Assessing overestimation of water demand in different types of non-residential buildings in the UK

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Abstract:

Water demand in buildings has reduced significantly over recent years as a result of the use of more water-efficient appliances and a heightened awareness of the need to conserve water. This has, in part, led to oversizing of water supply networks; a phenomenon that has given cause for concern from those responsible for the design of building plumbing systems. In spite of it being possible to define diurnal water use patterns as a specific feature of most non-residential applications, water demand is known to be different for different types of building and may be further influenced by factors such as occupancy and usage. Assessing water usage patterns hence becomes essential to develop new design approaches to provide a better estimate of water demand. It is therefore important to investigate water demand patterns in different types of non-residential buildings and determine whether or not current design methods in the UK remain appropriate.

This paper addresses water demand patterns in three different types of building, namely: mixed use, office and student accommodation. It investigates the oversizing problem by presenting a comparison of recommended design flow rates and monitored water demand. The paper also discusses the challenges of appropriate representation of student halls of residence.

The results clearly show that current design methods result in an overestimation and indicate the extent of oversizing for different types of non-residential buildings. Oversizing rates of 198% to 798% were found, and confirm that using the loading unit (LU) technique in current design codes is no longer an appropriate tool to estimate design flow. This outcome underscores the need to develop a new approach to support a better estimation of water demand.

Keywords

Water supply system, non-residential buildings, oversizing problem.

1 Introduction and background

Water is vital for life and is a critical resource for wellbeing. A growing global population, together with the impacts of climate change, have raised awareness across society in general and also within government for the need to have a strategy to reduce consumption. Long-term plans have been initiated by the UK government to increase supply whilst reducing demand (DEFRA, 2018). Additionally, both national and regional water labelling is in place to encourage people to use more efficient appliances such as low-flow taps and low and dual flush WCs. Replacing traditional products with water efficient models has already resulted in a significant reduction in water consumption (Kelly, 2015). In addition, working habits have changed, with working hours becoming more flexible. The difference in male:female ratio and in behavioural change amongst water users has also altered the overall demand (Pieterse-Quirijns *et al.*, 2013).

Despite a considerable reduction in water demand in buildings, there has been little, if any, corresponding change in system sizing approaches in the UK, and no significant updating of the design equations to adjust pipes and systems to a more appropriate scale and avoid oversizing.

In the UK, there are different design guides used to estimate water demand in buildings. In response to concerns that the traditional loading unit method results in over-estimation of the design flow, a study was undertaken by the LUNA Group (Loading Unit Normalisation Assessment) and provided recommendations for developing a new design approach, with greater accuracy, for residential buildings (Jack, 2017). However, there has been little research into the water demand arising from non-residential buildings and there is no evidence that the existing recommended design guides are able to address the oversizing problem. This paper summarises data collected from three case study buildings located at Heriot-Watt University in the UK. It provides critical information about water demand estimation in different types of non-residential building and investigates the extent of the oversizing problem.

1.1 The need for water conservation

Providing sufficient drinking water for populations globally has become a matter for some concern, even in seemingly water-rich countries such as the UK. There are many factors as to why fresh water has become more scarce a resource year upon year. These include: climate change, shifting demographics, increasing rates of ground water extraction, and increased chemical and organic pollution in water resources (Butler and Memon, 2006). The pressure on our water resources is also rising because of the need to retain sufficient water in our lakes, watercourses and wetlands to support the natural environment. In the UK, there are some areas that are over-abstracted or over licensed. In addition, water has to be used in an environmentally sustainable way in order to optimise its social and economic benefit. In some parts of the country, the amount of water taken from the environment causes damage to our ecosystems (Environment Agency, 2008). The Water Industry National Environment Programme notes that over 700 million litres per day of abstracted volume needs to be cut by water companies to address environmental problems and mitigate damage to ecosystems (DEFRA, 2018). These pressures are likely to be exacerbated in the future due to climate change impacts.

Reducing the amount of water consumed could make a considerable difference to water availability whilst also supporting the natural environment. The Water Resources Long-term Planning Framework states that a twin-track approach of reducing demand and increasing supply is needed to secure the resilience of water supplies over the next 50 years as preparation for a drier future (Water UK, 2016).

