# Research Report

## An assessment of the validity of the loading units method for sizing domestic hot and cold water services

CIPHE
CIBSE
HERIOT WATT UNIVERSITY
THE SOCIETY OF PUBLIC HEALTH ENGINEERS
Joint Research Project
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# Executive summary

The LUNA (Loading Unit Normalisation Assessment) project was initiated in response to the growing concern within the building services and public health engineering sectors that the traditional loading unit method used in the UK results in an over-estimation of the design flow for domestic hot and cold water systems. This over-estimation cannot be regarded as a theoretical problem that simply provides a sensible margin of safety. Over-estimation of the design flow will impact on the sizing of booster-pumps and is likely to lead to oversizing of piping within some parts of a building's water supply network. In addition to the obvious negative impact on energy efficiency and construction sustainability, there is concern that in oversizing pipework, the resultant lower velocities will have an adverse effect on water quality, will increase the risk of biofilm growth and will increase unwanted heat gain. This report focuses on medium-to-large scale residential buildings, as this is where the magnitude of oversizing is thought to be greatest.

This report summarises the outcomes of the first phase of the LUNA project, and provides a recommendation for the development of a new methodological approach for assessment of simultaneous flow rate for greater accuracy when sizing pipework, and associated plant selection. Although resourcing for this first phase of the project did not allow for data collection, data provided by a third party enabled a comparison against as-installed designs, thereby providing an indication of the difference between estimated and actual values. Outcomes show that although the loading unit system within BS EN 806-3 produces lower design flow values compared to other UK loading unit methods, concern remains about the predicted combined hot and cold water flow, in particular regarding the inability of this method to account for low-flow outlets on a range of water efficient appliances. Comparisons with other methods also show how those that employ an empirically-based statistical framework offer a better fit with measured data. The report discusses the relative merits of different statistical models concluding, on the basis of both statistical validity and a comparison with measured data, that a move away from the use of traditional loading units is now timely.

Although stochastic models have the advantage of being able to generate the most realistic scenarios representative of the demand placed on systems, these generally lie outside the timescale and resources available, and so overall, the evidence presented strongly suggests that an empirical model is best suited to the sizing of pipework and pump systems for mid-large size residential buildings. Development of the empirical parameters required by this new model will be addressed in phase 2 of the LUNA project, thereby subsequently informing technical guidance documents and potentially forming the basis for a new national standard.

Lynne Jack and Brian Whorlow

# An assessment of the validity of the loading units method for the sizing of domestic hot and cold water services

## 1 Introduction

There now exists relatively widespread concern across the building services and public health engineering communities that the loading units approach used for the sizing of domestic hot and cold water systems is no longer fit for purpose. In addition to the variance and diverging results produced by comparable codified documents, limited flow collection data and anecdotal evidence suggest significant over-estimation of the total peak simultaneous flow occurs for medium-to-large residential buildings. This aspect of the design impacts directly upon booster pump selection, and upon pipe sizes at central plant and throughout the 'spine' of the buildings’ supply network, adversely affecting installation cost, construction sustainability, space requirements, energy consumption, operational costs and potentially also water quality parameters. This situation has arisen for a number of reasons but primarily because of the way in which appliance type, design and usage patterns have changed significantly since the current probability-based method was first developed and adopted.

This document summarises the outcomes of the first phase of the Loading Unit Normalisation Assessment (LUNA) project, which aims to establish an improved model for the purposes of sizing domestic hot and cold water systems. The first phase of this work, reported herein, involves a review of UK and comparable design methods used to assess the peak design flow in domestic hot and cold water piping systems, and focuses on providing a recommendation for the framework/methodology best suited for system sizing for medium-to-large scale residential buildings, as this is where the magnitude of oversizing is thought to be greatest. It is acknowledged that some oversizing may also occur in relation to commercial and other buildings. This determination allows for clarification on whether the existing loading units methodology should be retained and re-worked, or whether an alternative method is more suitable. Although the work reported is limited to medium-to-large residential buildings, this is not intended to define the scope of any subsequent LUNA research phase. It is also recognised that the outcome from the follow-on phase(s) of this project, where any re-working or revision may be fully developed and the necessary empirical parameters established could, indeed *should*, inform technical guidance documents and potentially form the basis for a new national standard.

