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Published in:
Building Services Engineering Research & Technology

DOI (link to publication from Publisher):
10.1177/01436244251318169

Publication date:
2025

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Kragh, J., Rose, J., & Buhl, L. S. (2025). The risks of oversizing domestic water piping - Measurement of peak flows in multistory residential buildings. *Building Services Engineering Research & Technology*, *46*(3), 361-374. https://doi.org/10.1177/01436244251318169

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This is the accepted author manuscript of the article: Kragh J, Rose J, Buhl LS.
The risks of oversizing domestic water piping – Measurement of peak flows in multistory residential buildings.
Building Services Engineering Research & Technology. 2025;0(0). Copyright: © The Author(s) 2025. doi:10.1177/01436244251318169

The risks of oversizing domestic water piping – Measurement of peak flows in multistory residential buildings

Jesper Kragh[a,*], Jørgen Rose[a], Leon Steen Buhl[b]

[a] Department of the Built Environment, Aalborg University, A C Meyers Vænge 15, DK-2450 Copenhagen SV, Denmark

[b] Installation and Calibration, Danish Technological Institute, Gregersensvej 1, DK-2630 Taastrup, Denmark

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Abstract

Over the past few decades, domestic water consumption in residential areas has declined significantly. This reduction can be attributed to several factors, including the widespread implementation of individual metering, rising water prices, development of more water-efficient sanitary fixtures, and an increased public awareness of water scarcity. However, there's a growing concern that plumbing designers may be inadvertently oversizing pipe installations for domestic water due to reliance on outdated design manuals and standards that promote overly conservative methods.

Traditionally, the primary standard for dimensioning domestic water pipes in Denmark has been to ensure that the installation can deliver the required water flow rate in 99.9 percent of outlet usage instances. To investigate this issue further, a recent project conducted by the Department of the Built Environment at Aalborg University, on behalf of The Danish Authority of Social Services and Housing, involved measuring the domestic water flow in eight multi-story apartment buildings.

The findings revealed that, on average, the investigated pipe installations were oversized by a factor of 2-3. This general oversizing results in an extended retention time for domestic water within the pipes, which poses risks such as the growth of Legionella bacteria—an increasingly prevalent issue not only in Denmark.

Practical Application

The study contributes to determine whether there was indeed an oversizing of the water pipe installation, as this could potentially lead to various adverse consequences. The conclusion based on the performed flow measurements was that the guideline for designing domestic water distribution pipes in general significantly oversized both hot and cold pipes. Two proposals that reduces the design flow rate by 25% and 50% was therefore developed to update the national Danish standard DS 439[1] and during 2023 it was finally agreed in the standardization committee to implement the proposal for a reduction of 25%.

Keywords: Domestic water pipes, water consumption, oversizing, peak flow, installation design, multi-story apartment buildings, flow measurements, Legionella, LCA

1 Introduction

Over the past decade, there has been a growing concern, both domestically in Denmark and internationally, regarding the significant oversizing of water installations for domestic use. Studies conducted in Norway, USA, Mexico and the UK have shed light on this issue, revealing that existing guidelines tend to overestimate peak flow rates by a substantial margin.[2-5] Specifically, the Norwegian study, which relied on field measurements, found that peak flow rates were overestimated by a factor of 1.2 to 2.6, depending on the type of building and the standards used for calculations. Similarly, research in the UK demonstrated that measured flow rates were only approximately 20% of expected peak flow rates.

The crux of the problem from the perspective of the Danish approach to dimensioning water installations lies in the reliance on assumptions and the misapplication of safety margins, as discussed by Knight et al[6], particularly in the context of oversizing pumps. Furthermore, studies have highlighted similar issues of oversizing in both residential and nonresidential buildings[7], as well as in heating, cooling, ventilating, and air-conditioning (HVAC) units.[8-12]

These findings underscore the need for a reevaluation of current design practices and standards to ensure that water installations are appropriately sized to match actual consumption patterns. Addressing this issue has implications not only for domestic water use efficiency but also for energy consumption, cost-effectiveness, Legionella risk[13], and overall sustainability in building design and operation.

Guidelines for sizing domestic water pipes are provided in the European standard DS/EN 806-3.[14] Annex C to this standard contains a reference to a national method. When designing water installations in residential construction, simultaneity of outlets plays a significant role. In Denmark, water installations are designed based on the instructions described in the Danish standard DS 439[1] where a simultaneity consideration is assumed, which was developed in connection with SBi report 178 "*New possibilities for the design of water and drainage installations*".[15] In the probability calculations that form the basis for the designing of water installations in homes and the like, a fixed probability of 99.9% is assumed that the desired water flow can be achieved at an outlet. For the determination of pipe dimensions and calculation of the network in general, the probability principle in DS 439 is expressed through a quantity called the design water flow q_d.

However, water consumption per person in Denmark has decreased by approx. 40% since 1986[16], when the original design method was drawn up. This must also be seen in the context of changes in resident composition in many homes and the introduction of individual metering which in a Polish study was shown to result in a reduction of the water consumption by 32%.[17] Changes in resident behaviour and increased use of water-consuming installations such as sanitary installations, washing machines and dishwashers, which can also affect the simultaneous use of domestic water. Fuentes et al[18] did a comparison of residential average daily DHW consumption profiles in different countries and the EC Directive tapping cycle[19] is presented showing a significant higher peak consumption in the EC directive than the country profiles. Normally in dwellings you will have a morning and evening peak as measured in a Portuguese study[20] but the question is whether there has been a development in the size of these peaks over time. Therefore, there is a reason to investigate whether the general statistical basis for the calculation and design methodology is still reliable as a basis for dimensioning domestic water pipes.

A similar analysis of the challenges faced by plumbing system designers when sizing water pipes according to an older 1940 U.S. standard, known as Hunter's curve, is presented by Asis and Subhasish[21] and discussed further by Hobbs et al[22], and an Australian study[23] found that measured peak flows were only 29%–37% of the corresponding flow rates specified by the current Australian standard resulting in the development of a new framework for estimating the fixture-use probability for peak water demand design in multilevel residential buildings.

