A comparison of UK domestic water services sizing methods with each other and with empirical data

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Abstract

Evidence suggests that DCWS sizing methods in many countries around the world tend to overestimate the actual peak water volume flow rate. Oversizing DWS systems does waste materials and money, but it also increases the length of time that it takes for water to pass through the system which can increase water temperatures with the associated risks that presents. This paper compares the three commonly used UK DCWS sizing methods and reveals variance in the methods, the design flow rates calculated and the amount of diversity applied by each method. BS EN 806[1] returns the lowest design flow rates of the three methods and also applies significantly greater diversity.

Empirical DCWS volume flow rate data from two case study buildings revealed that all three UK sizing methods significantly overestimated the peak water volume flow rates but that BS EN 806[1] was the closest. Additional empirical data from seven more buildings has been used to validate the data from this study and add confidence to the findings. This research provides useful evidence to help engineers select the most appropriate UK DCWS sizing method and to anticipate the likely range and fluctuation of DCWS flow rates.

Keywords DWS, domestic water service, DCWS, domestic cold water service, DHWS, domestic hot water service, water, loading unit, volume flow rate, probability, oversizing

Engineers tend to be conservative by nature and generally err on the side of caution to ensure that there is never any cause for customer complaint about their designs. This is understandable but there can be negative consequences if the full implications of such decisions are not fully understood. This paper reveals significant oversizing compared to empirical data from each of the three UK DWS sizing methods and highlights the reasons for this. The practical application of this paper lies in the presented results data and analysis which will help engineers make this important choice between the available sizing methods.

1.0 Introduction

There are three commonly used sizing methods for domestic cold water services (DCWS) for United Kingdom (UK) buildings at the time of publication. BS EN 806[1] is the current European sizing standard, but in part 3 Annex C it grants engineers discretion to use the 'UK method' as defined in BS 8558[2] when deemed appropriate. Some engineers have preferred to use the guidance issued by the Institution of Plumbing[3] believing that this results in more accurate sizing than the "UK method". BS 8558[2] also offers complementary guidance to BS EN 806[1] and confirms that an investigation is underway into the loading units (LUs) used in the UK's traditional sizing guidance (i.e. BS 8558[2]). Until the publication of new recommendations, designers may use BS EN 806[1] for residential applications and BS 8558[2] elsewhere.

CIBSE AM12[4] states that *"experience from continental schemes indicates that BS 6700[5] factors (now published as BS 8558[2]) are too conservative"* for predicting design Domestic Hot Water Service (DHWS) volume flow rates. Instead, it directs readers to use the Danish Standard DS 439[6].

Agudelo-Vera C[7] states that oversizing pipework reduces water velocities which mean that the water remains in the distribution pipework longer than is ideal for health and hygiene reasons. This problem is most extreme in tall buildings where the domestic cold and hot water pipework may run within the same riser space resulting in undesired heating of the cold water.

There have been some reports that current sizing methods can lead to an overestimation of water demand. Wong L[8] calculated a theoretical design water flow rate using a 'fixture unit' method, probably following the ASHRAE[9] guidance, although not specifically stated in the article. This prediction was compared with theoretical data from a model developed using measured data from 1300 households in 14 typical Hong Kong high rise buildings. The data revealed that the water demand predicted from analysis of the measured data method was around 50 – 60% of that calculated using the 'fixture unit' estimation method, which was said to be the current design practice adopted for high-rise residential buildings in Hong Kong. A Brazilian team[10] found similar results with measured data being 23% lower than the design flow rate calculated using the Brazilian standards.

Researchers from The Netherlands[7] analysed the Dutch guidance on drinking water supply systems, which had been developed using data measured between 1976 and 1980. The authors state that the old guidelines overestimated peak demand values due to an increased range of available appliances and changes in the behaviour of building occupants. The importance of accurately estimating peak demand values is stressed as poorly designed, and oversized systems are less efficient thus more expensive, but can also cause stagnant water. By using data gathered from a range of buildings of different water usages the team constructed a stochastic model called SIMDEUM, standing for Simulation of Water Demand, an End-Use Model. Subsequent research[11] highlights that in designing a DCWS distribution system, the peak value of the total water demand, referred to in their report as the MMFcold, or maximum momentary flow of cold water, is of great importance. The research uses a procedure developed in 2010 to derive design demand equations for the peak demand values of DHWS and DCWS in both residential and non-residential buildings. The study found a good correlation between their demand equations and measured patterns of use, which was much more accurate than the current Dutch guidance, indicating that their calculations were reputable.

Using these demand equations, the Dutch study[7] found that the results of simulations matched measured values of peak water demand and that the pipe diameters in the systems they studied were considerably larger than necessary. They hypothesise that the issue of oversizing may be present in other countries, and state that their SIMDEUM model could be easily adapted for use in other countries when specific information of users and appliances is available. The authors confirm that a 2013 revision of the Dutch guidelines incorporated the design demand equations presented in the paper.

Based on this review, it is likely that the UK DWS sizing methods may be overestimating the peak flow rates for buildings. The questions were how significant is the margin of oversizing, and which of the three UK sizing methods would be most appropriate for multi-unit residential buildings. This research has been designed to answer these two questions. The next section compares the three sizing methods and draws out the distinctive features of each. The latter sections set out the method by which measured data was obtained and compared to the design flow rates predicted by each of the three sizing methods. Additional datasets gathered from the same type of building are used to validate the data from this study. The results published in this paper enable engineers to be confident regarding which DWS sizing method to apply to avoid oversizing their DCWS systems.

2.0 Sizing method review

This section introduces the three most commonly used UK DWS sizing methods and compares them with each other. All three methods utilise 'loading units' (LUs) generated from a probability analysis, developed from the original work of Hunter[12]. These methods set the chance that the design volume flow rate will be exceeded for 1% of the time as discussed in CIBSE Guide G[13]. All three methods require the summation of the downstream loading units for each pipe section, and some form of conversion chart is used to determine the design volume flow rate. These charts apply varying levels of diversity. The differences in approach taken by each method are discussed and compared in the following three sections.

