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## Domestic hot water system in residential buildings

*Production, distribution and consumption energy loss. Monitoring campaign in two Danish detached houses*

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# Domestic hot water system in residential buildings: production, distribution and consumption energy loss. Monitoring campaign in two Danish detached houses.

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**Abstract.** The share of the energy use for domestic hot water (DHW) in the total energy consumption of buildings is becoming more and more prominent. Depending on the building typology it varies between 20% to 50% of the total energy usage for old and new built single family house, respectively. The aim of this paper is to determine the energy losses in the DHW installation with division between: a) loss at the production point, b) loss in the distribution, and c) loss at the draw-off points using the results of the measurements of DHW consumption in two single family houses connected to district heating grid. The total  $E_{\text{loss}}$  for the two houses vary between 17% and 26%. For House 1, the production loss accounts for 8%, the pipe loss for 15% and loss at the draw off points for 3%. Moreover, the results shown that the layout of the house, in particular the placement of the bathrooms with showers or bath tubs has significant impact on the size of the distribution losses.

## 1. Introduction

Building sector is accountable for 40% of the global CO<sub>2</sub> emissions and 30% of worldwide energy use [1], improvement of the building efficiency has been clearly identified as a key solution to tackle current and pending environmental and energy challenges [2]. Within the last decade, more stringent demands for space heating and electric energy consumption together with new, lower energy frames have become effective. However, with regards to the energy use for preparation and distribution of the domestic hot water (DHW) no significant changes have been made. The same standard value of 250 L/m<sup>2</sup> year for DHW consumption as 15 years ago is still used for energy performance calculations for single-family houses, even though several studies have pointed the consumption rates of DHW has decreased since 2000 [3–5].

Consequently, the share of the energy for DHW in the total energy consumption of buildings is becoming more and more prominent [6]. Various campaigns on DHW have assessed that an average Danish dwelling dedicates between 20% to 35% of the total energy need to DHW production and operation [4,7]. The values further increase to around 40 to 50% of the total energy usage for low-energy building [4,7,8]. The DHW installation can be divided into three parts: production, distribution and consumption of the hot water. As summarized by Pomianowski et al. [6] in their review the energy losses in the DHW have been measured for very few buildings and the focus was primarily on the circulation losses [7]. However, with the introduction of PEX pipes and use of manifold in the DHW



installations in detached single family houses, the circulation installation is no longer part of the DHW installation design.

Therefore, the aim of this study is to provide novel knowledge into the area by measuring the DHW consumption in two single-family houses in Denmark. The objective of the measurement campaign is to determine the energy consumption for producing DHW and to identify the energy losses with division between: a) loss at the production point, b) loss in the distribution, and c) loss at the draw-off points.

## 2. Methodology

This sections includes the description of case building and the monitoring set-up used to measure the energy losses in the DWH installation.

### 2.1. Case buildings

The DHW measurements were conducted in two detached single-family houses located in Denmark. House 1 & 2 are built in new established neighborhoods and represent the catalogue houses. Family in House 1 represents the typical “2+2” working family, and the occupants in House 3 are a young working couple involved in many sport activities. Table 1 summarizes the key characteristics on the case buildings.

**Table 1.** Details on the case buildings.

Case ID	House 1	House 2
		
Heated floor area [m <sup>2</sup> ]	195	160
Construction year / valid building code	2013 / BR10	2017 / BR15
Number of bathrooms	2	2
Circulation installation	NO	NO
Monitoring period	September – October 2018	March – April 2019
Selected day for analysis	13 September 2018	11 April 2019