As a result of undertaking water conservation planning, water usage has changed across recent decades. Figure 1 shows the per capita water consumption in the UK between 1999 and 2017. It can be seen that there was an obvious reduction in water consumption from 150 to 140 litres per person per day (l/p/d) between 2005 to 2012. Minimum water efficiency standards were introduced into the building regulations in 2010 which required that all new homes were designed so that their calculated water use was no more than 125 l/p/d (DCLG, 2014b). Subsequently, a proposed water standard set a new threshold of 110 l/p/d (DCLG, 2014a) with the intention that this may be achieved at little additional cost (DEFRA, 2018).

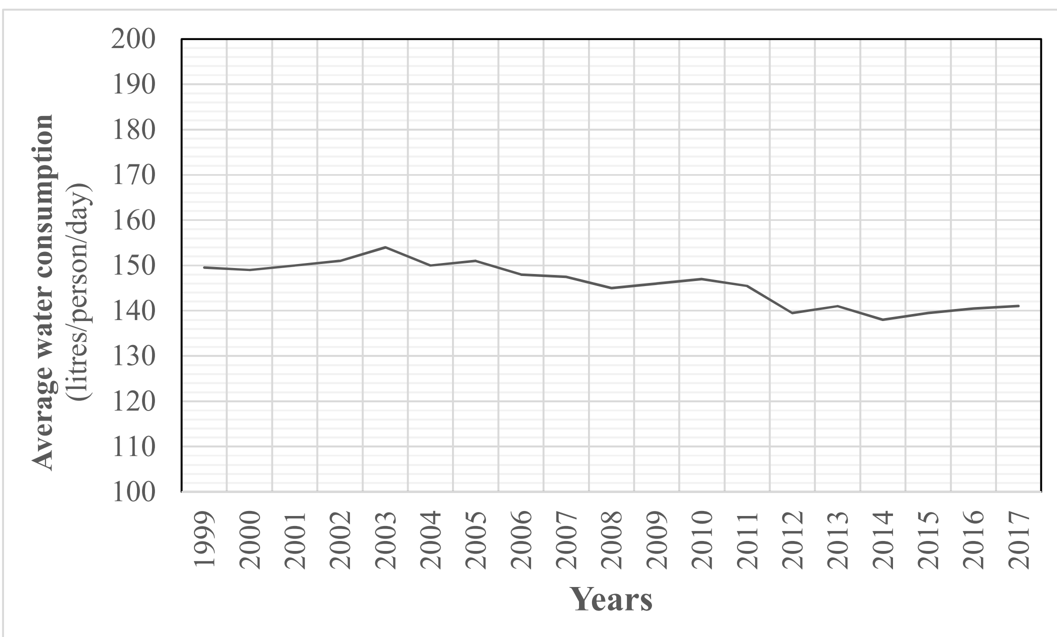

Figure 1 Per capita water consumption in the UK between 1999 and 2018 (DEFRA, 2018)

1.2 Oversizing problem

It is essential for each building to have a water supply system that provides an adequate quantity of water at all end use points at all times. Flow rates, therefore, should be designed to an acceptable level of confidence considering energy efficiency, health consequences and sustainability. Despite considerable efforts by water companies to provide high quality water, it is recognised that quality may deteriorate in water distribution systems because of any oversizing problems (Blokker, 2010) This also encourages the growth of Legionella which is acknowledged as a global problem, particularly in non-residential buildings. Furthermore, oversized systems are usually much less energy efficient and therefore cost more in terms of operation. The oversizing of water systems not only affects the cost of pipes but also leads to oversizing of storage tanks, booster pumps, and water heating devices, wasting both money and energy (Blokker, 2010; Pieterse-Quirijns *et al.*, 2013, 2014; Omaghomi and Buchberger, 2014). The British Standards Institution BS 8558 (2015) guidance also highlights concern related to overestimation of peak demand and states that this can result in larger than necessary pipe sizes, and related adverse effects.

1.3 Water demand estimation

It is important to provide adequate amounts of water to different sectors such as agriculture, industry, and the built environment, and to manage available water resources in the most efficient and equitable way. Information about water demand is also required to design water and wastewater infrastructure such as pipelines, treatment plants and storage. Water engineers hence need to know the water requirements of all types of users, as inaccurate demand estimates result in either underestimation which leads to inefficient use and inadequate service provision, or overestimation which leads to under-performance of systems with possible negative health consequences (Ilemobade, Van Zyl and Van Zyl, 2010). In addition, reliable water demand forecasting is essential to provide the basis for tactical, operational and strategic decision-making for potable water utilities organisations. For example, water companies need to know what the day-to-day water demand will be in order to operate their treatment plants properly to meet demand. They also need to predict the water demand for the next 20–30 years in order to plan treatment plant expansions and/or identify and develop new water sources (Donkor, Mazzuchi, Soyer and Roberson, 2014).