2.1 BS 8558:2015[2] Guide to the design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages

"The UK method" as defined initially in BS 6700[5] which was first published in 1987, revised in 1997 and 2006 before being withdrawn and superseded by BS 8558 in 2011 which itself has been revised in 2015. The harmonised European standard BS EN 806-3 explains in Appendix C that designers are free to use their nationally approved sizing method (BS 6700[5] for the UK – now BS 8558[2]) if they deem it appropriate. BS 8558:2015[2] suggests that BS EN 806-3[1] may be used for residential buildings and that "traditional UK loading units" (BS 8558[2]) may be used for commercial and public buildings.

In “the UK method” there is a single LU value given for each outlet type with the exception being wash hand basins where a higher value is applicable in buildings with periods of peak usage such as schools or theatres and a lower value for non-peak uses.

A chart is provided to convert LUs to a design volume flow rate. The chart is formatted with a logarithmic scale allowing ample detail to be provided at LUs between 10 and 200 while enabling the chart to extend up to a total of 8000 loading units, which equates to a flow rate more than 30 litres per second.

2.2 BS EN 806-3:2006[1]. Specifications for installations inside buildings conveying water for human consumption

In 2000 Britain began the process of standardising the guidance for DWS with the European Union (EU). In 2006 BS EN 806-3[1] which presented new guidance for the sizing and design of DWS was published and superseded BS 6700[5].

The use of LUs in BS EN 806-3[1] is the same as BS 8558[2] apart from there are no ranges of loading units given for any outlet type to account for peak or non-peak use.

Figure 1 is the LU to volume flow rate conversion chart for BS EN 806-3[1]. Again, the axes use logarithmic scales, but this time the largest LU value is 5000 loading units, which equate to 9 litres per second, significantly less than the two other methods. A notable feature of this conversion chart is that for loading units below 300 the resultant design flow rate depends upon the highest single value LU fed from that pipe section.

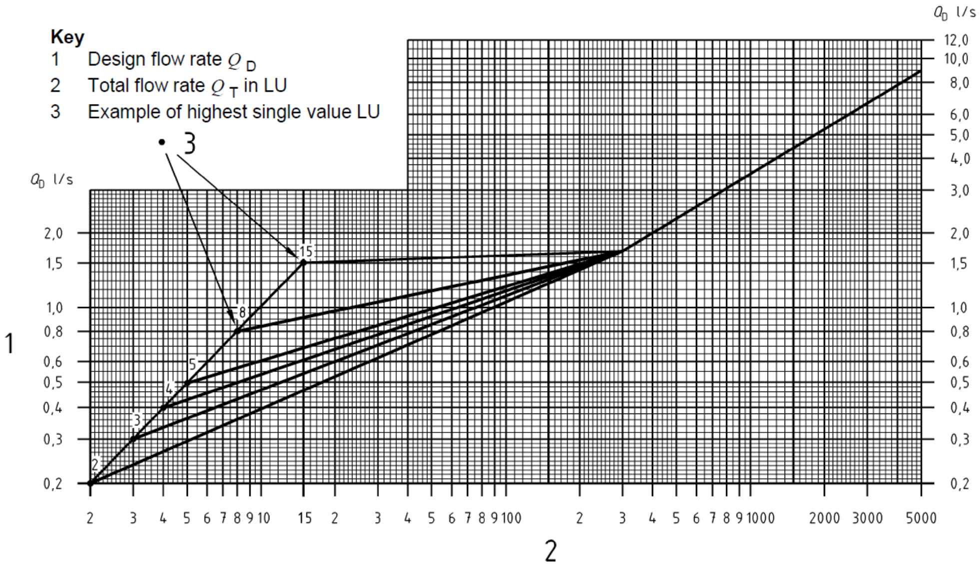

Figure 1 BS EN 806-3[1] Fig B.1 Loading units to design volume flow rate

2.3 The Institute of Plumbing[3]. Plumbing Engineering Services Design Guide.

The Institute of Plumbing (IoP) guidance[3] is preferred by some UK engineers because it provides ample data and a much more significant discussion regarding the generation of the LU values and also because it appears to offer the designer more flexibility. The choice between low, medium and high LUs depends upon the frequency of use. Low use is applicable where outlets have 20 minutes between uses, which it suggests is appropriate for dwellings. It recommends 'Medium use' for applications where there are 10 minutes between uses, as predicted in public buildings with no peak use. Applications where there are just 5 minutes between uses, such as in concert halls or theatres i.e. peak use, should use the 'high use' values.

The charts presented to convert LUs to flow rate use logarithmic scales and peak at 8000 loading units that equates to approximately 30 litres per second. In these respects, it is similar to the chart presented in BS 8558[2]. Where it differs, is that it also enables pipe sizes to be directly selected based on the pressure (head) loss per metre run of pipe and the resultant water velocity. In this way, many useful features are combined into the one chart.

2.4 Comparison of Loading Units between the three sizing methods

BS EN 806-3[1] states that “one loading unit is equivalent to a draw-off rate of 0.1 litres per second.” In contrast, the LUs presented in the Institute of Plumbing Guide, and BS 8558[2] are not simply linked to flow rate as BS EN 806-3[1] but also take account of the length of time which the outlet will be in use and the outlet's patterns of usage. Therefore, the basis for the value of LUs is significantly different for BS EN 806-3[1] compared to the other two sizing methods.

Table 1 displays the LUs for a range of common outlet types for each of the three sizing methods. The number of LUs for the BS EN 806-3[1] and Institute of Plumbing[3] ‘low use’ columns are identical, where values are displayed. BS 8558[2] LUs are similar to those provided by the Institute of Plumbring[3] for ‘medium use’ and therefore appear broadly comparable. In contrast, the Institute of Plumbing ‘high use’ loading units are significantly higher than either alternative method.