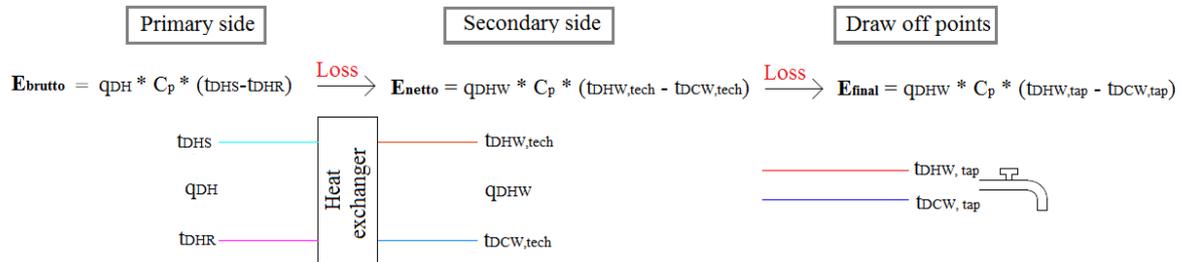
Both case buildings are connected to the district heating (DH) grid. Yet, the DHW production compose of different technologies. In House 1, DHW is produced by the plate heat exchanger thus no water tank is present. In House 2 the DH is the secondary heat source for DHW preparation, because the house is equipped with a compact heat pump (HP), which is a complementary ventilation and heating system providing the house with ventilation, heat recovery and production of DHW. The DH is used to heat up the DHW only if the HP cannot meet the demand.

DHW installation in both case houses is made from PEX pipes and a manifold in star plumbing circuit. The DHW pipe network of Ø15 is located above the ground deck insulation in order to utilise the distribution heat losses for additional space heating.

### 2.2. Monitoring set-up

The measurement set-up installed in each house consists of two parts: i) the high resolution measurements of flow and temperature of cold and hot water at each draw off point and ii) the energy meters at the DHW production point in the technical closet. The set-up at each draw off point in House 1 and House 2 includes two Huba flow sensors type 236 [9] (1 for cold and 1 for hot water) a waterproof box with Arduino micro board and power supply. In House 1 the set-up at the DHW production point includes Ultrasonic Flow Transmitters (KATflow) [10] at the DHW supply pipes to manifold and at the DH supply and return pipes. In House 2 the energy used for DHW production is monitored by the BMS system. Figure 1 presents the main measuring points and formulas used for energy calculations at different

points in the DHW installation. The data was collected with the resolution of 8 Hz. Further details on the monitoring set-up and campaign can be found in [11].



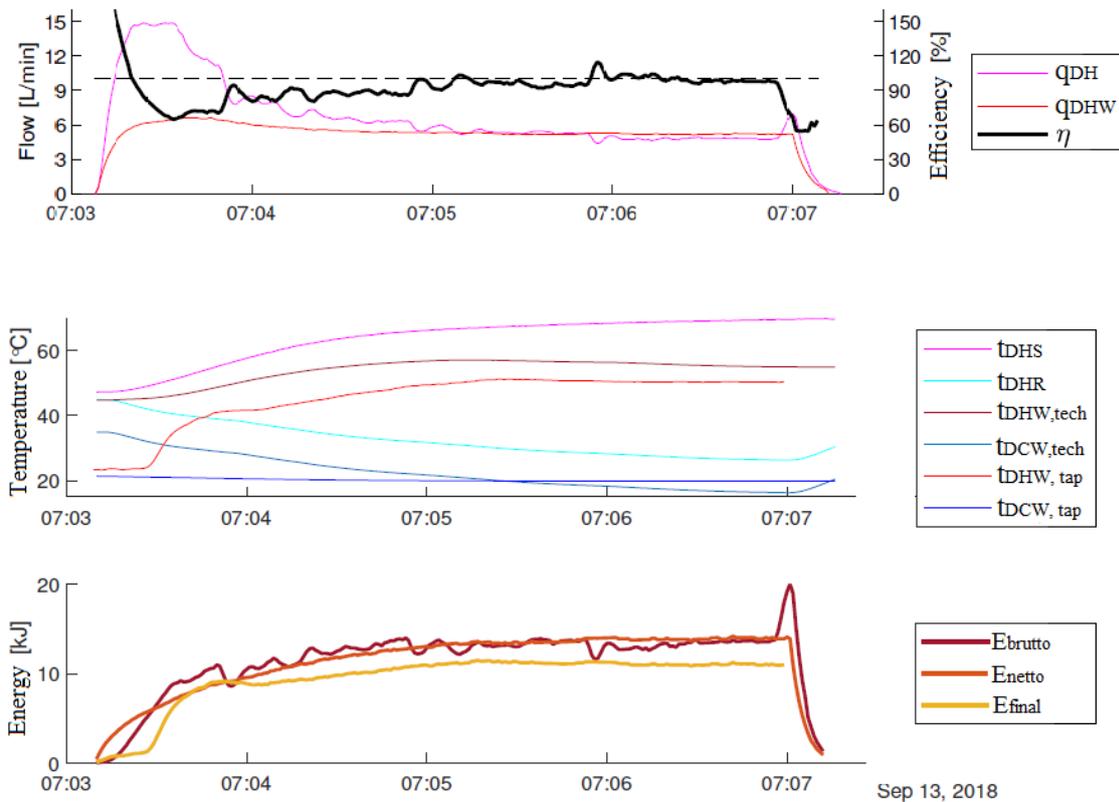
**Figure 1.** Principle schematic of energy loss and indication of measuring points in the analysed buildings.

