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Energy consumption for domestic hot water use in Norwegian hotels and nursing homes

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Abstract. Domestic Hot Water (DHW) production constitutes a significant proportion of the energy demand of modern buildings, and as the building envelope is improved the share increases. This article discusses the results from a measurement campaign in Norwegian hotels and nursing homes. The energy demand for DHW and distribution heat losses for 3 hotels and 3 nursing homes are shown. The results show that number of bedrooms is a better parameter for describing DHW consumption than sqm of heated floor area. There are large variations in the measured distribution losses, mainly due to malfunctioning of the hot water circulation system. For nursing homes, the measured energy consumption is significantly lower than the normative profiles, which can have large impact on the requirements for the design of the building heating system. For hotels, the measured energy consumption is in the range of the normative profiles.

Nomenclature

$\dot{Q}_{prod}$	Delivered energy to the DHW production unit (kWh)	T_{HTHW}	High temperature hot water outlet temperature. Before mixing valve (°C)
$\dot{Q}_{HW}$	Energy in consumed hot water (kWh)	$\dot{V}_{CW}$	Total cold water flow rate (l/s)
$\dot{Q}_{HWC}$	Energy loss in circulation (kWh)	$\dot{V}_{CWT}$	Cold water flow rate into the DHW production unit (l/s)
$\dot{Q}_{distr}$	Total distributed energy (kWh)	$\dot{V}_{HW}$	Hot water flow rate (incl. hot water circulation flow) (l/s)
T_{CW}	Cold water inlet temperature	$\dot{V}_{HWC}$	Hot water circulation flow (l/s)
T_{HW}	Hot water outlet temperature. After mixing valve (°C)	cp	Heat capacity of water (kJ/kgK)
T_{HWC}	Hot water circulation return temperature (°C)	ρ	Density of water (kg/m^3)

1. Introduction

In the last decades, there has been an increasing focus on the energy demand in buildings, and the building regulations are moving towards zero energy buildings. The main measures have been on improving the building envelope. As the space heating demand in buildings is reduced, the relative importance of the energy for domestic hot water (DHW) increases. The energy needed for DHW in the developed world constitutes of between 10 and 20% of the total energy demand in residential buildings and between 5 and 10% of the total energy demand in commercial buildings [1]. With the current Norwegian building regulations, over 50% of the total calculated thermal energy demand is used for DHW for several building categories [2]. However, the assumption on DHW demands and heat losses are based on old and uncertain values. Previous studies have shown heat losses in the DHW circulation lines up to 70% of the total energy demand for DHW in residential buildings and even higher in offices and institutions [3]. In modern buildings with highly efficient building envelopes, uncontrolled heat losses contribute less to useful heating, and might even increase the energy demand for cooling.

To improve the knowledge on energy consumption for DHW, a measurement campaign has been initialised. The campaign comprises twelve buildings, focusing on nursing homes (4), hotels (4) and apartment blocks (4), as these building categories have high DHW consumption according to the Norwegian standard normative numbers [4]. Measurements are performed to investigate both maximum flow rates and energy flows in the system and are set up to measure energy demand for both hot water use and heat losses in the system.

2. Description of buildings

6 buildings, 3 hotels (HO) and 3 nursing homes (NH) are included in this study. The main parameters describing the buildings are shown in Table 1.

HO1 and HO2 are built according to similar specifications, and are both typical conference hotels, but HO1 does have higher share of non-business guests. HO3 is a more compact hotel, without restaurant and conference halls.

The main difference between the nursing homes, is the room density (# rooms per total area). NH3 has a much lower room density than the other two buildings. In addition, NH3 has bypassed a large part of the circulation system

Table 1. Main building parameters

Hotels	Area [m^2]	# Rooms	Heat source	Distribution heating	Storage	Measurement period
HO1	21 278	434	District Heating	Circulation	None	April-May 2018
HO2	24 500	355	District Heating	Circulation	6 x 1000 liter	Aug.-Sept 2018
HO3	4 934	165	Electric water heaters	Circulation	8 x 1000 liter	Aug.- Sept.2018
Nursing Homes						
NH1	11 618	148	Electric water heaters	Circulation	6 x 400 liter	Jan-Feb 2018
NH2	3 327	52	Electric water heaters	Electric heat tracing	3 x 600 liter	May-Jun 2018
NH3	6 774	50	Local area heating + electric water heaters	Circulation	3 x 400 liter	May-Jun 2018

3. Measurements

Flow, temperature and energy measurements were performed on DHW production system in each building. At each location, the measurement equipment was installed for a period of approx. 6 weeks. Flow rates and temperatures were measured with an interval of 1s, and then averaged to 2 seconds before analysis. In the energy analysis in this article, the data are resampled to 1 hour time steps, to analyze typical profiles.