Table 1 Loading Units comparison

	BS 8558 LUs	BS EN 806-3 LUs	IoP LUs		
			Low	Med	High
WC flushing cistern	2	1	1	2	5
Wash basin (15mm)	1.5 - 3	1	1	2	4
Sink tap (15mm)	3	2	2	5	10
Bath tap (domestic)	-	4	4	8	16
Bath tap (20mm)	10	8	-	11	-
Bath tap (25mm)	22	-	-	-	-
Shower	3	2	2	3	6

2.5 Comparison between conversion charts

All three sizing methods provide a conversion chart to determine a design flow rate for a known number of loading units. Data from these charts have been used to produce Figure 2, which illustrates the relationship between flow rate and LUs for each method. The data for BS EN 806[1] assumes that the largest single outlet LU was two (i.e. a sink or a shower).

The relationship between LU and flow rate for BS 8558[2] and the Institute of Plumbing[3] is very similar up to flow rates of 12 l/s, and even after this point the maximum difference is only approximately 8%. In contrast, the values for BS EN 806[1] are extremely different. In Figure 2 it appears that the flow rate is always lower for any number of loading units for BS EN 806[1], however, for flow rates up to 0.6 l/s, BS EN 806[1] has a lower number of LUs than either of the other methods. This effect can be seen more clearly in Figure 3.

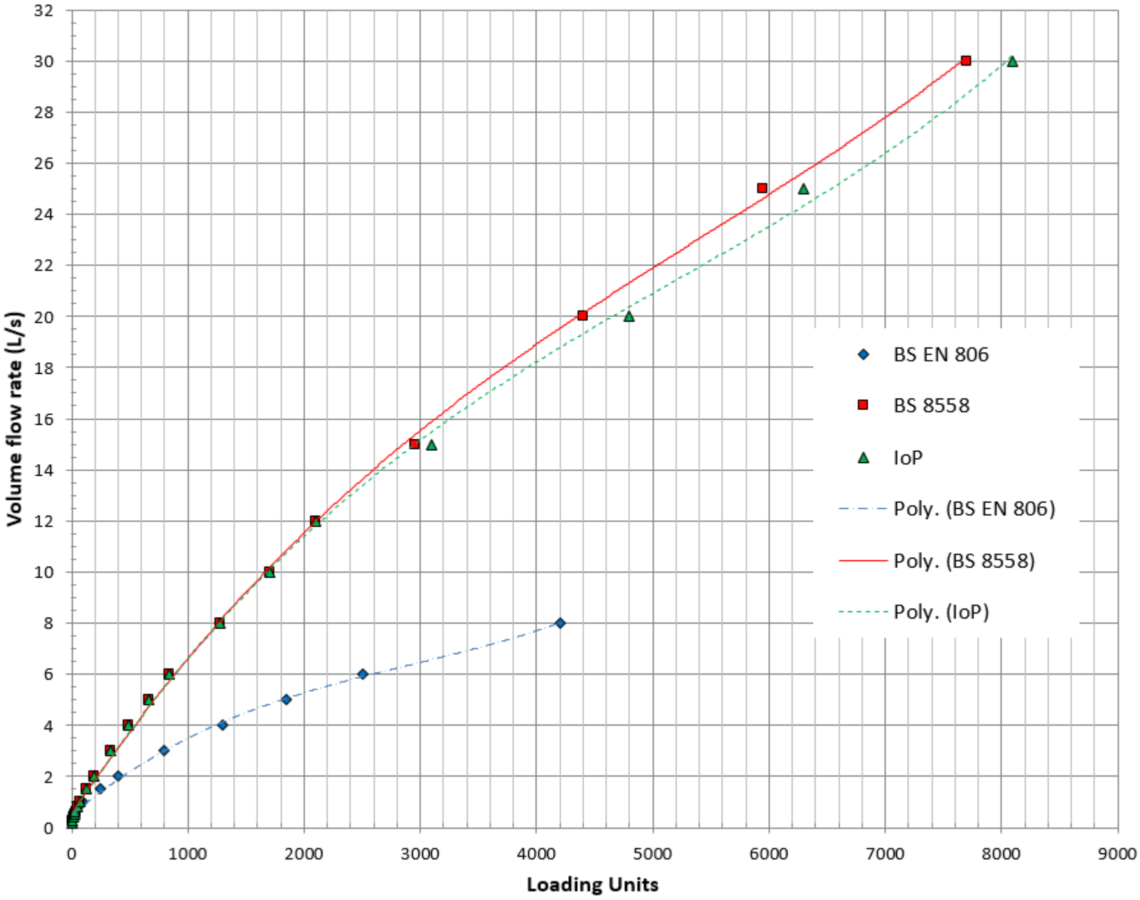

Figure 2 Loading unit to flow rate comparison

The gradient of the trend lines shown in Figure 2 relates directly to the amount of diversity applied by each method. With no diversity, a doubling of the number of loading units would double the flow rate. For BS EN 806[1] a doubling of LUs from 1000 to 2000 equates to an increase in flow rate of approximately 51%. Both the Institute of Plumbing[3] and BS 8558[2] methods result in an increase of approximately 75% over the same range. In other words, within this range, BS EN 806[1] provides a diversity of 49% compared to just 25% for the other two methods.

Figure 3 is formatted to focus on the pipe sections closer to the system outlets i.e. with loading units less than 280. Additionally in Figure 3 data from BS EN 806[1] assuming a largest single outlet loading unit of 15 (i.e. a DN 20 flush valve), labelled '806 LU (15)', has been added to show the full extent to which BS EN 806[1] may lead to larger pipe sizes closer to the system outlets. This effect may seem extreme, but there is a clear logic to this approach, namely that the pipe size should be selected to provide the design flow rate of the largest outlet type served. In practice, this is not likely to result in different pipe sizes between the sizing methods since high flow rate outlets have larger pipe connection sizes to suit. Hence, in practice, the pipe sizes close to a large outlet will tend to be determined by the type and size of outlet rather than what size the sizing methodology suggests.