Most of previous methods are based on probability distribution functions, e.g., binomial distribution, however, extensive research has shown that these methods often fall short in predicting peak simultaneous flow due to the human factor in probability of use. de Souza Groppo el al[24] made a review of methods used for predicting water demand. Their review demonstrated how recent years has seen a multitude of new emerging statistical techniques, including more complex probabilistic methods, stochastic modeling, AI, and machine learning algorithms within the field of predicting peak water use. These approaches enhance traditional design methodologies by incorporating complex data patterns and uncertainties inherent in water usage. For instance, more advanced models can effectively capture variability in consumption behavior, as demonstrated in[3] where authors used semi-direct methods to simulate the use of plumbing fixtures, resulting in an estimated peak water demand which was 2.6 times lower than that of the more traditional approach. Stochastic methods, as explored by Rathnayaka et al[25] , provide robust frameworks for predicting urban residential end-use water demands, and authors demonstrated statistical stability of the selected probability distributions used for modelling the complex behaviour of consumers. Additionally, AI techniques, such as those highlighted by Kavya et al[26], offer sophisticated predictive capabilities by leveraging historical data to uncover hidden trends. Here authors showed that deep learning models outperform machine learning models, and that the Long-Short Term Memory model demonstrated the best prediction. Collectively, these techniques enable more accurate and reliable design parameters, ensuring that domestic water systems can meet demand efficiently.

1.1 Pre-study

In 2019/2020, a study was carried out by the Department of the built environment, Aalborg University, where the total water consumption in three large apartment buildings owned by the public housing company fsb was logged for a period of approx. three months.[27] The analysis of the measurement results showed that the measured peak flows were significantly smaller than the calculated design peak water flows, determined according to standard DS 439, corresponding to a factor of 2-3. The measurements performed in the preliminary study were 5-minute measurements. That is, the logged value was the average water flow during the 5 minutes. Thus, within the 5 minutes there will also be a higher peak flow, which is interesting to clarify in connection with the design of distribution pipes. Overall, however, it was concluded that the measurements carried out in the preliminary study indicated that domestic water distribution pipes in general are over-sized when using the method described in the Danish standard DS 439.

1.2 DS 439 - Standard for water installations

When designing water installations in residential construction in Denmark, DS 439 – chapter 2 can be used cf. BR18 § 404 subsection 2. DS 439 uses two significant parameters in connection with the designing calculation of the water pipe installations:

- The assumed water flow (q_f) [l/s])
- The design water flow (q_d) [l/s].

The assumed water flow is the peak flow assumed at the individual outlet points and is explicitly indicated in DS 439 table V.2.2.4 for the distinct types of outlet points. The table is reproduced in Table 1 below.

	Assumed water flow q_f [l/s]	
Outlet	**Cold water**	**Hot water**
Bathtub	0.3	0.3
Bidet	0.1	0.1
Shower	0.15	0.15
Courtyard/garden watering	0.2	
Sink	0.1	0.1
Kitchen sink	0.2	0.2
Slop sink	0.2	0.2

Valve for hosing down floors etc.	0.2	0.2
Household washing machines	0.2	
Household dishwashing machines and connected to cold water	0.2	
Household dishwashing machines and connected to hot water		0.2
Toilet cistern	0.1	

Table 1. Assumed water flows at the most frequently used outlets in dwellings.[1]

It is also described in DS 439 that, for apartments and single-family houses, the sum of assumed water flows can be set to 0.8 l/s for hot and cold water respectively, regardless of whether a summation of the assumed water flows for all outlet points exceeds 1,6 l/s. For a typical apartment with one kitchen and one bathroom with a shower, this would mean that water is drawn from all outlets and that the washing machine and dishwasher are in use at the same time.

The assumption of simultaneity for outlets and the size of the assumed water flows is used in DS 439 to determine the design water flow, q_d, by the functional expression presented in Eq. (1):

$$q_d = 2 \cdot q_m + \theta \cdot \left(\sum q_f - 2 \cdot q_m\right) + A \cdot \sqrt{q_m \cdot \theta} \cdot \sqrt{\sum q_f - 2 \cdot q_m} \qquad \text{[l/s]} \qquad (1)$$

Where,

q_d is the design water flow for distribution pipe to randomly used outlets (l/s)

q_m is the weighted mean water flow to several outlets connected to the distribution pipe (l/s)

$\sum q_f$ is the sum of the assumed water flows q_f of outlets according to table V 2.2.4 in DS 439

A and θ are constants that depend on the desired safety against overloads.

For water installations in residential and similar buildings, where the outlet points are used briefly and randomly, A can be set to 3.1, θ to 0.015 and q_m to 0.1 l/s according to DS 439. Thus, Eq. 1 reduces to:

$$q_d = 0{,}2 + 0{,}015 \cdot \left(\sum q_f - 0{,}2\right) + 0{,}12 \cdot \sqrt{\sum q_f - 0{,}2} \qquad \text{[l/s]} \qquad (2)$$

Figure 1 shows the design water flow q_d for residential buildings using the reduced formula expression from Eq. (2).