3.1. Measurement equipment

An important feature for the measurement equipment was that it had to be non-intrusive to the DHW system. Therefore, clamp-on ultrasonic flow meters were used for flow measurement and Type-T thermocouples where mounted on the pipe wall.

The flow meters have a specified accuracy of 1.6% of reading ±0.01 m/s [5], and the Type-T thermocouples have an error specified as maximum of 1.0 °C or 0.75% above 0 °C [6].

3.2. Installation of measurement equipment

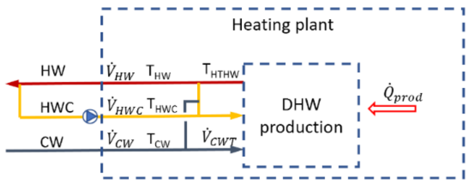

Figure 1. Principle drawing of DHW heating plants with typical measuring points.

There are variations in how DHW systems in Norway are designed, both in regard to energy sources, but also with respect to system layout. Figure 1 shows a principle drawing of how most heating plants are built, with typical measuring points used in the DHW measurements. When possible, all measuring points shown, are logged. However, in many cases, the pipe sections between junctions are too short or there are other branches that influence the measurements. As a minimum, T_{HW}, T_{HWC}, T_{CW}, $\dot{V}_{HW}$ and $\dot{V}_{HWC}$ are measured.

3.3. Energy calculations

Equation (1), (2) and (3) shows the formulas for calculating the energy flows. If $\dot{V}_{CW}$ is not available, it is calculated with equation (4).

$$\dot{Q}_{HW} = \frac{\dot{V}_{CW}}{\rho} * cp * (T_{HW} - T_{CW}) \tag{1}$$

$$\dot{Q}_{HWC} = \frac{\dot{V}_{HWC}}{\rho} * cp * (T_{HW} - T_{HWC}) \tag{2}$$

$$\dot{Q}_{distr} = \dot{Q}_{HW} + \dot{Q}_{HWC} \tag{3}$$

$$\dot{V}_{CW} = \dot{V}_{HW} - V_{HWC} \tag{4}$$

4. Results and discussion

For comparison of the daily energy consumption profiles, the energy in consumed hot water ($\dot{Q}_{HW}$) is used. For comparison of the distribution efficiencies between the buildings, the average daily energy consumption is calculated, assuming that the measurement period is representative for the whole year.

In the following, the hotels and nursing homes are studied separately, and they are then both compared to the normative consumption profile in the Norwegian technical standard SN/TS 3031 [4].

4.1. Hotels

Figure 2 shows the daily mean energy profile for hotels per heated floor area, per room, and per overnight guest. All the three hotels have a similar DHW profile, with a large energy peak in the morning. The results indicate that number of rooms or number of guests are better parameters for describing the consumption than the floor area, which is commonly used in normative numbers, as the curves are better aligned and the relative difference is smaller. HO2 deviates somewhat from HO1 and HO3 in energy consumption per guest. A possible explanation can be that, since HO2 is a conference hotel situated in the suburbs of Oslo, there are daytime visitors that are not counted as overnight guests. These guest do not shower, but they do increase the activity at the kitchen. However, it is difficult to see that this should explain the whole difference.

Table 2. Average daily energy consumption and distribution energy losses for hotels

	HO1				HO2				HO3			
	kWh /day	Share of total	Wh /m2	Wh /room	kWh /day	Share of total	Wh /m2	Wh /room	kWh /day	Share of total	Wh /m2	Wh /room
$\dot{Q}_{HW}$	1581	75 %	74	3642	1142	85 %	47	3216	432	81 %	88	2617
$\dot{Q}_{HWC}$	527	25 %	25	1215	194	15 %	8	547	102	19 %	21	618
$\dot{Q}_{distr}$	2108	100 %	99	4856	1336	100 %	55	3763	534	100 %	108	3235

Table 2 shows the daily average energy consumption for consumed DHW and the distribution losses (in the circulation system). When comparing the circulation losses, it is important to note that in HO1 it was discovered that the circulation system was highly unbalanced. A large part of the circulation system did not have sufficient flow to maintain the temperature. This will result in lower distribution losses, but parts of the hotel will have long waiting time for hot water. Based on the knowledge from HO1 one can question if the circulation system at the other hotels are working properly. This especially applies to HO2, which has very low specific losses (Wh/m^2)

