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**Abstract.** Sizing of domestic hot water pipes are to a large extent based on calculations of peak flow rate according to current guidelines. This article compares detailed field measurements of peak flow rates in Norwegian hotels, nursing homes and apartment buildings with calculated values according to Norwegian NS 3055, German DIN 1988-300 and European EN 806-3 code of practice. Results indicate that existing guidelines overestimate the peak flow rate by a factor of 1.2– 2.6, depending on type of building and which standard the calculations are based on. In most cases, this also resulted in oversizing the pipes. Calculations according to NS 3055 are closest to the field measurements, on average overestimating the peak flow rate by a factor of 1.6. To analyze the effect of different measurement intervals, the measured peak flow rate is also calculated as a moving average for different time steps (t). Compared to using an interval of 2 s, averaging the data over 10 s would underestimate the peak flow rate by a factor of 0.80– 1.0. Using a 30 s interval would underestimate the peak flow rate by 0.67– 0.94.

## 1. Introduction

As a result of an increased insulation rate and more efficient space heating systems, the energy demand for domestic hot water (DHW) is a substantial part of the total energy demand in newer buildings [1] [2]. The European Union sets a goal that by the end of 2020, all new buildings should be nearly zero-energy buildings [3]. Oversized DHW systems lead to increased energy losses, both directly due to the increased area for heat loss, but also due to inefficient operation [4]. Norwegian building acts and regulations (TEK) sets technical requirements to drinking water installations. Energy efficient DHW production and distribution systems also need to i.e. maintain the desired comfort level of its' end users and the hygienic quality of the water [5]. Optimal design of DHW systems, including selection of proper pipe sizes and thermal operating strategies, therefor becomes increasingly more important.

The peak flow rate is a basic parameter in hydraulic design of drinking water installations that predicts simultaneous demand during service conditions. Sizing of domestic hot water pipes according to Norwegian NS 3055 [6], German DIN 1988-300 [7], and European EN 806-3 [8] codes of practice are to a large extend based on calculations of peak flow rate. The number of, and the design flow rates for the different types of draw-off points, are used to calculate the peak flow rate for a given pipe run, with the corresponding coincidence factor. With new types of mixing valves, IoT-based technologies and water saving aerators, the basis for calculations is believed to be out-dated [9]. Studies from Belgium [10], UK [4] and Denmark [11] also suggest that current codes of practice oversize DHW installations inside buildings.

The objective of this work is to improve knowledge about peak flow rates for DHW systems by comparing calculations according to current codes of practice with field measurements. The paper also drafts the impact of different time steps for analysis of measurement data.

## 2. Method

### 2.1. Field measurements of peak flow rate

Included in this study are three hotels (HO), three nursing homes (NH), and two apartment buildings (AB) in Oslo and Drammen (Norway). See table 1 for description of buildings included in the measurement campaign. The number of mixing taps for different type of draw-off points are derived from detailed floor plans, technical drawings, visual observations on-site, and information from building owners.

**Table 1.** Number of different types of mixing taps

| Building | # Rooms or apt. | Wash basin | Kitchen sink | Shower | Bath tub |
|---|---|---|---|---|---|
| HO 1 | 434 | 514 | 31 | 316 (292[a]) | 173 |
| HO 2 | 355 | 527 (423[a]) | 30 | 275 (260[a]) | 105 |
| HO 3 | 165 | 178 | 18 | 161 | 0 |
| NH 1 | 148 | 175 | 121 | 158 | 0 |
| NH 2[b] | 52 | 53 | 4 | 52 | 0 |
| NH 3[b] | 50 | 55 | 5 | 55 | 0 |
| AB 1 | 56 | 56 | 56 | 56 | 0 |
| AB 2 | 96 | 96 | 96 | 96 | 0 |

[a] DIN 1988-300 exclude a second wash basin and shower tray in addition to bath tub within one usage unit. Numbers used for calculation of peak flow rate according to the German standard.
[b] Number and type of mixing tap estimated based on number of rooms. It is assumed that each room have a wash basin and shower. Additional tapping points based on inspection.