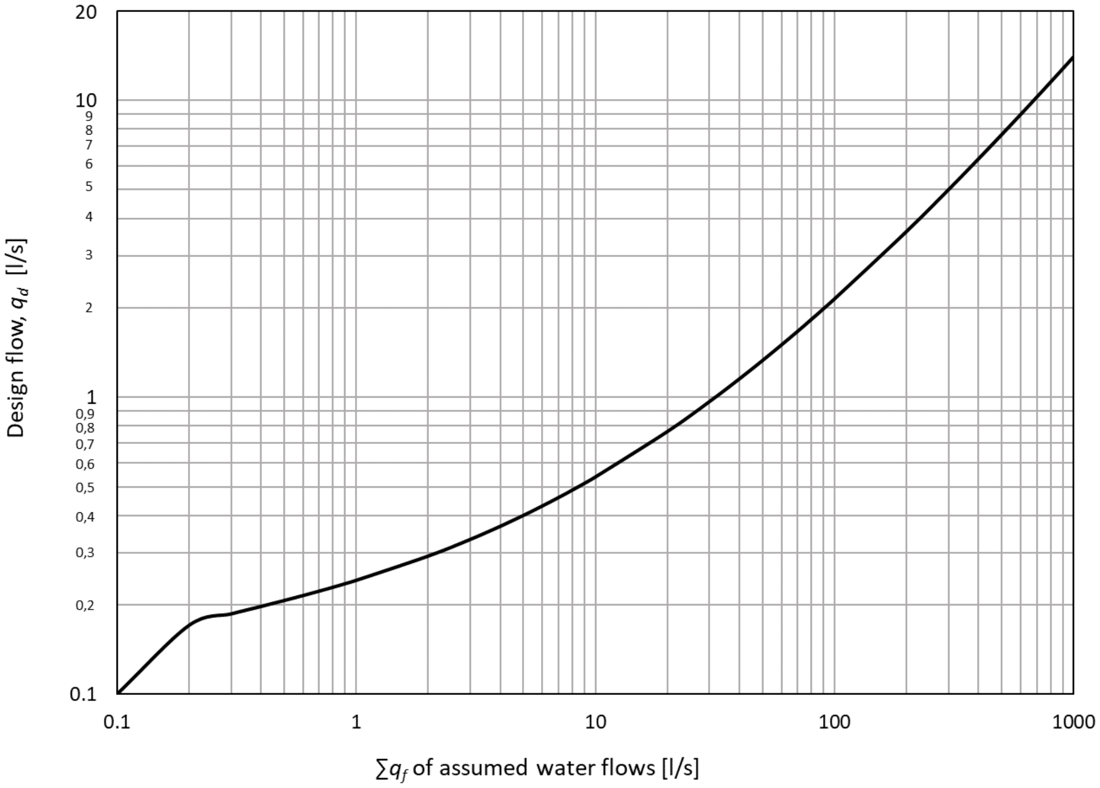

Figure 1 the design water flow q_d for residential buildings using the reduced formula expression from Eq. 2.

Dimensioning of water installations using Eq (2) is stated in DS 439 to have a security of 0.001 so that the actual water flows do not exceed the design flow. This means that one allows that the actual water flow in 0.1 % of the time may be reduced due to simultaneous use of outlets.

At the same time, it is also recommended in DS 439 that the water flow at individual outlets should not be less than 70% of the assumed water flow when other outlets in the installation are used simultaneously. This rule is used if a single or a few outlet points are located somewhere in the installation, where they are challenged in terms of being able to deliver the required water flow. The main priority of this rule is to ensure against a general over-dimensioning of the entire water installation.

2 Methods

2.1 Measurements

The measurements that were carried out in the preliminary study were based on 5-minute measurements, which in relation to peak flows and the simultaneity of use of outlets is a relatively large time interval. In this follow-up study, the possibilities of being able to obtain outlet data with a significant shorter logging interval have therefore been investigated. The best possible solution within the framework and time horizon of the project was a collaboration with the company Dantaet A/S, which has developed a leakage protection system for domestic water installations.

2.2 Multi-storey buildings

From Dantaet A/S's building portfolio, eight multi-storey residential properties were selected where the consumption measurements required for the analysis were possible and within the framework of the project. The properties with a total of 745 apartments were chosen so that there was both new/older and large/small residential properties. In the eight properties, consumption measurements were made on a total of 31 distribution water pipes. Basic information for the eight property cases is presented in Table 2. In most of the multi-storey residential properties there are shared laundries, but often in combination with a large proportion of the apartments having their own washing machine. For two of the selected properties, they also contain smaller commercial rental targets to a lesser extent. It has been assessed that the water consumption from these businesses is limited and in an order of magnitude that will not affect the conclusion regarding measured peak flows, consumption patterns and simultaneity of water consumption.

Property number	Town	Erection year	No. of apartments	No. of distribution pips	Smaller commercial part of the property
1	Odense	1961	97	4	Yes
2	Århus	1969	166	5	Yes
3	Aalborg	1971	43	4	No
4	Copenhagen	1934	214	10	No
5	Odense	2019	145	2	No
6	Odense	1827	6	2	No
7	Odense	1994	48	2	No
8	Copenhagen	1972	26	2	No

Table 2. Basic property information where the domestic water consumption was measured.

2.3 Outlet locations

For all apartments in the eight residential properties, it is assumed that there are at least the outlets per apartment, as shown in Table 3. It has been stated by several of the property managers that the apartments can also be equipped with washing machines and dishwashers and, to a lesser extent, also bathtubs. These installations are also included in the analyses to the extent that they are assessed to have been installed in the individual properties. If there is no information about the installations, they are omitted from the assumed water flows, as it thus provides a conservative basis for comparison between the assumed water flows and the measured consumption.

Information has also been obtained about communal laundries in the properties. These are also included in the assumed water flows corresponding to an ordinary washing machine, which is also considered to be a conservative estimate, since in a peak load there may be several machines in use at the same time.

Outlet point	Assuming water flow qf [l/s]	
	Hot	Cold
Kitchen sink	0.20	0.20
Shower niche	0.15	0.15
Bathroom sink	0.10	0.10
WC cisterns		0.10

Table 3. Outlets per apartment and assumed water flows [1].

2.4 Measuring method and measuring equipment

Existing measuring and logging equipment from the company Dantaet A/S was used to log the water consumption, which is normally used to monitor leaks or accidental water consumption. These existing meters were reprogrammed by Dantaet A/S to a minimum logging interval of 10 seconds.

This means that the logged water flow corresponds to the average water flow during the 10 seconds. For 4 of the 31 water pipes, however, the log interval was 60 seconds for technical reasons.

The logging stamp was:

Serial number; Time stamp; Flow rate in litres per hour; Consumption during the measurement period in litres

2.5 *Measurement period*

The water consumption measurements were started at the beginning of September 2021 and were completed at the turn of the year 2021/2022, corresponding to 4 months of measurements. During the measurement period, the Covid19 pandemic in Denmark was thus still part of everyday life for many people, and there may be residents of the properties in question who have worked more from home than before the pandemic. However, Denmark was not shut down to the same extent as at the start of the pandemic when schools and institutions also shut down. However, primary schools went on Christmas holiday 3 days earlier in 2021 than planned, which thus happened within the measurement period. If the residents' everyday life has been affected by the Covid19 pandemic and they have been at home more than usual, this is assessed to affect the measurements to a generally higher consumption, which will result in a conservative assessment of a possible oversizing of the water pipes based on the measured water flows.