The first step in designing a water pipe network in any building is the estimation of the likely simultaneous peak water demand. In most of the design guides used for this purpose, flow rate is estimated, then designers assign reasonable values of design parameters and analyse the system to check whether the requirements of the users are met. (The Institute of Plumbing, 2002; BS EN 806-3, 2006; BS 6700:2006+A1:, 2009; BS 8558, 2015).

2 Case studies

In order to understand the water demand patterns in different types of non-residential buildings, flow rates were monitored and recorded in three different buildings at Heriot-Watt University in Edinburgh. The selection of buildings was based on size and usage parameters. The first building, the 'Estates' building, is a two-storey office building (Figure 2). The flowmeter was installed on the outlet pipe of the storage tank which supplies the building through gravity-feed. During flow measurement, the building was used by a maximum of about 50 persons.

Figure 2 Estates building

The second building monitored was the Hugh Nisbet building which is a three-storey mixed-use building. The building includes offices, a shopping area, canteen and coffee shop (Figure 3). Water is distributed to the building from two storage tanks. The building was used by about 1,150 persons during two weeks of flow measurement.

Figure 3 Hugh Nisbet building

The third building reviewed was the Christina Miller Hall; a five-storey student accommodation block (Figure 4). Here, water is pumped from a storage tank to the building using a set of booster pumps. The building was designed to be occupied by 133 students. It will be appreciated that water usage patterns in student accommodation may be different to other types of non-residential buildings such as those accommodating offices or shops. BS 6465-1:2006+A1, (2009) classifies this type of building under (bedrooms in hotels, hostels, and similar accommodation) category.

Figure 4 Christina Miller Hall

Information about the buildings, users, distribution pipe lines and sanitary appliances was collected in collaboration with technical staff. The number and type of appliances in each building are summarised in Table 1.

Table 1 Number and types of appliances in each building

Appliance	Estates building	Hugh Nisbet building	Christina Miller hall
WC	9	45	132
Wash hand basin	8	72	132
Urinal	2	18	
Kitchen sink	5	19	30
Shower	1		132
Cleaners sink	1	5	8
Washing machine			8
Dishwasher	1	6	
Total	**27**	**165**	**442**

3 Design flow rate estimation

Most UK design guides have changed over the years and different guides are available for designing water supply networks in buildings. The latest British Standard is BS 8558, published in 2015. This recommends the use of BS EN 806-3 to estimate design flow rates in residential buildings, and what is referred to as the 'traditional' method for all other applications (non-residential buildings).

BS 8558 explains that care is required when assessing the combined demand of cold and hot water supplies in order to reduce the effect of oversizing. For sanitary appliances fed with both cold and hot water, the traditional loading unit model assumes that the system demand imposed by the appliance is met fully by each separate supply, which is logical when separate cold and hot water taps are fitted to an appliance. BS 8558 states that this assumption is not valid when mixer taps or valves are used and it confirms that individual loading units relevant to the cold and hot water supplies ought not to be added together for sizing any combined cold and hot water demand.

BS EN 806-3, which is recommended for use for residential buildings, is the harmonised version of the UK and European Union guidance, the first part being published in 2000 and the fifth and final part in 2012. It introduced a new water demand estimation by assuming one loading unit to be equivalent to 0.1 l/s draw-off which results in a reduction in predicted water demand. In recent work by (Tindall and Pendle, 2017), who assessed the application of different guides to estimate design flow rates, results illustrate that BS EN 806-3 best predicts water demand for residential buildings (in comparison to BS6700 and the CIPHE Design Guide).

BS 6700 was published in three iterations between 1987 and 2006 and it was withdrawn in 2012. However, while BS 6700 used the same group of LUs and conversion chart as used in BS 8558, BS 6700 disregarded the difference in water demand resulting from the use of combined taps and mixers. Thus, when used in this study, the relevant LUs for hot and cold water supplies for BS6700 were added together for each appliance with the exception of the WC, urinal, washing machine and dishwasher; all of which use only cold water. It can hence be seen that BS 6700 results in the highest design flow rates.

The Plumbing Engineering Services Design Guide was published by the Chartered Institute of Plumbing and Heating Engineering (CIPHE), previously the Institute of Plumbing (IoP), and provides more detailed industry guidance for estimation of design flow rates. This guide uses LU values developed from the same probabilistic method, but enables more detailed LU information by considering period and frequency of use of each appliance. The latest version, published in 2002, provides a range of LU values including three classifications of use: Low, Medium, and High. The three groups are applied to reduce the effect of variations in capacity, flow rate, period and frequency of use of the appliances. This also helps designers make a professional judgement about the best LU value for use for different building types.