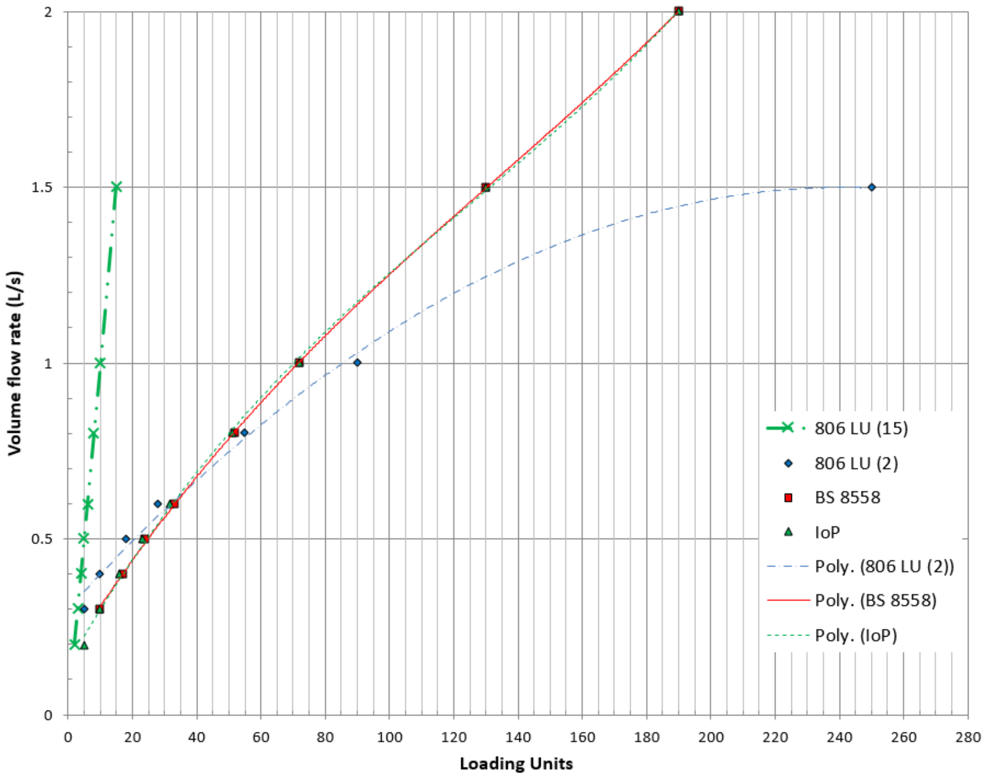

Figure 3 Loading unit to flow rate comparison near the outlet

The next section sets out the method used to gather empirical data to compare with the flow rate predictions from each sizing method and outlines the building data used and the assumptions made.

3.0 Method

A leading UK manufacturer of booster sets kindly provided datasets of flow measurements recorded at a range of different building types with the intention that these could be used to validate the data recorded in this study. The largest number of datasets were available for multiunit residential buildings, and so the decision was taken to record additional data sets for this building type to generate the largest dataset possible. A number of different multi-storey residential blocks were initially selected, and following surveys, two were deemed as appropriate case study buildings. These buildings are named Block A and Block B within this study.

Design flow rates for each block were calculated using each of the three UK sizing methods for comparison with the measured (empirical) data. To gather the empirical data, it was advantageous to utilise a non-intrusive flow measurement technique. Therefore a Bell Flow Systems BFU-100M Ultrasonic Flowmeter was used with the transducers installed in a 'V' configuration as illustrated in Figure 4.

Figure 4 Image showing the installation method of transducers

A Tinytag TGP-0804 Current Input Data Logger was used to record the data at a frequency of 10 seconds. This recording rate enabled data to be gathered for a full week while also being of sufficiently fine resolution to capture short term peaks in the water flow rate. The recorded current data was converted to volume flow rate in a spreadsheet and the volume flow rate exceeded for 1% of the measurement period was determined for each block. The additional datasets are incorporated with the two gathered within this study to validate the study data and therefore increase confidence in the study conclusions.

3.1 Building Data and Assumptions

Block A is a 26 storey residential block consisting of 125 two bedroom flats. The building dates from 1966 but has recently benefited by being renovated. The landlord restricts the tenancies to residents over 55 years of age, and therefore most occupants are retired, which may result in the use of water being spread relatively evenly throughout the day.

Block B is a 43m tall apartment block with 60 two bedroom flats and 30 single residences. The building was completed in 1961 although it has also benefitted from the modernisation of individual flats. The building occupants range in age and employment status and so it may be anticipated that it will be more likely that there will be morning and evening peaks in the water consumption.

According to the landlord's records, both buildings were fully let to tenants although it could not be verified how many people were resident in the buildings during the measurement periods.

Flats in both blocks had the following outlet types installed; shower, WC, wash hand basin, bath, and kitchen sink. Both blocks use electrically heated DHWS storage vessels within each flat fed from the incoming DCWS supply. The authours have assumed that showers were to be thermostatically mixing and fitted with flow limiting devices and that the wash hand basins had mixer taps fitted. Therefore, only the cold water LUs were accounted for these two outlet types and

DHWS LUs only allocated for the baths and kitchen sinks. These points align with the guidance given in BS 8558[2]. The 'low usage' LU values were utilised for the two sizing methods that offered a range of values based upon building usage.

Table 2 shows the total number of LUs and the design flow rates calculated using each of the three UK methods.

The numbers of washing machines and dishwashers could have only been ascertained by a survey or return of questionnaire from each flat, which time constraints precluded, and therefore these outlet types were excluded from the analysis. Consequently, the degree of oversizing reported by this study may be underestimated to some extent.