# 2 Project methodology

Figure 1 illustrates the methodological approach adopted for the Phase 1 work. It also helps define the following sections within this report. The work commenced with a review of relevant international standards so as to establish the range of documents from which examples may be drawn and upon which any proposed new statistical framework might be based. It is important to note here that this review was not a comprehensive review of all European and international standards; rather it was a review of documents judged by the research team to be relevant and/or to provide a theoretical model that merited investigation. Using this list of codes, the statistical framework for each was then categorised and once any aspects of commonality had been identified, a number of standards were selected as those for which a direct numerical comparison of design flow would be made.

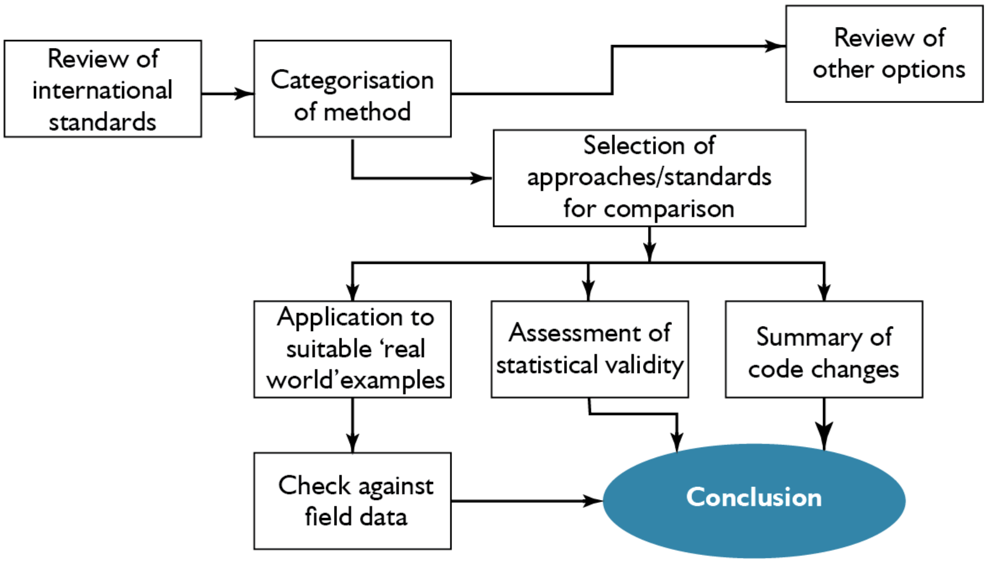


**Figure 1** Methodological approach for phase 1

For the purposes of this comparison, a number of case study buildings were identified. These buildings all fit the broad categorisation of mid-large scale residential buildings. Using drawings provided by members of the LUNA group[1], design flow rates for each were then established using the codes and techniques shortlisted. It can be seen that the outcome of this aspect of the work allows a comparison of sizing across international standards. However in order to achieve a true comparison against an as-installed design, a verified field dataset was used as a comparator.

In parallel, an assessment of the statistical validity of the shortlisted methods was also undertaken. The two main sources of information that then allowed conclusions to be drawn were the comparisons between flow results from relevant codes and measured data, alongside the findings from the analysis

[1] Comprising CIBSE, CIPHE, SoPHE and industry representation; see the LUNA Group members list on page 1.

of statistical validity. Information has also been presented, where available, on recent or ongoing changes to international codes that might reflect similar concerns over pipe sizing methods. Additionally, information on alternative approaches, that are currently the subject of ongoing research investigations internationally and that remain some way from implementation, are presented but that might be adopted in the longer term.