In this work, we have opted to use conventional sizing methods for all three buildings and additionally, have applied BS EN 806-3 to the Christina Millar building in order to assess its performance when applied to student accommodation. Although this latter application is not necessarily in-keeping with pre-defined guidance, it can be seen that the demand profile for halls of residence differs from other non-residential settings and is, in fact, more in line with domestic consumption patterns. BS 6700, although technically withdrawn, has also been used to show its performance in non-residential buildings and to emphasise the difference introduced by combining LUs for cold and hot water supplies to all types of sanitary appliances.

Figure 5 illustrates the flow rates estimated by each of the design guides (BS 6700, BS 8558, BS EN 806-3 and the CIPHE Design Guide [Medium]), for each of the case study buildings discussed above. In the Christina Miller hall when applying the CIPHE Design Guide, [Low] loading units were used for the appliances in the individual rooms and [Medium] in the shared kitchens.

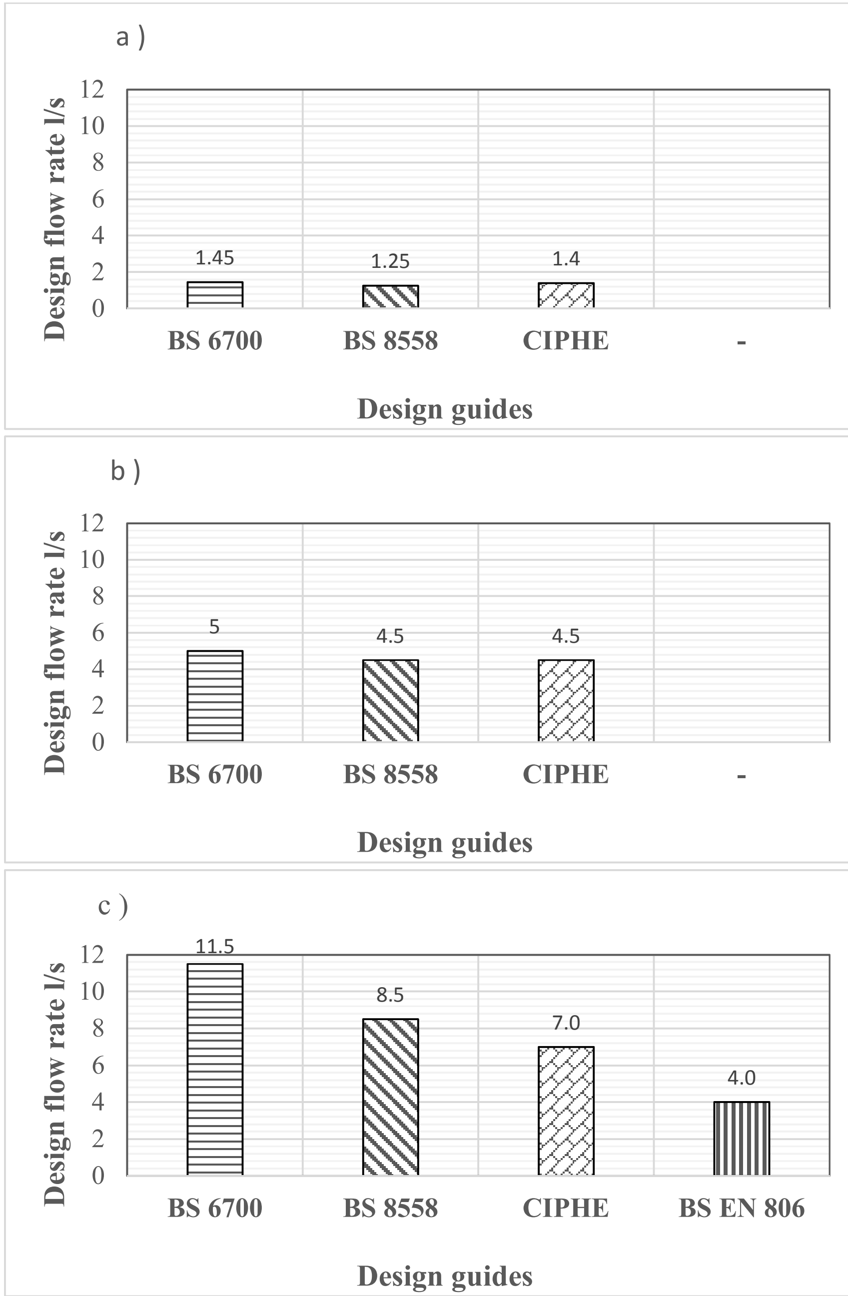

Figure 5 Estimated design flow rate using different guidance for a) the Estates building, b) the Hugh Nisbet building, and c) Christina Miller hall