Table 2 Total loading units and design flow rates for each case study building and method

	BS EN 806-3	BS 8558 (non-peak)	IoP (Low)
Block A (LUs)	2,000	4,062	2,000
Block B (LUs)	1,440	2,925	1,440
Block A design volume flow rate (l/s)	5.3	19.9	11.0
Block B design volume flow rate (l/s)	4.3	14.8	8.4

4.0 Data Analysis

This section presents the recorded volume flow rate data from Blocks A and B, and on each graph, a broken red line indicates the measured volume flow rate exceeded 1% of the measurement time. As discussed earlier in section 2.0, all three sizing methods use a probability analysis which is designed to return a design value that statistically will be exceeded for 1% of the time.

4.1 Block A Data

The sizing calculations returned design values for Block A ranging from 5.3 l/s to 19.9 l/s as can be seen in Table 2. Figure 5 illustrates the measured results for the full week of the study and reveals very similar patterns of usage on each day of the week and peaking at a value of 2.25 l/s on Saturday 29th March, significantly lower than any of the sizing method design values.

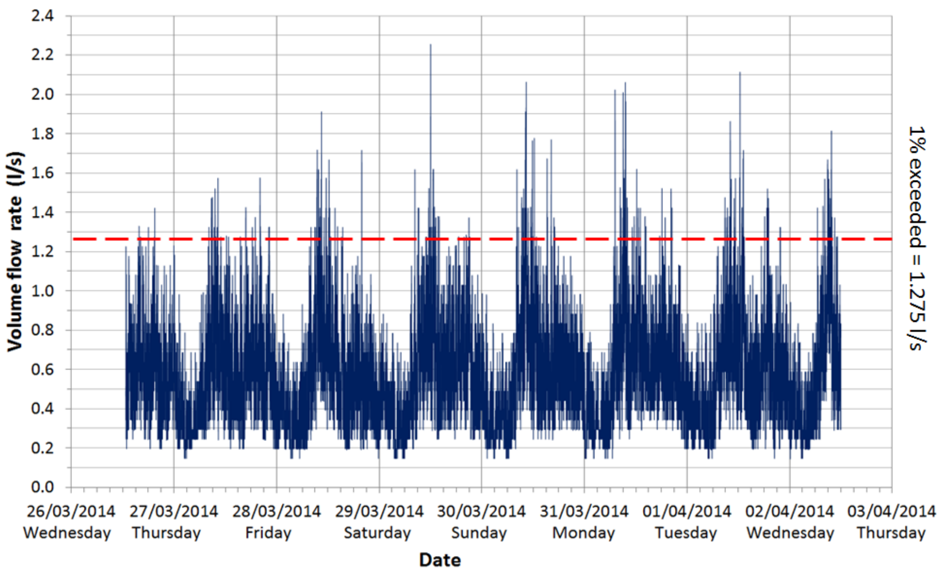

Figure 5 Block A 'Weeklong' DCWS volume flow rates

Figure 6 displays the data for the day of the peak flow (Saturday) and reveals the very short duration of the peak.

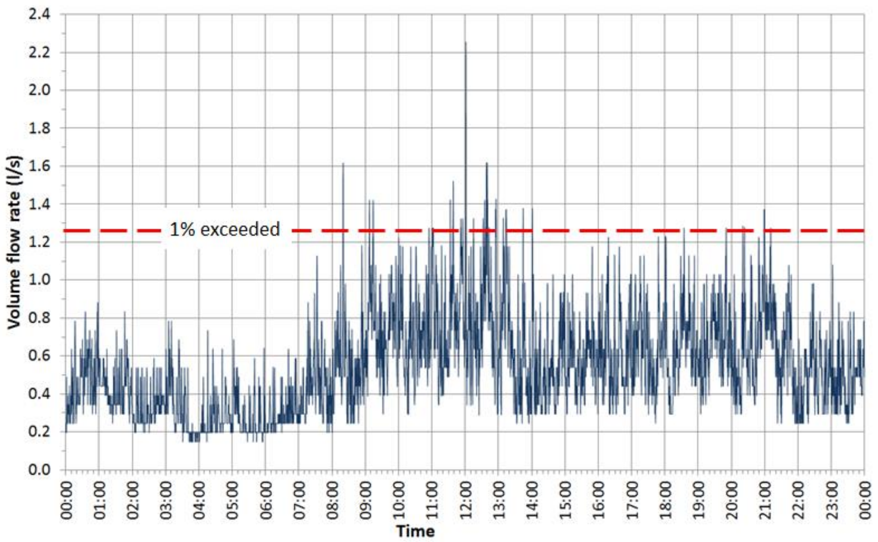

Figure 6 Block A 'Peak Day' DCWS volume flow rates

Figure 7 shows the data for the peak hour, between 12 noon and 1 pm on Saturday. At this scale, it can be seen that the peak flow occurs for less than one minute.