### 3. Results

Due to challenges with the measurement equipment and difficulties in obtaining high quality data simultaneously from sensors in technical room and at all draw off points, the energy losses are presented only for the selected dates given in Table 1. In these dates neither missing data nor errors were registered in the time series.

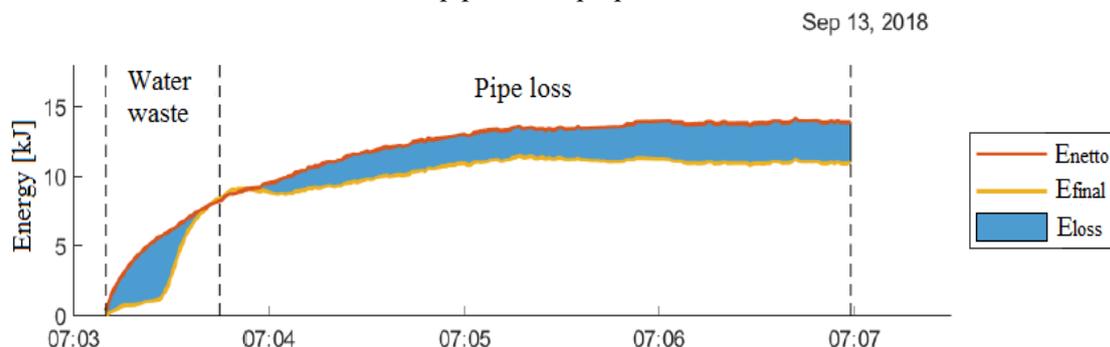
#### 3.1. Case building: House 1

An example of temperature, flow and energy loss in DHW installation first shower in the morning is presented in Figure 2. At the very beginning, the energy on secondary side ( $E_{netto}$ ) is bigger than energy on primary side ( $E_{brutto}$ ) and in consequence the heat exchanger efficiency is above 100%, which in principle cannot be true. It is a consequence of the temperature sensors of KATflow meter, which are located on the pipes with thermal inertia and thereby are initially influenced by high temperature in the technical closet rather than by temperature of standing still water in pipes. Thereafter, the temperature difference for district heating water increases and  $E_{brutto}$  exceeds  $E_{netto}$  DHW production efficient below 100%. Approx. 2 minutes inside the bath, at 07:05, stationary conditions are obtained ( $q_{DH} = q_{DHW}$  and  $\Delta t_{DH} = \Delta t_{DHW}$ ) leading to efficiency close to 100%. Due to the after-run (increase of flow at the primary side, which is a consequence of settings at the differential pressure controller), the energy consumption on the primary side increases at the end of the bath, which results in efficiency decrease. Across the entire bath, an average efficiency of 95% is obtained, corresponding to energy loss of 5%. The average efficiency of the second bath, which takes place 30 min after the first shower, is 92%.