4 Flow rate measurement

Recording in-situ flow measurements in different types of non-residential buildings is crucial to be able to assess the validity of current design guides and establish the extent of oversizing. It is also important to measure diurnal water demand on a per second basis to capture simultaneous usage of various appliances. Water flow in the main supply pipes within the case study buildings was measured using an ultrasonic flowmeter (a Portaflow

P330), as shown in Figure 6. This flowmeter is a non-intrusive device which is designed to work with clamp-on transducers to enable the flow of a liquid within a closed pipe to be measured without the need for any mechanical parts to be inserted through the pipe wall or protrude into the flow. The transducers and adjustable guide rails were secured in-situ after entering all pipe properties into the device ie. material, diameter, thickness so as to enable accurate calibration.

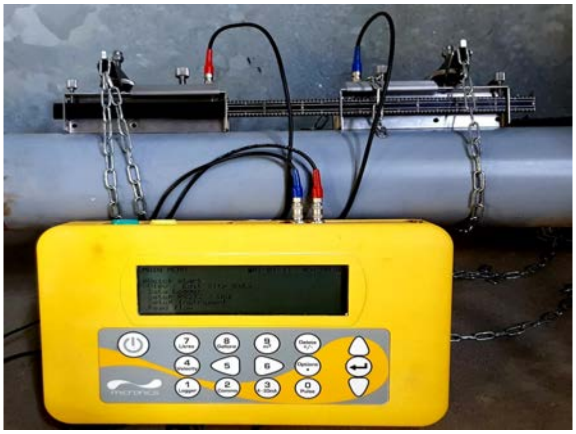

Figure 6 Ultrasonic flowmeter in place during monitoring

Each of the water systems in the selected case-study buildings contained large storage tanks located within the roof space that receive water from a main pipe and that feed the building either by gravity or using a booster pump set. Each flowmeter was installed on the main pipe between the storage tank and the booster pumps in the plant room, or was installed on the outlet pipe of the storage tanks in gravity-fed buildings. Flow rates were recorded every 5 seconds for a duration of around two weeks. It is worth mentioning that we believe that this is the first time in the UK that water demand has been measured at such high resolution (5 seconds) in non-residential buildings.

Like most design guidance, British Standards use a 99^{th} percentile level of confidence. Thus, Cumulative Distribution Functions (CDF) were generated for this level of reliability from the data gathered in order to yield an appropriate comparison with flow rates obtained from design guides. Figure 7 shows the observed flow rates (Q') for each of the case study buildings. The maximum flow rate (Q'_{max}) was found to be 0.689 l/s for the Estates building, 1.62 l/s for the Hugh Nisbet building, and 1.77 l/s for the Christina Miller hall. The 99^{th} percentiles of observed flow rates ($Q'_{0.99}$) were found to be 0.42 l/s for the Estates building, 1.11 l/s for the Hugh Nisbet building, and 1.28 l/s for the Christina Miller hall.