2.6 *Pipe data overview*

During the measurement period, there have been only a limited number of errors with logging the water consumption in the 8 properties, despite the frequent logging interval. The missing data is assumed to be of no importance for the analyses. An overview of the pipe data is given in Table 4.

Pipe no.	Type of pipe [-]	Assumed water flow [l/s]	Design water flow [l/s]	No. of missed logning	Share of missing data [%]	Avg. log interval [sec]
1	Cold	30.4	1.31	53	0.0051	10.059
2	Cold	9.6	0.71	3	0.0003	10.059
3	Cold	20.8	1.05	28	0.0027	10.062
4	Cold	19.2	1.01	51	0.0049	10.058
5	Cold	96.3	2.82	33	0.0031	10.056
6	Cold	20.0	1.03	30	0.0029	10.064
7	Cold	4.8	0.53	25	0.0024	10.064
8	Cold	20.0	1.03	27	0.0026	10.064
9	Cold	24.8	1.16	38	0.0036	10.058
10	Cold	20.8	1.05	45	0.0043	10.058
11	Cold/Hot	48.0	1.75	37	0.0035	10.057
12	Hot	25.7	1.19	0	0.0000	60.348
13	Hot	18.0	0.97	0	0.0000	60.326
14	Cold/Hot	68.4	2.21	9	0.0009	10.053
15	Cold/Hot	28.0	1.25	406	0.0387	10.630
16	Cold/Hot	26.0	1.20	421	0.0402	10.629
17	Hot	14.9	0.88	22	0.0021	10.069
18	Hot	4.5	0.51	10	0.0010	10.064
19	Cold	5.5	0.56	20	0.0019	10.063
20	Cold	18.2	0.98	33	0.0031	10.073
21	Cold/Hot	49.0	1.77	114	0.0109	10.181
22	Cold/Hot	96.0	2.81	122	0.0116	10.092
23	Cold	36.0	1.45	63	0.0060	10.547
24	Hot	20.3	1.04	39	0.0037	10.549
25	Cold	55.2	1.91	452	0.0431	10.239
26	Hot	61.2	2.05	346	0.0330	10.239
27	Cold	53.6	1.88	417	0.0398	10.236
28	Hot	13.5	0.84	27	0.0026	10.078
29	Cold/Hot	37.5	1.49	81	0.0077	10.083
30	Cold	38.4	1.51	0	0.0000	60.298
31	Hot	21.6	1.08	0	0.0000	60.266

Table 4 Overview of pipe data and errors with logging the water consumption.

3 Analysis of measurement data

To initially validate the water consumption measurements, the property's average daily total (hot + cold) water consumption per resident is calculated and compared to typical key figure consumption.[16] As it can be seen from Figure 2, the selected properties are evenly distributed with consumption both above and below the national average of 104 l/day, which thus provides a good starting point for the interpretation of the measurement data in relation to dimensioning. The average consumption for all properties was 105 l/day.

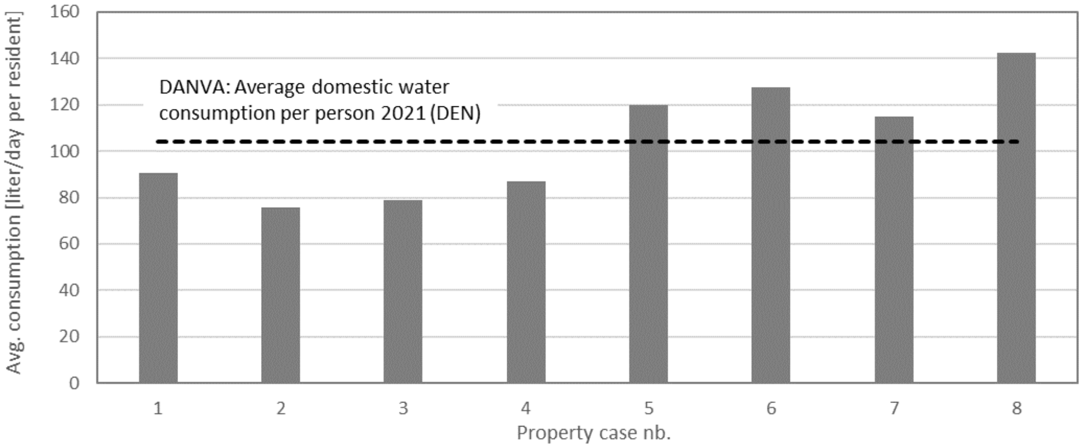

Figure 2 Average daily total water consumption in the measurement period from the beginning of September to the end of December 2021 for all the properties was 105 l/day per person. Danva's calculated average daily consumption for 2021 was 104 l/day per person.[16]

3.1 Cold and hot water

For the property cases where both hot and cold water have been measured, Figure 3 shows the share of hot water consumption in relation to the total consumption. On average, the hot water consumption in the 6 property cases is approx. 28.6% of the total water consumption corresponding to a distribution of approx. 30 liters of hot water and 75 liters of cold water.

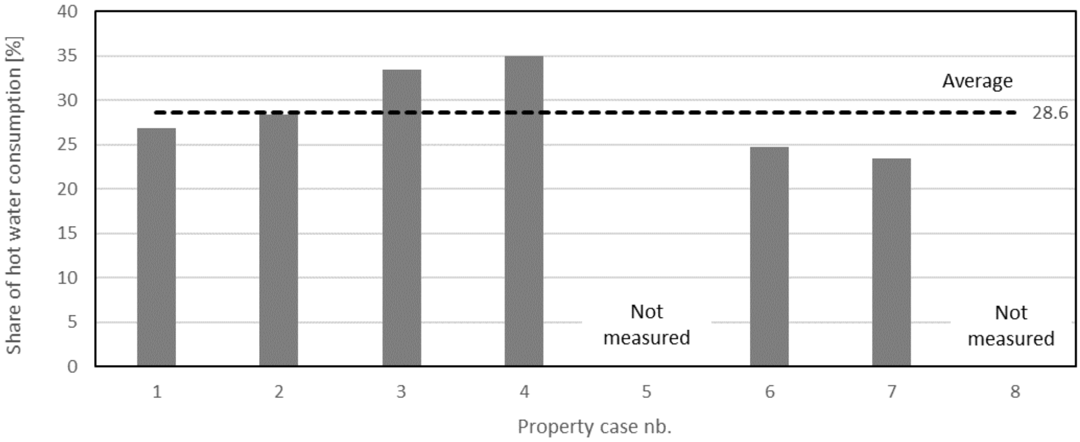

Figure 3 Measured hot water consumption's share of total water consumption in six residential properties.