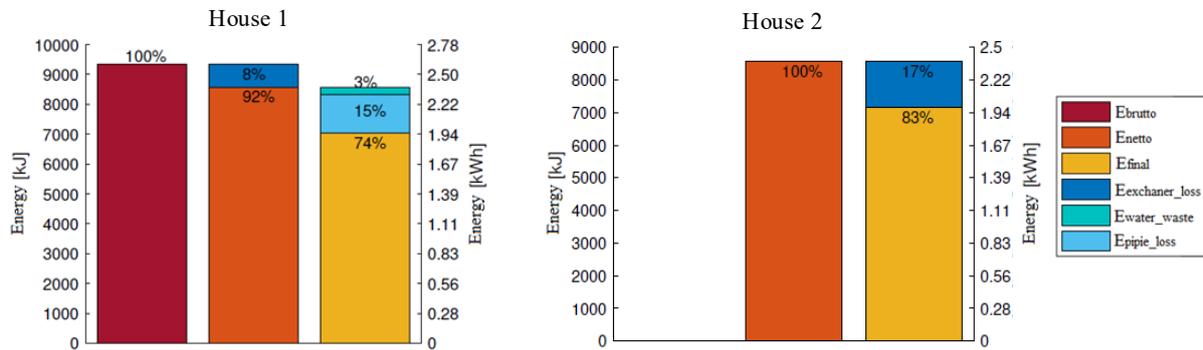
**Figure 2.** Flow, temperature and energy use for respectively  $E_{brutto}$ ,  $E_{netto}$  and  $E_{final}$  during the first shower in House 1 on 13/9.

As depicted in Figure 2, the energy at the draw off point ( $E_{final}$ ) is throughout entire shower the lowest energy, and the difference between  $E_{netto}$  and  $E_{final}$  reflects the heat loss ( $E_{loss}$ ) on DHW distribution pipes, seen also on Figure 3. Finally as shown in Figure 2, there is also initial loss related to water waste, and waiting time for acceptable comfort temperature. This loss is especially high for the first morning shower since detected waiting time is at 36 seconds until water reaches 40 °C. It is estimated that  $E_{loss}$  is divided between water waste and pipe loss in proportion 15% to 85%.



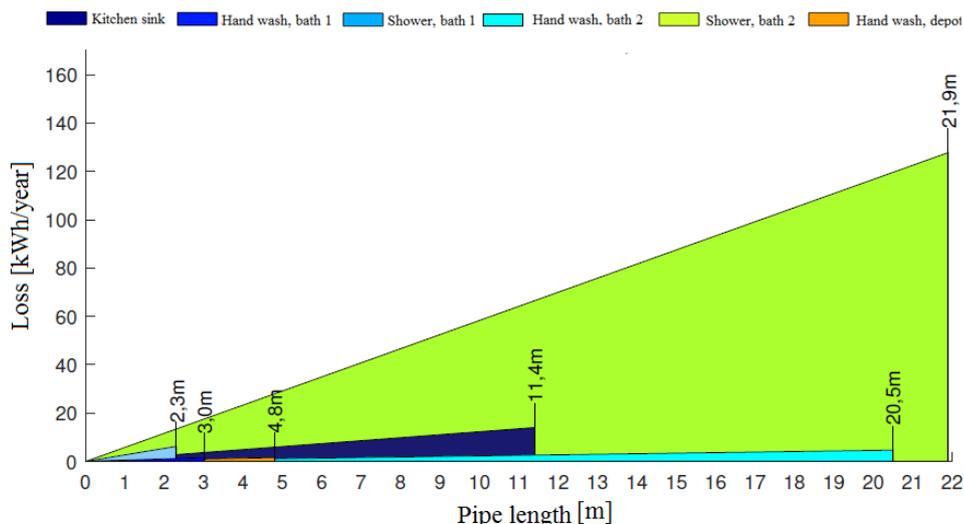
**Figure 3.** Indication on energy loss related to waste water due to waiting time and heat loss from DHW distribution pipes.

As presented in Figure 4 data collected on one selected day in House 1 indicates that 8% of energy is lost due to heat exchanger efficiency, 15% is lost from the DHW distribution pipes (only part of this heat is utilized for space heating) and 3% is related to waste water and waiting time for comfort temperatures.