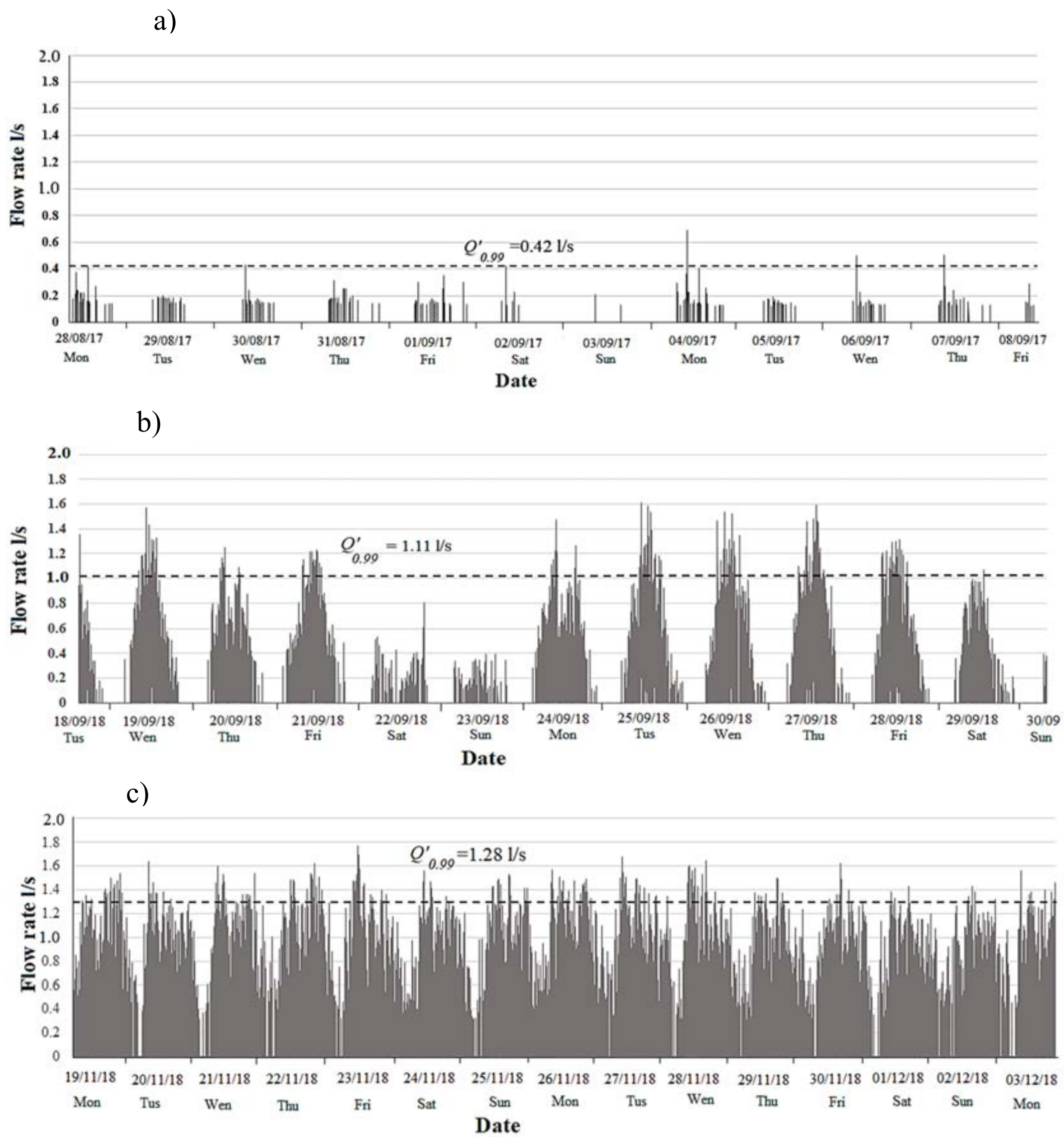

Figure 7 Observed flow rates in a) the Estates building, b) the Hugh Nisbet building and c) Christina Miller hall

5 Results and discussion

The comparison between flow rates obtained from design guides and the measured flows (99th percentile) is shown in Figure 8. Firstly, the results show comparability between design flow rates for both the Estates building and the High Nesbitt building, with all over-estimating. Secondly, the results show that despite the enhanced level of flexibility included in the CIPHE Design Guide, this has not resulted in a significant reduction in design flow rate across the piece. Despite taking into account peak times for water demand and frequency of use as recommended in the guidance, this yielded almost the same design flow rates as other guides for the Estates and Hugh Nisbet buildings. Thirdly, BS 8558 resulted in a slightly smaller flow rate than that calculated from BS 6700 and the CIPHE Design Guide for the Estates building. This lower estimation by BS 8558 resulted from excluding urinals in the calculation of LU and not applying the relevant LU separately to the hot and cold water supply for kitchen sinks. Finally, the design flow rates obtained from BS 6700 resulted in a significant over-estimation in all buildings. This is because it disregards the reduction in flow rate for appliances fitted with mixer devices. Notably, it can be seen that BSEN806, when applied to the student halls of residence, still over-estimates the flow.