3.2 *Example of measurements data*

Figure 4 presents measured flow data logged every 10 second from a cold and a hot and cold domestic water pipe for two different properties during a randomly selected weekday to provide an understanding of the data. Additionally, on Figure 4, the corresponding calculated design flow rate is illustrated with a dashed line for comparative analysis. Notably, a substantial variance is observed between the measured flow rates and the assumed design flow rates according to the standardization method.

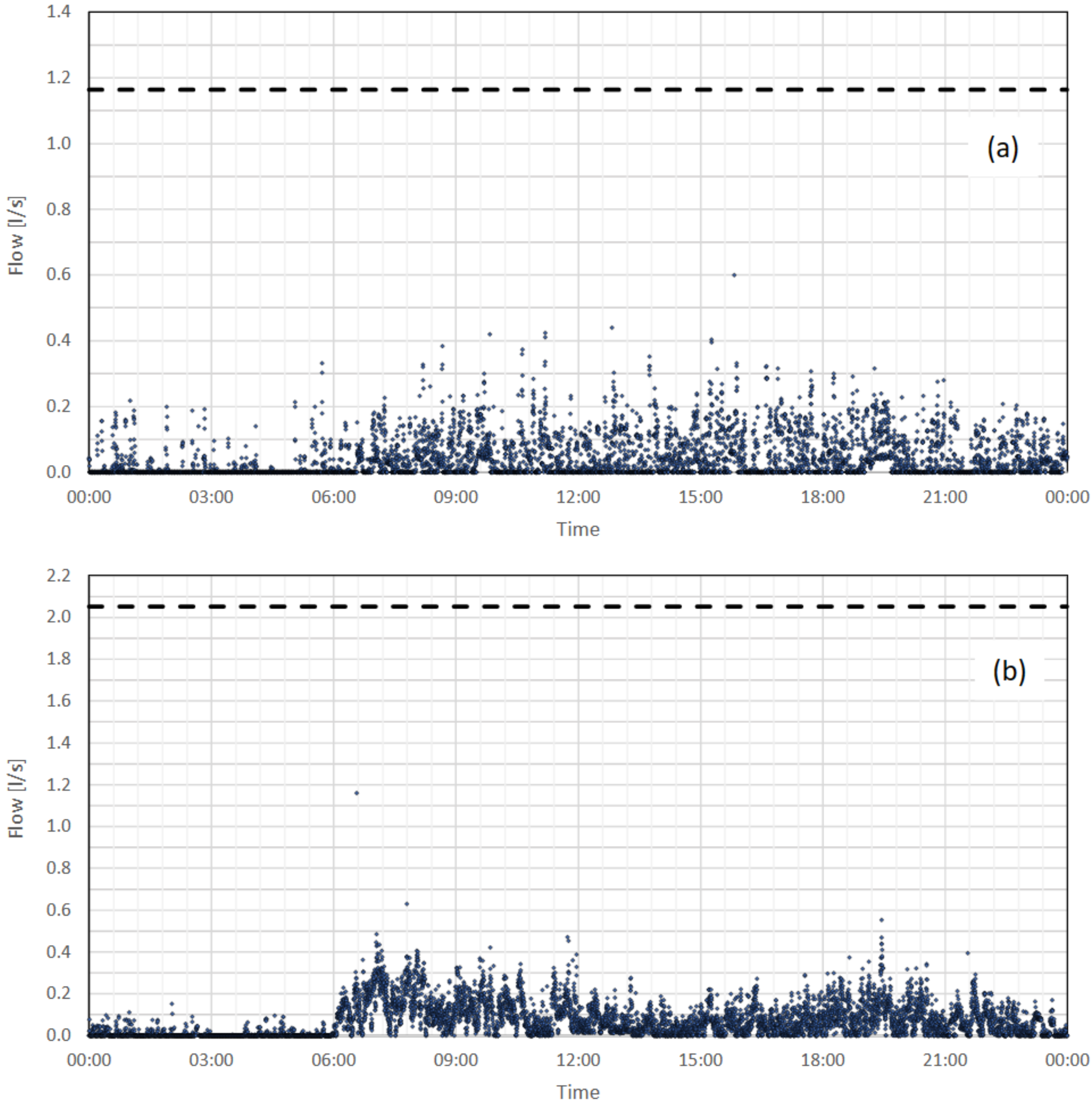

Figure 4 Example of measurement data during a random day for a cold (a) and hot (b) domestic pipe compared with the design flow rate.

3.3 *Measured peak flows*

In order to assess whether the distribution pipes are oversized, a data analysis of the measured water flows for each distribution pipe has been carried out. According to the description of the Danish design method in DS 439, you want a guarantee that the desired water flow rate can be achieved 99.9% of the time at the individual outlet point. The measured water flows were therefore analysed to give the measured peak flow at the 99.9th percentile ($P_{99.9}$). Figure 5 shows an example of the data analysis of a cold distribution pipe for one of the properties with 69 tenancies connected. It is seen that the water flow at the $P_{99.9}$ is significant below the design flow by a factor of approximately 3 and only in approximately 0.01 percentage of the time the flow is above the design flow of 1.91. The lower part of the figure shows that the peak flows primarily occur during mornings between 7 and 12 o'clock.