**Figure 4.** Daily average distribution of energy use and loss in DHW system in House 1 and House 2.

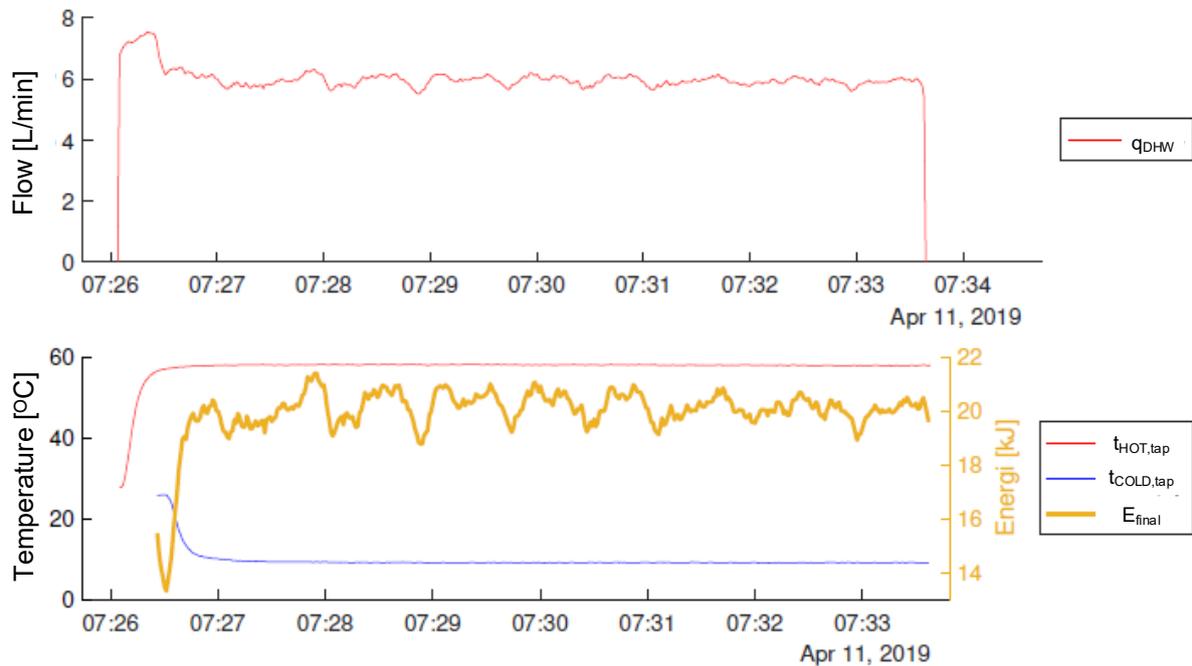
With the assumption that the heat loss registered from the technical room to draw off points on the selected day is representative for the average day the annual heat loss can be calculated in total at 156 kWh/year, with the shower in bathroom 2 being the critical and responsible for the energy loss of 128 kWh/year (82%). Consequently, taking the difference between  $E_{netto}$  and  $E_{final}$  and distribution of the DHW use between the draw off points described in [12] together with DHW pipes thermal characteristics the energy loss in DHW distribution assigned to each draw off point can be assessed. Results are depicted in Figure 5.



**Figure 5.** Estimated annual energy loss for water waste and pipes depending on the pipe length of the domestic water system in House 1.