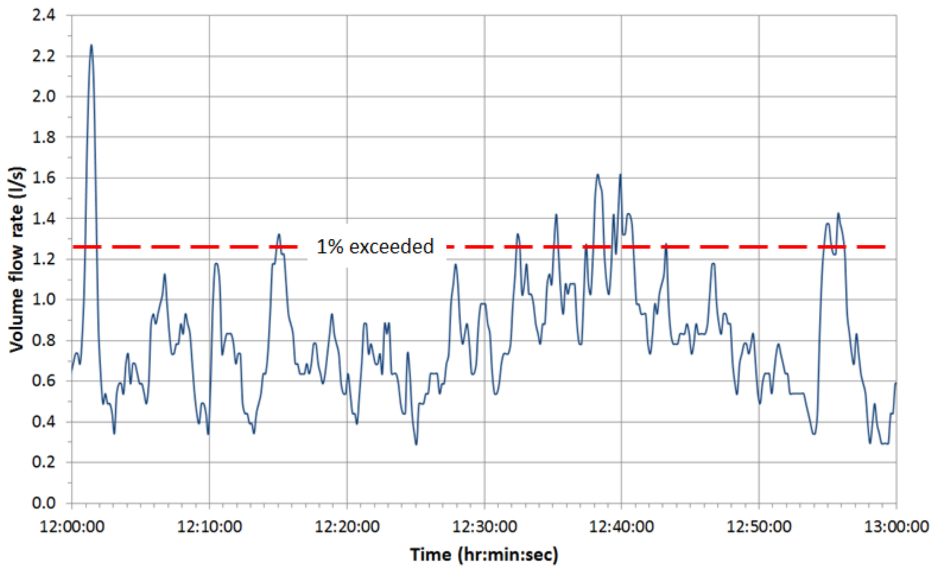

Figure 7 Block A 'Peak Hour' DCWS volume flow rates

4.2 Block B Data

The sizing methods returned design values ranging from 4.3 l/s to 14.8 l/s for Block B as displayed in Table 2. Figure 8 illustrates the measured results for the full week of the study and reveals more variability in the day to day patterns of usage than Block A. The peak value of approximately 1.3 l/s on Friday 4th April is again significantly lower than any of the sizing method design values.

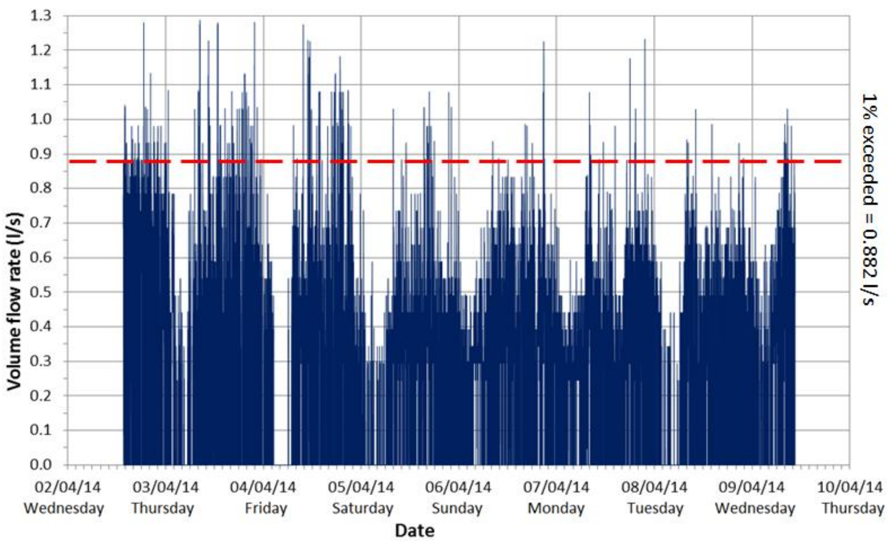

Figure 8 Block B 'Weeklong' DCWS volume flow rates

Figure 9 shows the data for the peak hour between 8 am and 9 am on Friday and reveals two similar peak values around five minutes apart.

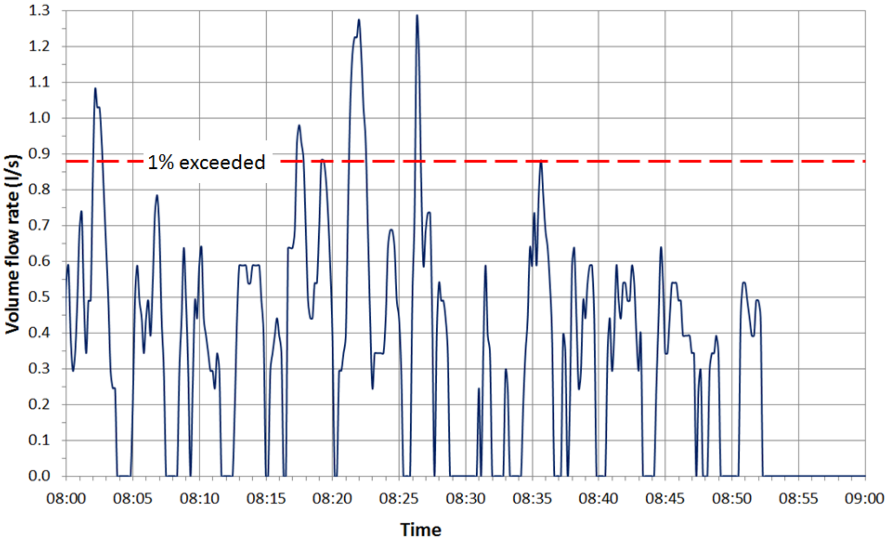

Figure 9 Block B 'Peak Hour' DCWS volume flow rates

4.3 Design vs. measured peak volume flow rates

Figure 10 displays the variance between the design volume flow rate calculated using the three UK sizing methods and both the measured peak for each block as well as the 1% exceeded flow rate. BS EN 806[1] returns a design flow rate significantly lower than the Institute of Plumbing guide[3] which is itself much lower than that returned by BS 8558[2]. Even the BS EN 806[1] design values are 233% greater than the measured peak for Block A and 331% greater for Block B. Arguably the fair comparison should be with the 1% exceeded flow rate, and this takes the percentage increases to 412% for Block A and 488% for Block B.

