020. https://www.sintef.no/en/projects/eldek-electricity-demand-knowledge/, accessed on 07/05/2020.

European Commission, Directive (EU) 2018/844 of the European Parliament and of the Council, Available from: https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG (Accessed October 16, 2019).

Fischer, D., Wolf, T., Scherer, J., & Wille-Haussmann, B. (2016). A stochastic bottom-up model for space heating and domestic hot water load profiles for German households. *Energy and Buildings, 124*, 120-128.

Gerin, O., Bleys, B., & De Cuyper, K. (2014). *Seasonal variation of hot and cold water consumption in apartment buildings*. Paper presented at the CIBW062 Symposium 2014.

The government's standard assessment procedure for energy rating of dwellings. (2019). In *Building Research Establishment, Watford, UK* (pp. 180): BRE Garston, Watford.

Lindberg, K. B., Bakker, S. J., & Sartori, I. (2019). Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts. *Utilities Policy 58, 58*, 62-88.

Marszal, A. J., Zhang, C., Pomianowski, M. Z., Heiselberg, P. K., Gram-Hanssen, K., & Hansen, A. R. (2019). Simple methodology to estimate the mean hourly and the daily profiles of domestic hot water demand from hourly total heating readings. *Energy and Buildings, 184*, 53-64.

Pedersen, L. (2007a). *Doctoral Thesis. Load Modelling of Buildings in Mixed Energy Distribution Systems. of*
Energy and Process Engineering. Trondheim: NTNU,

Pedersen, L. (2007b). *Load Modelling of Buildings in Mixed Energy Distribution Systems.* (PhD Thesis).

Riachi, Y., Rangod, N., & Guillemot, B. (2014). *A numerical model for determining hourly heating and DHW loads in district heating systems.* Paper presented at the The 14th International Symposium on District Heating and Cooling.

Sørensen, A. L., Lindberg, K. B., Walnum, H. T., Sartori, I. Aakenes, U. R. & Andresen, I. (2019). Heat Analysis for Energy Management in Neighbourhoods: Case Study of a Large Housing Cooperative in Norway. *IOP Conference Series: Materials Science and Engineering, 609*, pp. 1-7.

Tereshchenko, T., Ivanko, D., Nord, N., & Sartori, I. (2019). Analysis of energy signatures and planning of heating and domestic hot water energy use in buildings in Norway. *E3S Web of Conferences, 111*(06009), p. 1-8.

Unander, F., Ettestøl, I., Ting, M., & Schipper, L. (2004). Residential energy use: an international perspective on long-term trends in Denmark, Norway and Sweden. *Energy policy, 32*(12), 1395-1404.

Walnum, H., Sørensen, Å. L., Ludvigsen, B., & Ivanko, D. (2019). Energy consumption for domestic hot water use in Norwegian hotels and nursing homes. *IOP Conference Series: Materials Science and Engineering, 609*. doi:10.1088/1757-899X/609/5/052020

Appendix

The hybrid SM-ES method at 18 degrees was applied to 198 buildings from different building categories with measurements of HtTot. This table shows the resulting typical profile for DHW energy use in different building categories. n= the number of buildings in the test data within the building category.

	Apartment n = 58		Hotel n = 20		Nurs. home n = 31		Office n = 49		School n = 40	
Hour	WD	WE	WD	WE	WD	WE	WD	WE	WD	WE
0	4.10	3.93	4.85	5.42	2.92	3.09	1.26	1.35	1.49	1.57
1	3.12	3.38	3.40	3.98	2.81	2.92	1.20	1.27	1.42	1.48
2	2.47	2.96	2.58	2.95	2.62	2.78	1.19	1.30	1.31	1.50
3	2.02	2.74	2.19	2.57	2.77	2.79	1.11	1.00	1.23	1.44
4	1.83	2.28	2.33	2.56	3.06	3.01	1.17	1.11	1.13	1.29
5	1.75	2.03	2.70	2.48	3.40	3.19	1.15	1.10	1.22	1.32
6	2.08	2.02	4.17	3.47	3.82	3.55	1.57	1.29	1.39	1.52
7	3.31	2.48	6.76	5.23	4.40	3.88	1.64	1.31	1.41	1.57
8	4.42	3.10	8.58	8.36	5.17	4.63	1.97	1.46	1.84	1.67
9	4.79	4.09	8.81	10.59	6.39	5.32	2.20	1.49	2.52	1.74
10	5.14	5.26	6.79	9.12	6.62	5.30	2.37	1.55	2.83	1.88
11	5.05	5.68	5.99	7.35	6.56	5.33	2.56	1.75	3.01	1.93
12	5.12	5.80	5.48	6.43	6.35	5.38	2.67	1.74	3.22	1.97
13	4.98	5.77	5.07	5.57	6.19	5.35	2.67	1.82	3.30	2.09
14	4.85	5.64	4.76	5.20	6.17	5.36	2.62	1.84	3.28	2.07
15	4.80	5.29	4.63	4.88	5.79	5.13	2.56	1.77	3.34	2.19
16	4.94	5.16	4.64	4.82	5.24	4.87	2.36	1.76	2.94	2.06
17	5.28	5.24	4.70	4.72	5.13	4.83	2.15	1.79	2.63	2.09
18	5.50	5.40	5.19	5.26	4.82	4.73	2.00	1.78	2.44	2.08
19	5.44	5.35	5.62	5.44	4.69	4.62	1.94	1.64	2.25	1.99
20	5.38	5.24	5.64	5.71	4.57	4.51	1.79	1.65	2.07	1.98
21	5.18	4.80	6.07	5.91	4.21	4.00	1.68	1.49	1.89	1.89
22	4.94	4.37	6.68	6.16	3.72	3.63	1.56	1.34	1.68	1.68
23	4.43	4.09	6.78	5.90	3.23	3.10	1.32	1.24	1.53	1.54