Detailed measurements of water flows and temperatures were performed on the DHW production system in each building's heating plant, for a duration of approx. 6 weeks. The measurements were conducted with an interval of 1s, and then averaged for 2s before analysis. In order to avoid modifications to the water installations, non-intrusive clamp on ultra-sounds flow meters [12] and thermocouples mounted on the pipe outer wall were used [13]. Figure 1 is a principle drawing of DHW system layout with placement of measurement points.
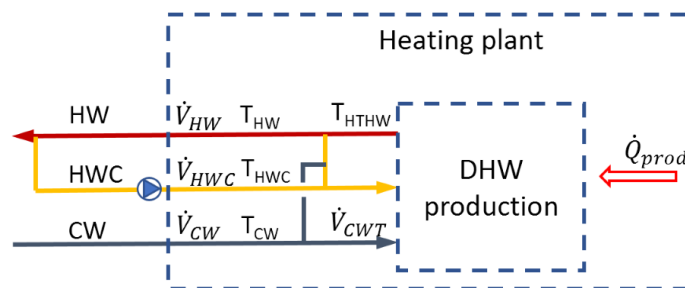


**Figure 1.** Principle drawing of DHW heating plant with measurement points.

where
$\dot{V}_{CW}$      is the cold water flow rate into the DHW production unit in [l/s];
$\dot{V}_{CWT}$      is the cold water flow rate at the inlet of DHW production in [l/s];
$\dot{V}_{HW}$      is the hot water flow rate to the distribution system in [l/s];
$\dot{V}_{HWC}$      is the hot water circulation flow rate in [l/s];
$T_{CW}$      is the cold water temperature in [°C];
$T_{HW}$      is the hot water temperature in [°C];
$T_{HTHW}$      is the hot water production unit outlet temperature in [°C];
$T_{HWC}$      is the hot water circulation temperature in [°C].

*2.2. Calculations*

*2.2.1 Water flow rate for hot water production.* Some buildings had short pipe sections where the flow branches off. This made it challenging to achieve accurate measurements of $\dot{V}_{CW}$ without interference from adjacent pipe runs. For these buildings, cold water flow rate into the production unit was then calculated according to equation (1).

$$\dot{V}_{CW} = \dot{V}_{HW} - \dot{V}_{HWC} \tag{1}$$

*2.2.2 Conversion to standardized DHW peak flow rates.* Measured DHW consumption were converted into standardized DHW peak flow rates according to equation (2). This, in order to factor in building specific conditions [10] and seasonal variations [14].

$$\dot{V}_{6010} = \dot{V}_{CW} \times \frac{\frac{(T_{DHW} - T_{CW})}{(T_{MIX} - T_{CW})} \times (T_{MIX} - 10)}{(60 - 10)} \tag{2}$$

where

| | |
|---|---|
| $\dot{V}_{6010}$ | is the calculated standardized peak flow rate; |
| $\dot{V}_{CW}$ | is the measured cold water flow rate for hot water production – see equation (1); |
| $T_{DHW}$ | is the average temperature of hot water at the active draw-off site(s) at the time in question; |
| $T_{CW}$ | is the average temperature of cold water at draw-off site(s) at the time in question. Minimal warming of the cold water from the main inlet to draw-off site is assumed. Any stagnant water in the pipe that might have been warmed up since the last draw is neglected. The cold water temperature measured in the heating plant is therefore used – see equation (4); |
| $T_{MIX}$ | is the average outlet temperature of the mixed water at draw-off site(s). A value of 38 °C is used. |

Since end-user measurements of flow and temperature were not available, the average temperature of hot water at draw-off site(s) was calculated from measurements of hot water departure temperature and the hot water circulation return temperature according to equation (3).

$$T_{DHW} = T_{HW} - \left(\frac{T_{HW} - T_{HWC}}{4}\right) \tag{3}$$

During the measurement campaign, a rather high cold water temperature was found in some buildings during periods with no hot water consumption. It is assumed that malfunction or the lack of check valves caused hot water from the DHW production unit to flow back into the cold water pipe. A weighted average of all cold water measurements according to equation (4) is therefore used.

$$\overline{T_{CW}} = \frac{\sum_{i=1}^{n} T_{CW,i} \times V_{CW,i}}{\sum_{i=1}^{n} V_{CW,i}} \tag{4}$$

*2.2.3 Analysis of peak flow rate with different time intervals.* DHW consumption can be characterized by short intervals with high consumption followed by long idle periods. To analyze this effect, the measured peak flow rate is calculated as a moving average for different time intervals (t).

$$\dot{V}_S(t) = MAX\left(\frac{1}{t}\sum_{i=1}^{t} \dot{V}_{6010,i}\right) \tag{5}$$

## 3. Results and discussion

### 3.1. Peak flow rate

Results from field measurements and calculations into standardized values for different time steps are presented in table 2. Variations of cold water temperature in the different buildings can be linked to the measurement period. A lower cold water temperature require a higher hot water flow to produce a set mixed temperature at draw-off site. Converting the measured peak flow rate into a standardized value according to equation (2) takes season variations of cold water temperature, building specific DHW production temperature and heat losses throughout the flow path into account. In order to compare the impact of different time steps, despite different DHW consumption, a ratio of $\dot{V}_S(t)/\dot{V}_S(2s)$ is plotted for each building in figure 2.