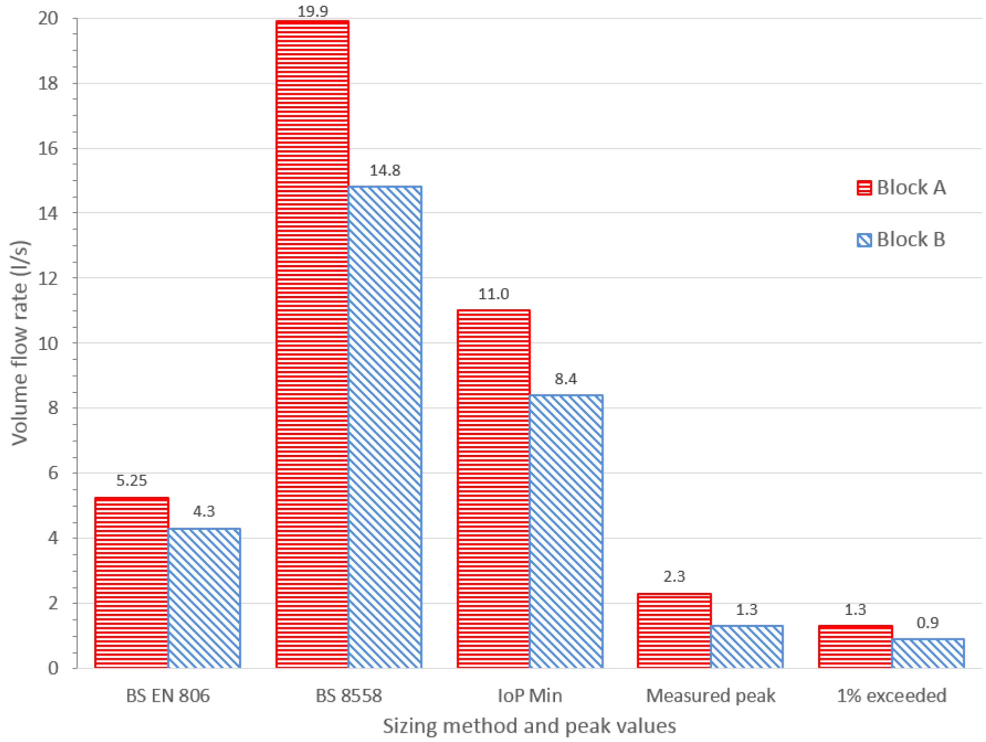

Figure 10 Design vs. recorded peak values

5.0 Validation

DCWS volume flow rate data sets for seven multi-unit residential buildings were provided by a leading UK manufacturer of booster sets for the purpose of validating the data from this study. Data for each building was recorded for one week using an ultrasonic flow meter. The details of the buildings are shown inTable 3 along with the calculated total number of LUs.

Table 3 validation building data and LUs

Building name	Number and type of accommodation	DCWS outlet types	Total Loading Units (Hot and cold)		
			BS EN 806-3	BS 8558	IoP (Min)
Kingsmead House	22 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	528	990	528
Westway M	27 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	648	1,215	648
The Artworks	33 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm	627	1,221	627
Gallions Point	45 two bed flats	whb, wc , bath, shower, kitchen sink, wm	855	1,665	855
Lowry Centre	154 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw	4,020	7,530	4,020
	12 three bed flats	whb & wc x3, bath, shower, kitchen sink, wm, dw			
Westway A to L	50 one bed flats	whb, wc , bath, kitchen sink, wm	4,070	7,700	4,070
	130 two bed flats	whb & wc x2, bath, shower, kitchen sink, wm, dw			
Glasgow Harbour	255 one bed flats	whb, wc , shower, kitchen sink	2,295	3,570	2,295

Figure 11 displays the measured peak volume flow rates at Blocks A and B (labelled primary data) as well as each of the seven validation buildings (labelled validation data). There is some variance around the line of best fit but not more than would be expected given the variation in size and fit out of the apartments and the variations in the building occupants. The measured peak volume flow rates for Blocks A and B align well with the validation data and thus adds confidence to the findings of this study.

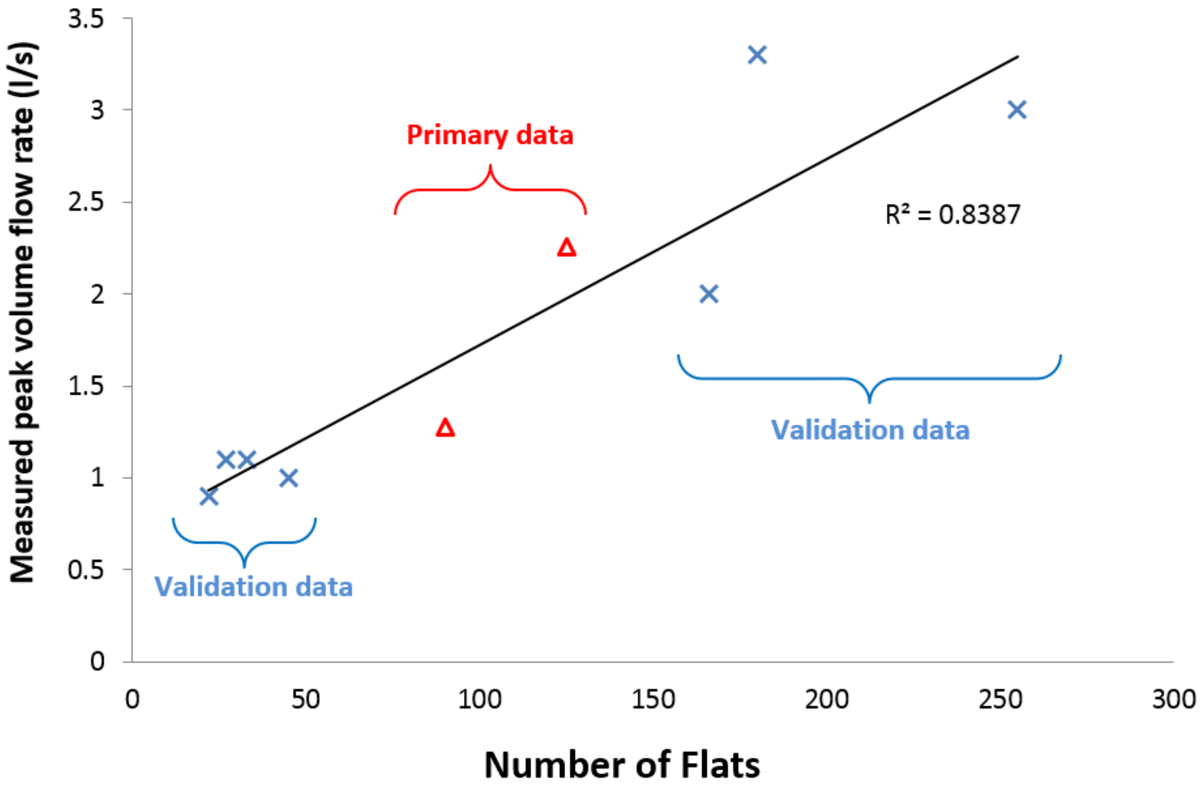

Figure 11 Peak measured volume flow rate for primary and validation data

Figure 12 displays the measured peak and the design flow rates for each of the three UK sizing methods for Blocks A and B and the seven validation buildings.