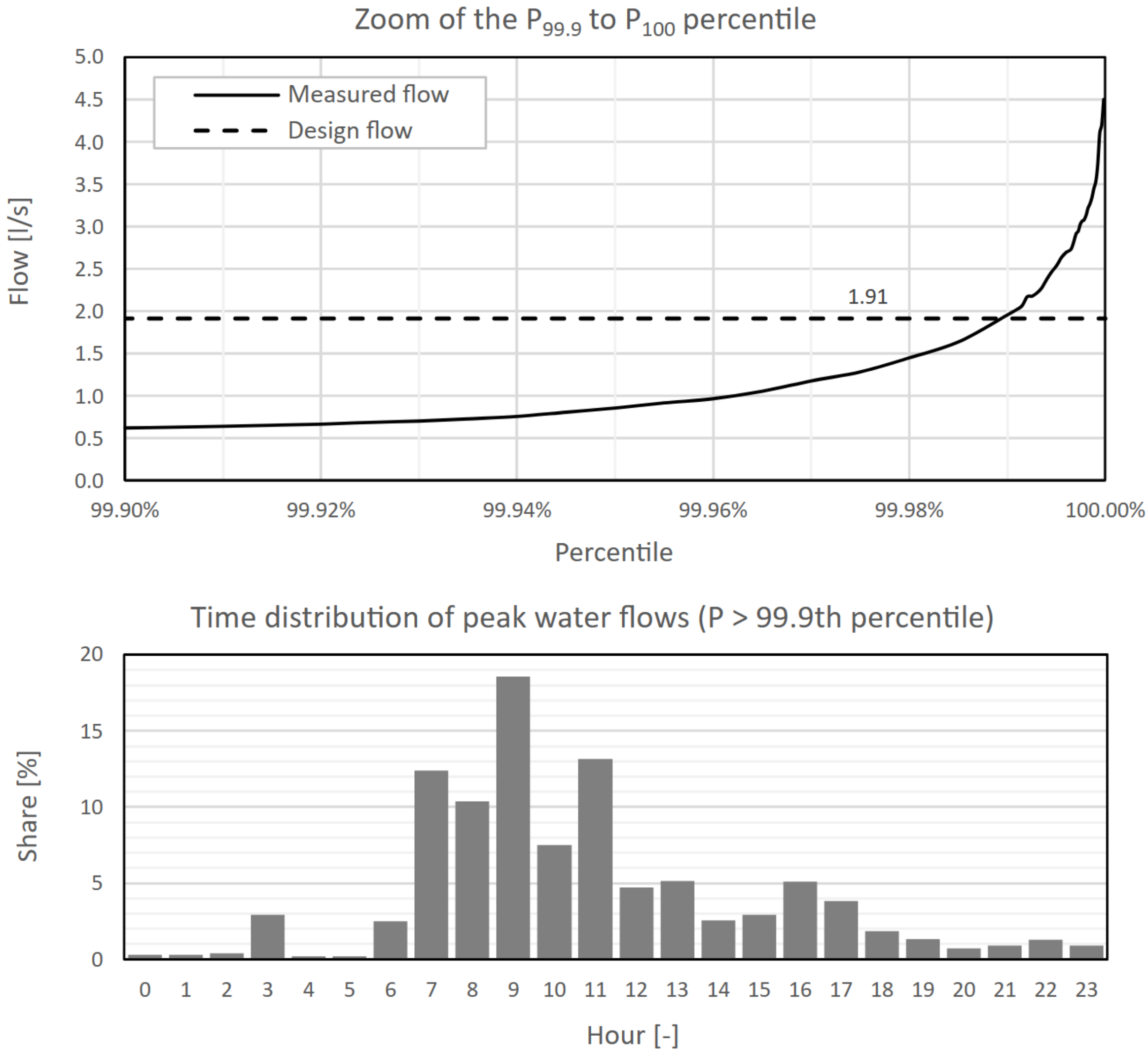

Figure 5 Example of data analysis of measured water flow for a cold-water pipe in a property with 69 tenancies. The upper figure shows a zoom for the 99.9th to 100 percentile and the lower figure shows how these are distributed in terms of time over the day.

Figure 6 shows for all 31 distribution pipes the measured peak flows at the 99.9th percentile compared to the design curve cf. Eq. 2. In general, it can be concluded that all the measured peak flows at the 99.9th percentile are significant below the design curve.

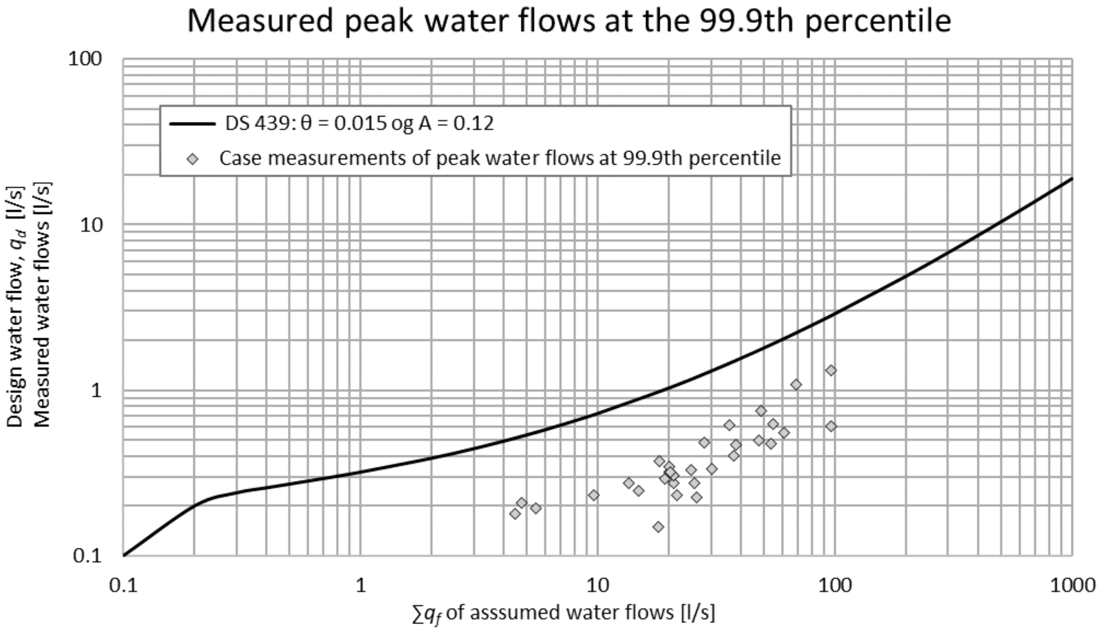

Figure 6 Peak water flows at the 99.9th percentile for three months measurement for the 31 distribution pipes compared with the design water flow curve as described in the Danish standard DS 439.