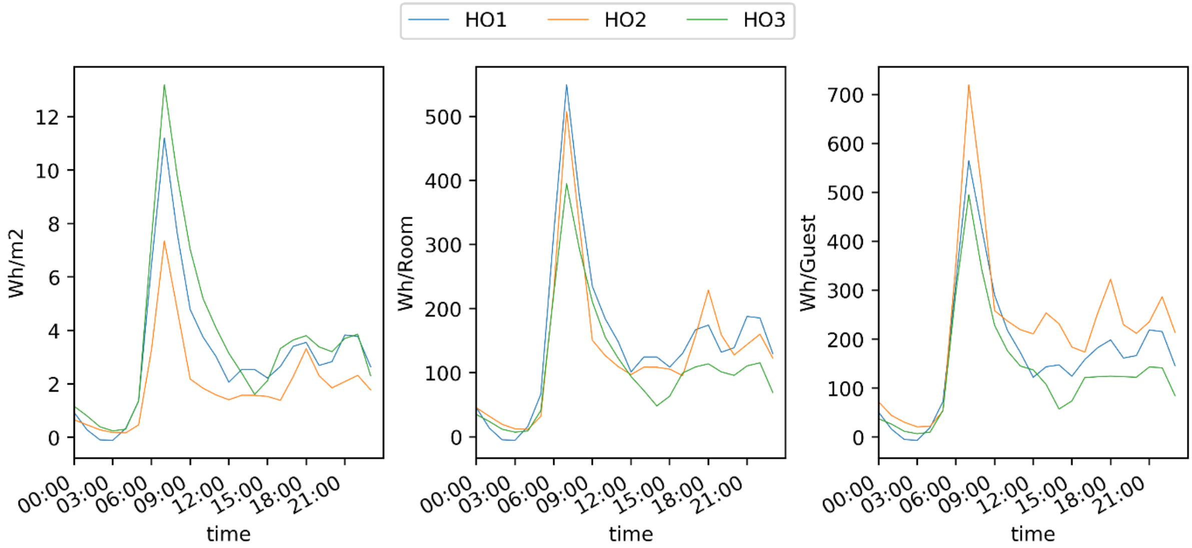

Figure 2. Daily mean energy consumption with hourly resolution for hotels per area, number of rooms and guests

4.2. Nursing Homes

Figure 3 shows the daily mean energy profile for nursing homes per heated floor area and per guest room. The shape of profiles show that the nursing homes have similar routines when it comes to DHW use, linked to morning routines and scheduled meals.

Again, one can see that the profiles per room deviates less than per square meter. For the energy consumption per room, NH1 stands out with a higher consumption. However, the measurements at NH1 were performed during winter, and the measurements at NH2 and NH3 during summer. Gerin et al. [7] showed how the consumption of hot water varies with season, mainly driven by the variation in cold water inlet temperature. During winter extra energy is needed to heat the cold water with lower inlet temperature. We measured an average difference in cold water inlet temperature of about 6 °C between NH1, and NH2 and NH3. This can explain 70% of the difference in daily energy consumption between NH1 and NH2.

Table 3. Average daily energy consumption and distribution energy losses for nursing homes

	NH1				NH2				NH3			
	kWh /day	Share of total	Wh /m2	Wh /room	kWh /day	Share of total	Wh /m2	Wh /room	kWh /day	Share of total	Wh /m2	Wh /room
$\dot{Q}_{HW}$	420	61 %	36	2836	111	63 %	33	2087	91	89 %	13	1823
$\dot{Q}_{HWC}$	272	39 %	23	1838	65*	37 %*	20*	1235*	12	11 %	2	234
$\dot{Q}_{distr}$	692	100 %	60	4674	176	100 %	53	3322	103	100 %	15	2057

* Energy consumed by electric heat tracing.

Table 3 shows the daily average energy consumption for consumed DHW and the distribution losses (in the circulation system or electric heat tracing). NH3 stands out with very low circulation losses. This turned out to be due to a large part of the circulation system being bypassed and that most of the circulation water returnes back to the hot water production unit. The measured temperature drop in the circulation loop was 0.5-1.0 °C. What is interesting, is the relatively high energy consumption of the heat tracing system in NH2. With reduced piping length (no circulation pipe), it would be expected that the energy consumption would be lower. In addition, local temperature measurements in the distribution show that the heat tracers are not able to sustain the hot water temperature above 45 °C during periods with low consumption. This indicates that the heat tracing system is very dependent on correct installation, to make sure that the energy is transferred into the DHW and not the surroundings.