# 3 Statistical models

Before discussing the categorisation of models used, it is useful to explain the way in which these have been defined for the purposes of this project. Three categories have been specified: probabilistic, stochastic and empirical. Definitions are given below.

— *Probabilistic models* are based on a prescribed probability distribution that associates some measure of likelihood of occurrence with each of the possible outcomes. Most of the models that rely on the application of standard probability theory are based on Hunter's methodology for estimating the 99$^{th}$ percentile of the simultaneous water demand during a busy period. Hunter's method is also based on the following assumptions:

- water use is a random process
- not all the fixtures/appliances are used simultaneously
- the problem of estimating simultaneous water demand during a busy period can be modelled within the framework of basic probability theory.

Hunter's technique can therefore be used to estimate the probability $p$ that, out of a total of $n$ appliances/fixtures of a particular type/kind, $r$ will be found to operate *simultaneously* at any arbitrary chosen instant. Hunter's method exploits the classical Binomial probability distribution theory to estimate the expected peak flow, based on the availability of the following information:

- $n$ = number of appliances/fixtures of a particular type/kind
- $t$ = average duration of operation (s)
- $T$ = average duration of successive operation (s).

— *Stochastic models* are designed to account for randomness and uncertainty, and are often based on Monte-Carlo simulation processes that initiate a modelling procedure driven by a set of input parameter values and initial conditions (obtained/collected through some known/measured data or by analysis of information to define various probability distributions). Stochastic models generate ensemble outcomes corresponding to different sets of input parameter values and initial conditions. Thus, stochastic modelling techniques are designed to exploit statistical probabilities of various input factors and variables to predict the probability of a desired outcome (or in this case, to generate a portfolio of water demand profiles).

The stochastic modelling approach allows the user to integrate various aspects of uncertainty (that are inherent in most natural processes) in the modelling procedure in a way that is not possible with a traditional empirical modelling style. Probability-based models allow for the integration of some form of uncertainty, but not to the extent enabled by a fully-developed stochastic model. It is also worth noting here that stochastic models can handle extreme values much more effectively than any other modelling scheme.

— *Empirical modelling* approaches (sometimes referred to as 'deterministic') facilitate an estimation of mathematical formulae/expressions. Formulae, charts and tables can be derived by exploring the mathematical/statistical relationships between input and output (measured/observed) data values. In general, most of the standards for the sizing of pipework are based on empirical approaches that can be grouped in to two basic types of modelling scheme:

- power law models
- square root models.

# 4 Review of relevant international standards

## 4.1 Establishing a 'long-list' of relevant codes

In establishing a list of relevant international standards, it is important to note that the intention was not to complete an international review. Rather, the intention was to establish a compilation of codes and guidelines deemed to be of relevance due to their suitability of approach to pipe sizing, their geographic and cultural applicability and their accessibility. This 'long-list', shown in Table 1 below, also includes relevant codes used in the UK.

It is worth noting here that an element of judgement had to be applied in establishing this long-list. We made every effort to ensure that our choices were not unduly influenced by access (or lack of) a version presented in, or able to be translated to, English. This meant that for some codes (that do not appear on our final long-list) there was some degree of interpretation of methods presented within codes to discern whether full translation and inclusion was justified.

| Code | Country | Statistical method |
|---|---|---|
| BS EN 806[1] | UK | Probability |
| BS 8558 (BS 6700)[2,3] | UK | Probability |
| CIBSE Guide G[9] | UK | Probability |
| CIPHE/IoP[10] | UK | Probability |
| IPC/UPC/NSPC[11,12,13] | USA | Probability |
| ISSO - 55 (Code)[5] | Netherlands | Empirical |
| ISSO 55 (via SIMDEUM) | Netherlands | Stochastic |
| SANS 10252-1[7] | South Africa | Empirical |
| UNE 149201[14] | Spain | Empirical |
| DIN 1988-300[6] | Germany | Empirical |
| DS 439[4] | Denmark | Empirical |
| SNiP 2.04.01-85[8] | Russia | Empirical |