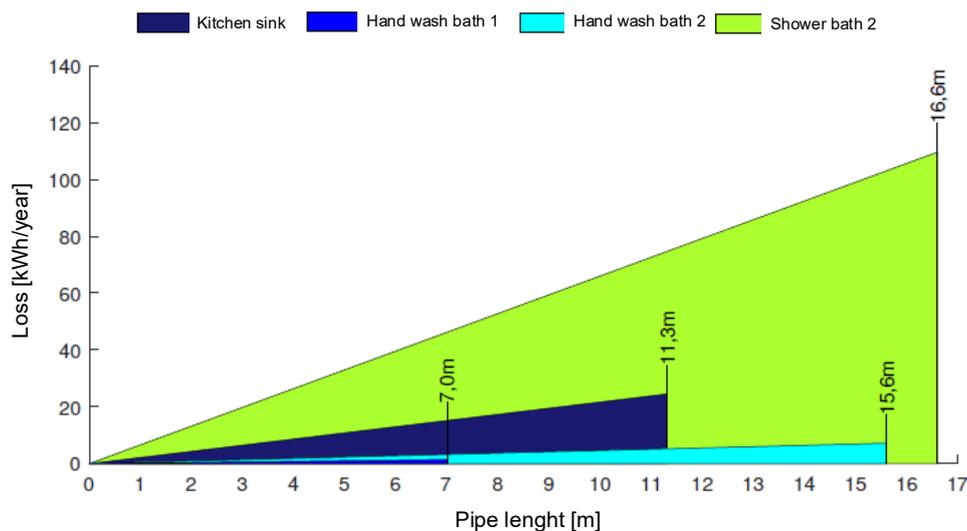
### 3.2. Case building: House 2

In House 2 the heat pump is the primary source of the DHW and during the measurements period there was no need for activation of district heating. Therefore,  $E_{brutto}$  and heat exchanger efficiency-  $\eta$  cannot be calculated. From the DHW draw and temperature profile depicted on Figure 5, can be seen that the flow at the beginning of the bath is slightly higher until the hot water temperature reaches approx. 58°C and cold water is mixed into the tap.



**Figure 6.** Flow, temperature and energy use for  $E_{\text{final}}$  during shower in House 2 on 11/4.

The same calculation method of  $E_{\text{final}}$  was used for each draw off point in the house and for every day during the measurement period. The  $E_{\text{netto}}$  data was obtained from the BMS system. Afterwards the daily average distribution of energy use and loss was calculated, see Figure 4.  $E_{\text{netto}}$  accounts for 100% of energy consumption, which is approx. 2.3 kWh per day with an average distribution loss from technical rooms to draw points at 17%. The annual energy loss is estimated for 144 kWh/year. Also in House 2 the shower is responsible for majority of this energy loss, namely 110 kWh/year (76%), see Figure 7.



**Figure 7.** Estimated annual energy loss for water waste and pipes depending on the pipe length of the domestic water system in House 2.

#### 4. Conclusions

This paper presents high frequency measuring campaign on energy loss from DHW taking account for a) loss at the production point, b) loss in the distribution, and c) loss at the draw-off points. Measuring campaign has been conducted in two single family houses with DHW distribution system typical for new catalogue houses and none of the monitored houses being equipped with DHW circulation system. The total  $E_{\text{loss}}$  for the two houses vary between 17% and 26% and accounts to waste water (waiting time for hot water), pipe losses and exchanger losses. In the study in the House 2 in which DH is not activated and entire DHW is produced by the HP the exchanger loss is not possible to determine. It is also the reason why loss in the House 2 is smaller by 9% from House 1 and the difference can be accounted to exchanger loss. Moreover, in both of the houses the location of the bathrooms with the most often activated showers are furthest from the technical rooms. As indicated in Figure 5 and Figure 7 it is the loss related to shower activity that constitute the major energy loss of losses allocated to different draw-off points' actions. Therefore, it can be concluded that for the energy efficient operation of the DHW system bathrooms with showers or bath tubs should be located as close as possible to the technical rooms/production of DHW. Finally, if the houses were equipped with circulation systems the  $E_{\text{loss}}$  accounted to energy loss on circulation pipes would be expected to represent highest share of total energy loss and the objective would be to design distribution systems with shortest possible circulations.

The results of this study cannot directly be aggregated to the whole building stock as energy losses in the DHW installation are correlated with the type, age and configuration of components. Yet, the results are applicable to the DHW systems in residential buildings with a manifold in star plumbing circuit, which constitute 11% of the Danish building stock (i.e. detached and semi-detached houses built after 2000) [13].

Another important conclusion from this monitoring campaign is that measurements must be conducted with very high frequency in order to be able to capture very short DHW draw-off events. In this study 8 Hz was used based on the lesson learned from authors' earlier work that was document in [11].

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