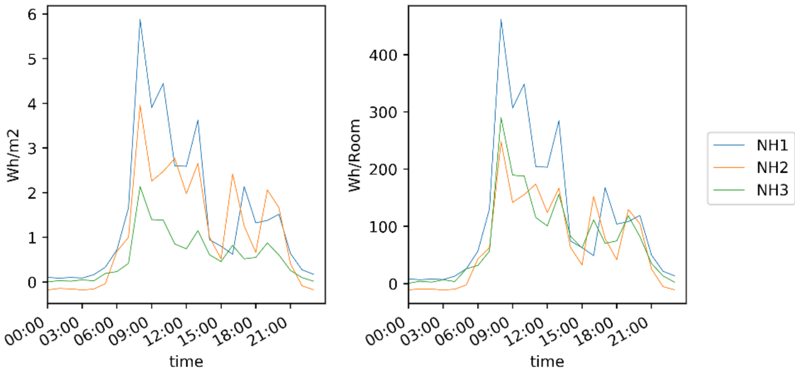

Figure 3. Daily mean energy consumption with hourly resolution for nursing homes per area and per bedrooms

4.3. *Comparison with national normative profiles*

Figure 4 shows a comparison between the measurement data and the Norwegian normative profiles. The normative profiles are used for verification of the building energy performance against the national regulation on technical requirements for construction works [8]. The normative profiles are defined by kWh per sqm of heated floor area. For the hotels, the daily energy consumption is similar, but the daily profile deviates significantly. The normative profile includes an afternoon peak, that is not seen in the measurements, but the measured morning peak is higher. For the nursing homes, the normative profiles are the same as for the hotels, while the measurements in the three buildings show significantly lower consumption. The normative profiles are not meant for dimensioning of hot water systems in buildings, but for calculation according to the building regulations. However, the building regulations have requirements to the design of the energy supply system (no fossil fuels and central distribution system). These requirements do only apply for 60% of the yearly heating energy demand (space heating, ventilation heating and DHW). Therefore, the applied values for DHW can have a large influence on the requirements to both the DHW production system and the heating system.

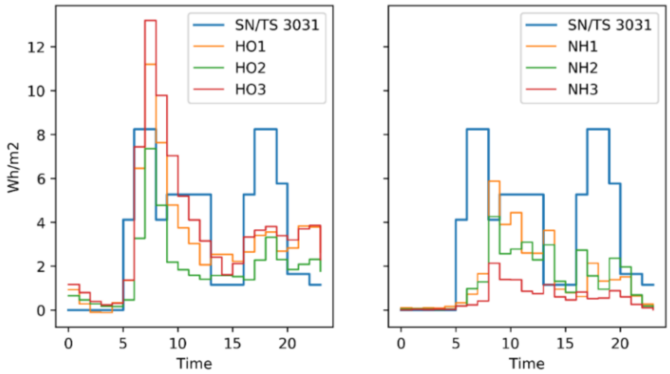

Figure 4. Comparison between the measurements and the Norwegian normative profiles *[4]*.

4.4. *Measures for reduced energy losses*

In general, the measured relative distribution losses are smaller than expected based on previous studies [3,9]. However, there are several indications that this is at least partly due to malfunctions in the circulation system. The most obvious measure for reduced energy losses is to increase the insulation of the system. When designing new buildings and DHW systems it is important to consider the location of tapping points and the optimal path for distribution lines. Electric heat tracing can also be an efficient option [3], especially in Norway where DHW is often produced with direct electric heating, but it requires high quality installation to operate efficiently.

5. Conclusion

Measurements on energy consumption for DHW production have been performed in three hotels and three nursing homes. The results show that sqm of heated floor area, which is often used, is a poor parameter for describing specific energy consumption. The measurements show large differences in the distribution energy losses, and in several cases, these are lower than expected. The measurements indicate that more than 50% of the measured circulation systems are not working as intended. Compared to the normative values used for calculations against the technical building regulations, the measurements from nursing homes deviated significantly on both daily and hourly basis, and this can have significant impact on the design of the building energy system. The conformity of the measured profiles and consumption may indicate that they are representative for the building categories. All the three have significantly lower consumption than the norm. However, three buildings in each category are not enough to give a statistically valid basis for defining new standard values, so more measurements are necessary.

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