Figure 7 shows the relationship between the design water flows and the corresponding measured peak flows at the 99.9th percentile. The average ratio is approx. 3.4 for all pipes and for water pipe no. 14, the smallest oversizing corresponding to approx. a factor of 2 is seen. At the same time, a color marking has been made of whether it is a cold, hot or cold & hot water pipe that is being measured. The measurements indicate a tendency towards a slightly higher oversizing for hot water pipes, although this is based on a limited number of cases.

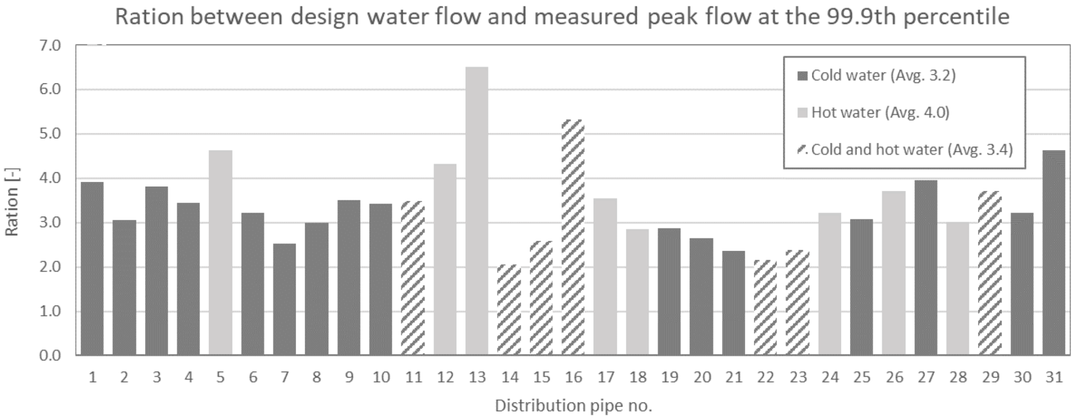

Figure 7 Ratio between design water flows and associated measured peak water flows at the 99.9th percentile for the 31 distribution pipes.

4 Proposal of amendment

Based on the analyzes of the measured peak flows at the 99.9th percentile together with the associated design peak water flows, it was found that a significant oversizing of distribution pipes occurs when using the DS 439 method corresponding to the functional expression given in Eq. 2.

The oversizing corresponds to approx. a factor of 3 on average for the 31 pipes and a factor of approx. 2 for the case with the smallest oversizing.

On the basis of the measured water flows, two amendment proposals for the Danish standard were prepared, where the coefficients of the function expression are changed so that the design-giving water flow on average for the entire course of the curve is reduced by approx. 25%, Eq. (3) and 50%, Eq. (4).

$$q_d = 2 \cdot 0.075 + 0.011 \cdot \left(\sum q_f - 2 \cdot 0.075\right) + 3{,}1 \cdot \sqrt{0.075 \cdot 0.011} \cdot \sqrt{\sum q_f - 2 \cdot 0.075} \qquad (3)$$

$$\approx 0.15 + 0.011 \cdot \left(\sum q_f - 0.15\right) + 0.089 \cdot \sqrt{\sum q_f - 0{,}15} \quad [\mathrm{l/s}]$$

$$q_d = 2 \cdot 0.065 + 0.009 \cdot \left(\sum q_f - 2 \cdot 0.065\right) + 1{,}5 \cdot \sqrt{0.065 \cdot 0.009} \cdot \sqrt{\sum q_f - 2 \cdot 0.065} \qquad (4)$$

$$\approx 0.13 + 0.009 \cdot \left(\sum q_f - 0.13\right) + 0.036 \cdot \sqrt{\sum q_f - 0.13} \quad [\mathrm{l/s}]$$

Figure 8 shows how the two proposed amendments to the functional expression for the design-given water flow are compared with the applicable functional expression (Eq. 2) and the peak flows measured at the 99.9th percentile.

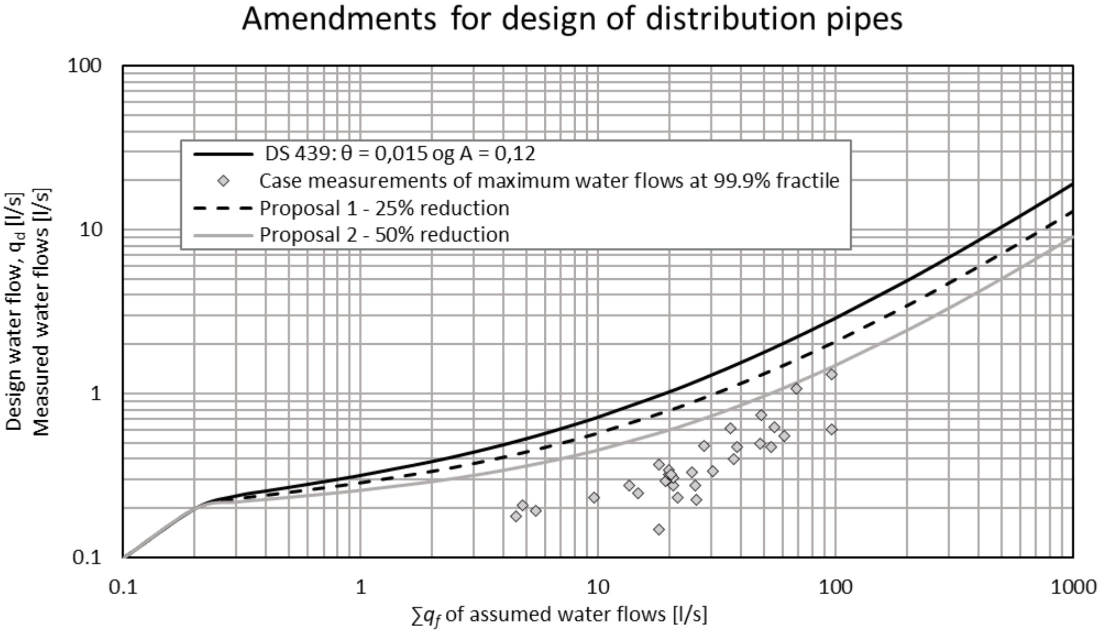

Figure 8 Amendment to the design of distribution pipes for domestic water in dwellings in DS 439.