**Table 1** 'Long list' of codes and standards considered

## 4.2 Selection of approaches/standards for comparison

Distilling the list shown above with the aim of avoiding duplication of statistical method and/or allocation of loading units, Table 2 below presents the list upon which a direct comparison of simultaneous flow rates was undertaken.

| Code | Country | Statistical method |
|---|---|---|
| BS EN 806[1] | UK | Probability |
| BS 8558 (BS 6700)[2,3] | UK | Probability |
| CIPHE/IoP[10] | UK | Probability |
| IPC/UPC/NSPC[11,12,13] | USA | Probability |
| ISSO 55 (Code)[5] | Netherlands | Empirical |
| SANS 10252-1[7] | South Africa | Empirical |
| DIN 1988-300[6] | Germany | Empirical |
| DS 439[4] | Denmark | Empirical |
| SNiP 2.04.01-85[8] | Russia | Empirical |

**Table 2** List of codes and standards considered for comparison of flow rates

### 4.2.1 Background information: BS EN 806

The recognised standard for sizing pipework systems within the UK is BS EN 806-3: 2006[1], which should be applied in conjunction with complementary guidance presented in BS 8558: 2015[2] (the replacement for BS 6700: 2006 + A1: 2009[3]). BS EN 806 is the UK version of a harmonised European Standard. This European Standard provides a low level of sizing harmonisation across CEN member countries as the design engineer has the option of using the loading unit method within the EN or the recognised national sizing method applicable in each country. BS 6700 is listed as providing a possible alternative sizing method for the UK as this was a 'live' Standard when Parts 1–4 of the European Standard were drafted however this has since been superseded by BS 8558[2]. According to the simplified method presented in BS EN 806-3: 2006 for pipe sizing for 'standard' installations, a loading unit (LU) value is assigned to each appliance where 1 LU is equivalent to a draw-off flow rate of 0.1 l/s. The sum of loading unit values for each section of the installation is then converted to a design flow rate using a nomogram. When the total LU value is less than 300, different curves representing the relationship between the total LU value and the design flow rate have been provided based on the highest single LU value.

It can be seen from this standard that the design flow rate is based upon the number, type and LU value of appliances for larger installations (where the total LU value is greater than 300) and specifically on the LU value of the appliance with highest draw-off flow rate (or highest LU value) for all other installations. It is also worth noting that the total flow rate is assumed as being derived from the sum of both hot and cold LU values. In accordance with guidance, the simultaneous flow calculations presented within this report are based, for BS EN 806[1], on the summation of both, but for the purposes of comparison, are shown alongside output data that uses loading units for the cold supply only.

It is believed that this loading unit system was derived from design practice used in Switzerland, and appears to be based on the probability model. However, within the study period for this report it has not been possible to establish what informs the scientific logic for creating different flow conversion curves when the sum of the connected loading units is less than 300. It should be noted that the design flow rates produced from this method are relatively low when compared to the traditional UK loading unit system, and to some degree have similarity with residential design flows produced by some other European methods; consequently, this is the reason why BS 8558[2] recommends that the BS EN 806[1] sizing method should be restricted to residential applications. Interestingly, the loading units recommended in the CIPHE/IoP *Plumbing Engineering Services Design Guide* (2002)[10] for the low frequency use of appliances are similar to those values given in BS EN 806.

However, for a given value of loading units, the two documents recommend different design flow rates, indicating that the conversion method used by each to estimate the design flow rate from a loading units value, differ.