**Table 2.** Measured and converted DHW peak flow rates with different time intervals

| Building | Measurement period in 2018 | $\overline{T_{CW}}$ [°C] | $T_{HW}$ [°C] | $\dot{V}_{CW}$ (2s) [l/s] | $\dot{V}_{6010}$ (t) [l/s] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | (2s) | (10 s) | (30 s) | (60 s) | (300 s) |
| HO 1 | April – May | 4.8 | 64.2 | 3.3 | 3.2 | 3.1 | 3.0 | 3.0 | 2.8 |
| HO 2 | Aug. – Sept. | 13.1 | 63.4 | 2.7 | 3.3 | 3.2 | 3.1 | 3.0 | 2.7 |
| HO 3 | Aug. – Sept. | 9.6 | 67.1 | 1.3 | 1.5 | 1.4 | 1.3 | 1.2 | 1.0 |
| NH 1 | Jan. – Feb. | 6.8 | 59.2 | 1.9 | 1.7 | 1.6 | 1.5 | 1.4 | 0.9 |
| NH 2 | May – June | 12.9 | 66.5 | 0.6 | 0.8 | 0.7 | 0.7 | 0.6 | 0.3 |
| NH 3 | May – June | 11.8 | 54.8 | 0.7 | 0.6 | 0.6 | 0.5 | 0.4 | 0.3 |
| AB 1 | Oct. – Dec. | 9.1 | 65.5 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.4 |
| AB 2 | Oct. – Dec. | 9.8 | 62.1 | 1.5 | 1.5 | 1.2 | 1.0 | 1.0 | 0.7 |
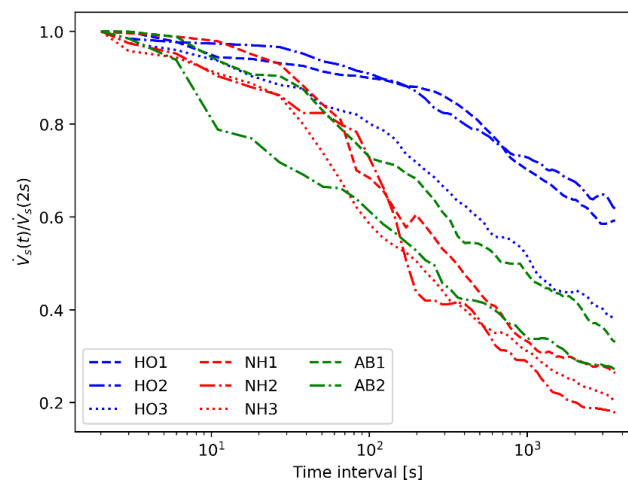


**Figure 2.** Measured peak flow rates with different time intervals. Ratio of $\dot{V}_S(t)/\dot{V}_S(2s)$.

Compared to using an interval of 2 seconds, averaging the data over 10 s would underestimate the peak flow rate by a factor of 0.80– 1.0. Using a 30 s interval instead would underestimate the peak flow rate by 0.67– 0.94, a 60 s interval would underestimate the peak flow rare by 0.67– 0.94, and a 300 s interval would underestimate the peak flow rate by a factor of 0.47– 0.88. As expected, a longer measurement interval is more critical for buildings with less frequent hot water consumption.

### 3.2. Comparison with calculated peak flow rates according to current code of practice

For each building where field measurements were conducted, DHW peak flow rate is calculated according to NS 3055, DIN 1988-300 and EN 806-3. The calculations are then compared to results from field measurements. In most cases the three guidelines overestimate the peak flow rate (factor of 1.2 – 2.6). Calculations according to NS 3055 are closest to field measurements, on average overestimating

the peak flow rate by a factor of 1.6 and with a range of 1.4– 2.1. If one omits hotel buildings, DIN 1988-300 is closer to measured peak flow rates than the other two standards. See figure 3 for results.

Pipe size for each calculated DHW peak flow rate is then selected based on a simplified method according to respective standard, assuming there is enough available friction loss in the pipe run. Peak flow velocity for the different pipe sizes, at the measured peak flow rate $\dot{V}_{6010}(2s)$, are then derived from nomograms for copper pipes with a hydraulic roughness of $k= 0.0015$ mm. See figure 4 for results.
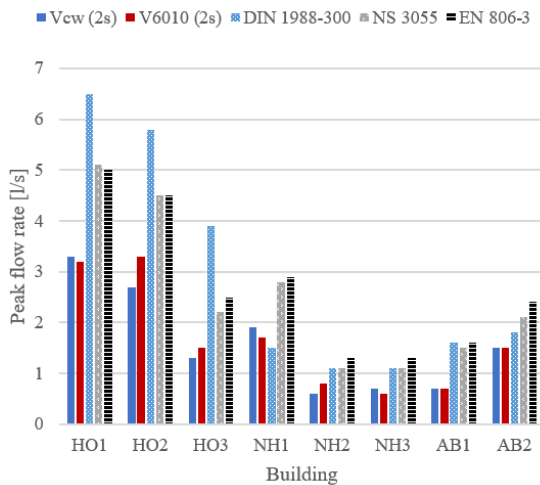