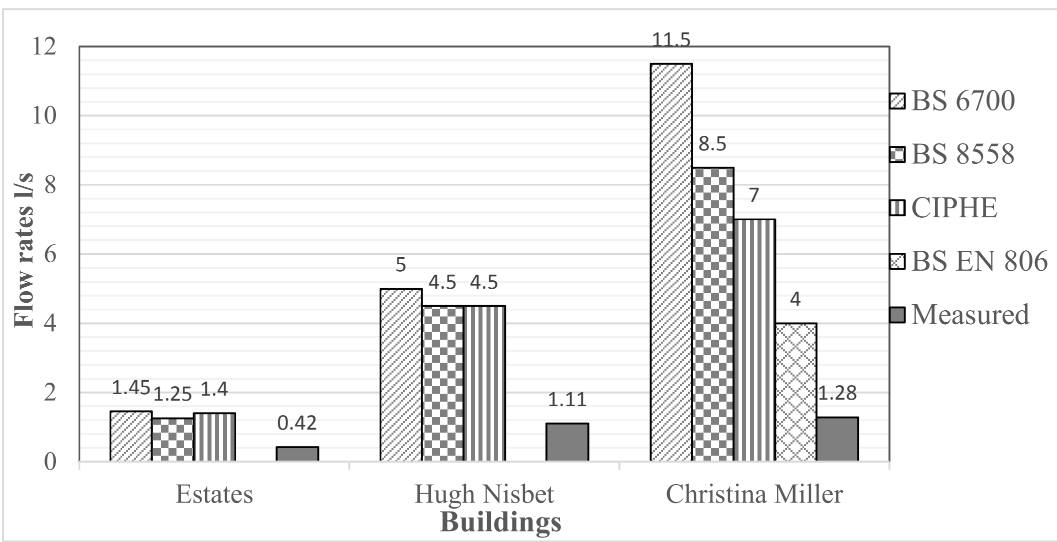

Figure 8 Comparison between design and measured flow rates

It can be seen that significant differences emerge dependent upon the selected design method. This is because each approach has different LUs and LU-to-flowrate conversion charts. In-keeping with previous studies, and as expected, all design methods produced significantly greater design flow values than those measured in each of the case study buildings. The extent of overestimation of water demand is shown in Figure 9. The lowest values of overestimation were found to be 198%, 305%, and 213% for the Estates building, the Hugh Nisbet building and the Christina Miller hall respectively.

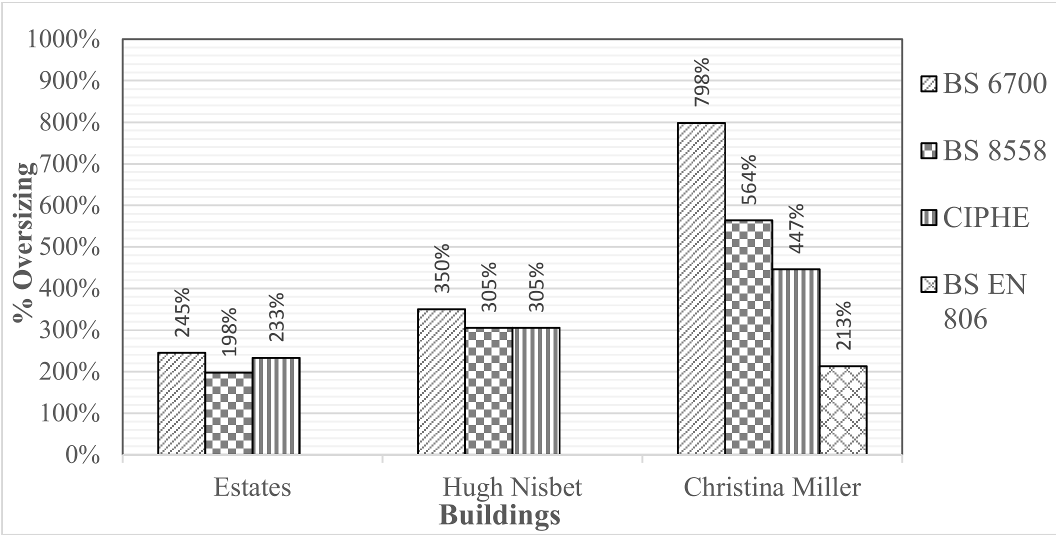

Figure 9 Percentage of oversizing based on measured flow rates

6 Conclusion

Design flow rates were calculated for three non-residential buildings using different design guides available in the UK. In order to provide a comparison and to assess the validity of current design guides, flow rates were measured in each of three buildings at a frequency of every 5 seconds for two weeks. Results clearly show the degree of over-estimation. In addition, despite the fact that the CIPHE Design Guide provides a range of flexible options for the selection of appliances (including different LUs for separate taps and mixers in washbasins, and provides three classifications of demand (low, medium and high), it's use still resulted in the prediction of high flow rates. It was also found that the application, to the student halls of residence, of the standard normally assumed to give the lowest demand prediction, BS EN 806-3, still resulted in a significant overestimation by 213% when compared to measured flow rate.