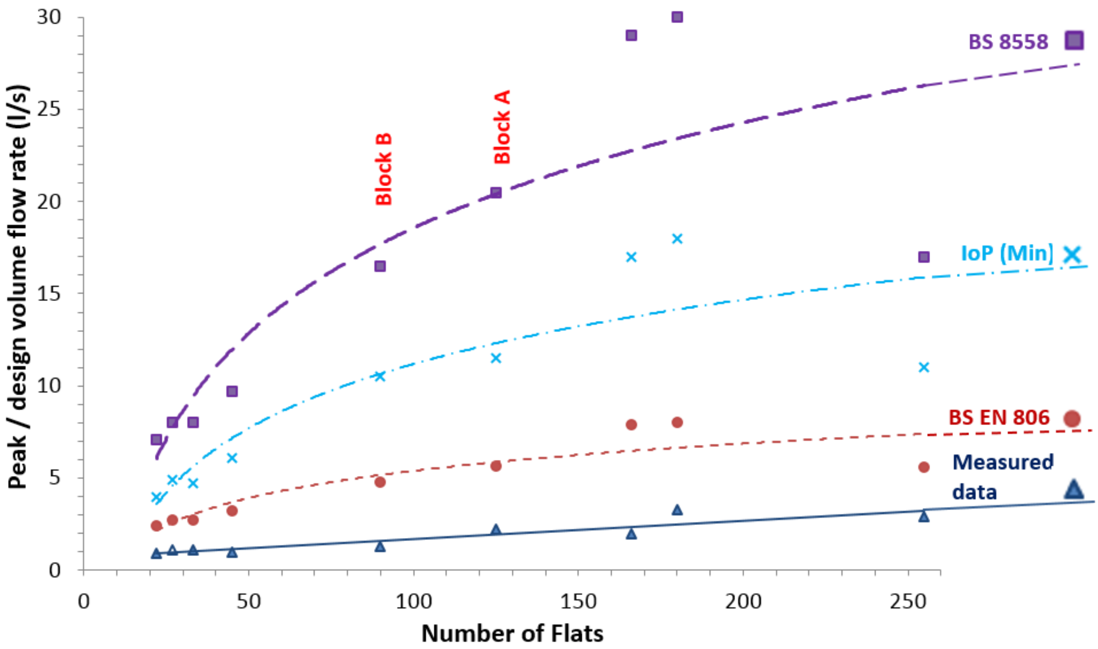

Figure 12 Peak and design volume flow rates for all buildings

It is evident that BS EN 806-3[1] is the best of the three UK sizing methods for predicting DCWS volume flow rates for multi-unit residential buildings on two grounds. Firstly, the predicted volume flow rate is closer than those returned by the other two methods for all buildings in the study. Secondly, the gradient of the line of best fit is almost parallel to that for the measured data. This should mean that BS EN 806-3[1] can be used for larger residential projects without excessively oversizing the pipework. The same cannot be said of the IoP[3] and BS 8558[2] methods both of which indicate, due to the gradient of the lines of best fit, that as the size of the development increases so will the margin of error.

It is interesting to note that there is significantly less variance from the line of best fit for the measured data compared to the sizing method trend lines. Focusing on the three buildings to the right-hand side of Figure 12 it can be seen that the first two from the left (Lowry Centre and Westway A to L) are both well above the trend lines while the one to the extreme right (Glasgow Harbour) is well below. The apartments at the Lowry Centre and Westway A to L developments are mainly two bedrooms and have two WC's and baths, whereas those at Glasgow Harbour are exclusively one bedroom, have just one WC and showers instead of baths. Whether an apartment has two separate WC's or one will not affect the overall use of WCs, rather the occupancy rate will be the more important factor. In addition, bath taps have large LU's and are not frequently used and this appears to have contributed to the higher predicted design flow rates for the Lowry Centre and Westway A to L. In combination, these facts explain the variance in the predicted design flow rates shown in Figure 12. Therefore, if design flow rate calculation methods are to be made more accurate in future they will need to take into account the number of occupants and their preferences rather than focusing entirely upon the number and type of outlets. It is interesting to note that Danish Standard DS 439[6] bases the heating required for DHWS purely upon the number of dwellings, a method that the data from this study would support.

6.0 Conclusion

This study has shown that the three UK DCWS sizing methods make different assumptions regarding the generation of Loading Units, and they differ regarding the amount of diversity applied when converting the number of LUs into a design volume flow rate. BS EN 806[1] applies significantly greater diversity once the number of loading units exceeds 50, i.e. away from the final pipe runs to the outlets. This greater diversity appears to closely match the empirical data from this study which makes BS EN 806[1] suitable for use for very large projects without excessively overestimating the design flow rate.

BS EN 806[1] has been shown to provide the closest design values for the residential buildings within this study. There is still a significant margin between the measured peak flow rates and the design values, and so this should help designers to feel confident in applying this method rather than either the Institute of Plumbing guidance[3] or BS 8558[2].

Finally, it would be wise for Engineers to consider carefully what the likely range of actual flow rates for a project is likely to be given the data presented in this study. All three sizing methods overestimated the design flow rates for the multi-unit residential buildings, and this knowledge should influence decisions such as the selection and specification of booster sets.

These findings should be welcome news for all Building Services Engineers who are interested in narrowing the design to operation performance gap.

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8.0 List of figures