**Figure 3.** Comparison of measured and calculated peak flow rates. $\dot{V}_{CW}(2s)$ is the measured cold water flow rate for hot water production. $\dot{V}_{6010}(2s)$ is the measured value converted into a standardized peak flow rate. Field measurements were performed for a duration of approx. 6 weeks.
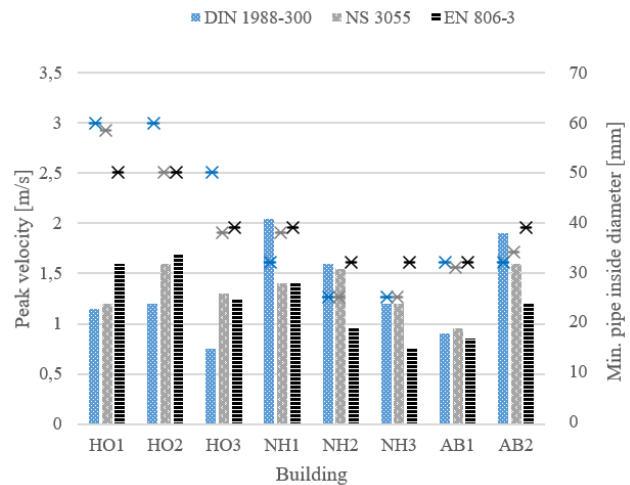
**Figure 4.** Selection of copper pipe size according to DIN 1988-300, NS 3055 and EN 806-3 based on calculated DHW peak flow rates in figure 3. Pipe size on secondary axis marked with an x. Peak flow velocity for the different pipe sizes, at measured peak flow rate $\dot{V}_{6010}(2s)$ in each building, are derived from nomograms.

Selection of DHW pipe size should ensure that each draw-off site has enough water flow at times with peak demand. The available pressure difference, hygienic quality of the water, waiting time for hot water, wear and tear (corrosion), noise, and risk of water hammer should also be taken into consideration. Several of these factors will work against each other and it can be difficult to determine which one(s) to base pipe sizing on. Type of building and its intended area of use will affect the performance requirements and consequentially the basis for pipe sizing. Oversizing is associated with higher investment costs, but may also lead to inefficient operation of e.g. pump sets and valves. In addition to pipe size, the length of the distribution pipes and their flow path is important. To reduce heat losses and the waiting time for hot water, DHW production should be placed as close to the tapping points as possible. System design is hence important.

*3.3. Limitations*
Field measurements were performed for a limited amount of time. It is therefore uncertain to what extent the DHW consumption for the measurement period is representative for the whole year and the technical lifetime of the DHW system. In addition, the occupancy rate of the hotels and the number of residents present in the nursing homes and apartment buildings during the measurement period is also a factor.

Building specific conditions and end user behavior also influence DHW consumption. The amount of hot water leaving the production unit(s) is depending on the desired water temperature at draw-off site(s). Measurements were carried out in the central heating plant with little knowledge of, and access to, the distribution and circulation pipe runs. Supply pressure, individual head and heat losses throughout the system are therefore unknown as well as the inlet and mixed temperature at draw-off site(s). When converting to standardized values of $\dot{V}_{6010}(2s)$, an estimated average outlet temperature of the mixed water at draw-off site(s) was therefore used.

## 4. Conclusion

Field measurements of peak flow rates have been performed in three hotels, three nursing homes, and two apartment buildings in Norway, during a 6 weeks measurement period. When comparing measurements with calculated values according to Norwegian NS 3055, German DIN 1988-300, and European EN 806-3 code of practice, results indicate that existing guidelines overestimate the peak flow rate by a factor of 1.2 – 2.6. In most cases, this also resulted in oversizing the pipes. Calculations according to NS 3055 are closest to field measurements, on average overestimating the peak flow rate by a factor of 1.6

To analyze the effect of different measurement intervals, the measured peak flow rate is calculated as a moving average for different time intervals (t) and plotted as a ratio of $\dot{V}_S(t)/\dot{V}_S(2s)$. Compared to using an interval of 2 s, averaging the data over 10 s would underestimate the peak flow rate by a factor of 0.8– 1.0. Using a 30 second interval would underestimate the peak flow rate by 0.67– 0.94.

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