This study clearly shows that the design flow rates obtained from current design guides used in the UK result in a significant overestimation for different types and sizes of buildings. Although the latest British Standard (BS 8558:2015) recommends the use of BS EN 806-3 for residential buildings and the "traditional" method for non-residential buildings, none of these fully address the oversizing problem. The results indicate that it is not possible to accurately estimate water demand using the current design guides and highlights the need to develop a new approach for better estimation of water demand in non-residential buildings.

7 References

Blokker, E. J. M. (2010) *Stochastic water demand modelling for a better understanding of hydraulics in water distribution networks*. Water Management Academic Press. doi: 10.1017/CBO9781107415324.004.

BS 6465-1:2006+A1 (2009) *Sanitary installations-Part 1: Code of practice for the design of sanitary facilities and scales of provision of sanitary and associated appliances*. BSI 2009.

BS 6700:2006+A1: (2009) *Design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages -Specification*. London: BSI 2009.

BS 8558 (2015) *Guide to the design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages - Complementary guidance to BS EN 806*. London: BSI 2015.

BS EN 806-3 (2006) *Specification for installations inside buildings conveying water for human consumption — Pipe sizing- Simplified method*. London: BSI 2006.

Butler, D. and Memon, F. A. (2006) *Water Demand Management*. London: IWA Publishing.

DCLG (2014a) *Housing Standards Review: Cost Impacts*, *Department for Communities and Local Government, EC Harris LLP*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/353387/021c_Cost_Report_11th_Sept_2014_FINAL.pdf.

DCLG (2014b) *Housing Standards Review Summary of Responses, Summary of Responses*, *Department for Communities and Local Government*.

DEFRA (2018) *Water conservation report: Action taken and planned by government to encourage the conservation of water*. Available at: https://www.gov.uk/government/publications.

Donkor, E. A., Mazzuchi, A. T., Soyer, R. and Roberson, J. A. (2014) 'Urban Water Demand Forecasting: Review of Methods and Models', *Journal of Water Resources Planning and Management*, 140, pp. 146–159. doi: 10.1061/(ASCE)WR.1943-5452.

Environment Agency (2008) 'Water resources in England and Wales - current state and future pressures', *Environmental Agency*. Available at: www.environment-agency.gov.uk.

Ilemobade, a a, Van Zyl, J. E. and Van Zyl, H. J. (2010) 'New guidelines for non-domestic water estimation in South Africa', in *Integrating Water Systems: Tenth International Conferance on Computing and Control for Water Industry, CCWI 2009*. Sheffield, UK, pp. 543–549.

Jack, L. B. (2017) *An Assessment of the Validity of the Loading Units Method for the Sizing of Domestic Hot and Cold Water Services*. CIBSE

Kelly, D. A. (2015) 'Labelling and water conservation : A European perspective on a global challenge', *Building Services Engineering Research & Technology*, 36(6), pp. 643–657. doi: 10.1177/0143624415571758.

Omaghomi, T. and Buchberger, S. (2014) 'Estimating water demands in buildings', *Procedia Engineering*, 89, pp. 1013–1022. doi: 10.1016/j.proeng.2014.11.219.

Pieterse-Quirijns, E. J. *et al.* (2014) 'Validation of non-residential cold and hot water demand model assumptions', *Procedia Engineering*. Elsevier B.V., 70, pp. 1334–1343. doi: 10.1016/j.proeng.2014.02.147.

Pieterse-Quirijns, E. J., Blokker, E. J. M., Van Der Blom, E. and Vreeburg, J. H. G. (2013) 'Non-residential water demand model validated with extensive measurements and surveys', *Drinking Water Engineering and Science*, 6(2), pp. 99–114. doi: 10.5194/dwes-6-99-2013.

The Institute of Plumbing (2002) *Plumbing Engineering Services Design Guide*. Hornchurch: The Institute of Plumbing (IoP) was renamed as the Chartered Institute of Plumbing and Heating Engineering (CIPHE) in 2008.

Tindall, J. and Pendle, J. (2017) 'A comparison of UK domestic water services sizing methods with each other and with empirical data', *Building Services Engineering Research and Technology*, 38(6), pp. 635–649. doi: 10.1177/0143624417719009.

Water UK (2016) *Water resources long term planning framework (2015-2065)*. Available at: https://www.water.org.uk/publication/water-resources-long-term-planning/.

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