These proposals may seem conservative; however, it should be noted that the data used here is quite limited and new design values should therefore still ensure a relatively good margin to measured values to accommodate variance in user profiles and simultaneity. Furthermore, not all new domestic water installations are water-saving, such as waterfall shower fittings, which thus increases the assumed water flow of the individual outlet.

5 Perspective

According to ECDC's latest report, in 2021, the EU witnessed the highest annual notification rate of Legionnaires' disease to date.[28] The same trend is also seen in Denmark.[29] Legionella can cause disease in the lungs and can be dangerous for children and the elderly. The Legionella bacterium thrives very well in lukewarm stagnant water. It is difficult to calculate the importance a smaller pipe dimension will have for the occurrence of Legionnaires' disease, but a reduction in the residence time of the water in the pipes and a higher velocity to avoid the formation of biofilms in general will, all other things being equal, reduce the total risk.

Oversizing pipe installations is also inappropriate from a resource perspective. With an optimal design of domestic water installations, significant material savings can be achieved, which will be the focus in the future when Life Cycle Assessment (LCA) requirements for construction are introduced. Table 5 shows the material savings for stainless steel pipes, if distribution pipe dimension is reduced by one size. In average the saving is between 20-30% of the pipe material but the reduction in pipe diameter will also for hot pipe systems reduce the necessary insulation material by approx. 30%.

Outer diameter	Material weight[A]	Material saving by one dimension less		
[mm]	[kg/m]	Pipe size reduction	Stainless steel	Pipe insulation[B]
15	0.351	-	-	-
18	0.426	18 mm → 15 mm	18%	28%
22	0.625	22 mm → 18 mm	32%	30%
28	0.805	28 mm → 22 mm	22%	32%
35	1.258	35 mm → 28 mm	36%	29%
42	1.521	42 mm → 35 mm	17%	23%
54	1.972	54 mm → 42 mm	23%	32%

[A]Stainless steel AISI 316L

[B]Based on insulation thicknesses cf. DS 452 annex A.[30]

Table 5 Material savings by reducing distribution lines for domestic water in stainless steel with one dimension.

For a domestic water installation in a typical block of flats with 6 floors and 12 apartments per rise, the total weight of distribution pipes (ladder strings) is approx. 80 kg per rise corresponding to a saving of approx. 20-25 kg stainless steel. The global warming potential to produce steel is 3.7 kg CO_2 eq. per kg[31] which will thus contribute significantly to the LCA account for a building's climate impact. Also, there will be additional material saving for fittings, pipe bends and other components by reducing the pipe dimension.

Therefore, achieving optimum sizing for domestic water installations will be a key focus in the future, ensuring environmental sustainability, efficient resource utilization and reducing health risks. The aspects that reduced sizing will influence is:

- Lower installation costs
- Lower material consumption
- Lower risk of Legionella growth
- Lower heat loss from hot pipes
- Lower operation cost for circulation pipes

6 Discussion

Considering our current understanding of resource scarcity and the ineffectiveness in reducing greenhouse gas emissions, the question of whether we should compromise on the design requirements for a building's technical installations is a contentious one. Many technical systems for water, heating, cooling, and ventilation are intentionally oversized to ensure that users rarely experience issues like insufficient heat, poor air quality, or low water pressure. If we could accurately

This is the accepted author manuscript of the article: Kragh J, Rose J, Buhl LS.
The risks of oversizing domestic water piping – Measurement of peak flows in multistory residential buildings.
Building Services Engineering Research & Technology. 2025;0(0). Copyright: © The Author(s) 2025. doi:10.1177/01436244251318169

calculate the cost of this oversizing, we might then evaluate whether the financial, resource, and environmental impacts justify such an approach.

Regarding sizing water pipes according to Danish rules, it can be discussed whether it is appropriate that the requirement for not exceeding the design flow must be met 99.9% of the time, and whether a lower percentage could be acceptable for most users in practice. In the investigated property cases the time where the measured peak flow was above the design peak flow was limited (less than 0.01% of the time).

Another method to reduce the design peak water flow could be to lower the assumed water flows at the individual outlet points. However, the current values in DS 439 are in line with the European standard DS/EN 806-3: 2006[14], which is in line with the products available on the market.

7 Conclusion

A measurement of the water flow has been made in eight multi-story residential properties distributed over 31 distribution pipes. The measurements were carried out as 10-second measurements starting at the beginning of September and until the turn of the year 2021/2022.

In the analyses, conservative assumptions have been made regarding the theoretical calculation of the design peak water flow, so that it is set low. For example, the smaller commercial leases in some of the properties have been disregarded. Likewise, water consumption for dishwashers and washing machines is only included for newer properties or if it has been specifically stated by the property manager that it is an installation that is common in the apartments. Common outlet points in the properties, such as a basement sink or outdoor outlet, are also omitted from the analyses.

The analysis of the measurement results shows that the measured peak flows at the 99.9th percentile compared to the calculated design water flows, determined according to Danish standard DS 439:2009 Norm for water installations[1], are significantly smaller, corresponding to a factor of 3 on average and a factor of approx. 2 for the case with the smallest oversizing.

The conclusion based on the performed flow measurements was that the guideline for designing domestic water distribution pipes in general significantly oversized both hot and cold pipes. Two proposals that reduces the design flow rate by 25% and 50% respectively was therefore developed to update the national Danish standard DS 439[1] and during 2023 it was finally agreed in the standardization committee to implement the proposal for a reduction of 25%.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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