### 4.2.2 Background information: BS 8558

BS 8558: 2015[2] provides complementary guidance to accompany BS EN 806[1], as noted above. Reflecting on its development, it may be seen that the publication (in 2012) of the fifth and final part of BS EN 806-3[1] signaled the withdrawal of BS 6700[3], where some of the content of BS 6700[3] that was not detailed in BS EN 806-3[1] was incorporated in BS 8558[2]. The recommended method for the estimation of design flow rates in residential buildings noted in BS 8558[2] refers the reader to BS EN 806-3[1] and it may be seen that the method used is therefore also based on the application of probability theory and the use of loading units. However, BS 8558[2] also presents what is referred to as the 'traditional' method for the application of loading units, noting that BS EN 806-3[1] should be used for residential installations and the 'traditional' method for all other applications. BS 8558[2] also suggests that for non-residential buildings the CIPHE 'low', 'medium' and 'high' loading units might be more appropriate, as these allow a professional judgement to be made about loading unit allocation. It should be noted that the loading unit listing and their values in use today, as presented in BS 8558[2], are the same as when first introduced into the UK when BS CoP 310[15] was published in 1965, and by comparison it can be found that the resulting design flow rates are also similar, albeit that the original conversion graph was graduated in gallons per minute (gpm). It should also be noted that the guidance originating from BS 6700[3] relating to the assessment of the total design flow from the combined hot and cold demand is based on the sum of the hot and cold water loading units, although this is questionable and may result in oversizing. BS 8558[2] alludes to this and recommends that for flow-limited mixed-water outlets, only one loading unit value should be used in the assessment of the combined demand. This is because the single hot or cold loading unit value is based on meeting the full functional requirement of the outlet. It is also noted that several American codes do not advocate adding together the full hot and cold loading unit values when assessing the total building demand.

Although the work reported herein refers principally to mid-large scale residential buildings, it was decided to retain reference to BS 8558[2] and the now withdrawn BS 6700[3] (together, and as shown in Tables 1 and 2) as they not only present the same loading unit values but also offer reference to a previously often-used method of sizing. It is believed that this provides a useful reference for those who are familiar with different methods. Importantly, and as was the case for BS EN 806-3[1], a total flow rate based on the sum of both hot and cold loading unit values has been calculated; firstly to provide a direct comparison with other methods and also because, in applying all relevant codes and standards to the case study buildings, it has been assumed that no mixers exist. However, also as was the case for BS EN 806[1], and for the purposes of comparison, data are presented for which the hot and cold loading units have not been added together.

### 4.2.3 Background information: CIPHE/IoP *Plumbing Engineering Services Design Guide* (2002)

The *Plumbing Engineering Services Design Guide* (2002)[10] published by the Chartered Institute of Plumbing and Heating Engineering (CIPHE) (formerly the Institute of Plumbing (IoP)) offers a recognised industry standard for the sizing of pipework systems within the UK. This guidance takes account of appliance type, flow rate, period of use and frequency of use characteristics to establish a loading unit system, based on the application of probability theory, to satisfactorily reflect a 'maximum simultaneous design flow rate'.

Evidence suggests that the CIPHE developed the UK loading unit system based on the Hunter probability theory (see section 3). Design guidance published by the IoP in 1966 is essentially identical to the guidance within the CoP 310[15]. Subsequent CIPHE/IoP design guidance has been modified in an attempt to refine/modernise the loading unit values, and the current publication includes a range of loading unit values for high/medium/low frequency of use, thus allowing the design engineer to apply professional judgement when selection the loading unit for a particular application. 'Low use' is recommended for '*dwellings and other buildings where appliances are used by a single person, or a small group of people, as a private facility*'; 'medium use' is recommended for '*appliances that are available to be used by a larger group of people, as and when they require on a random basis with no set time constraint, typically associated with 'public use' toilets'*, and 'high use' is recommended for '*appliances to be used by large numbers of persons over a short period*' such as in theatres, concert halls and sports venues.

With reference to the scope of the work reported herein, the reader is directed to the 'low use' data as this applies to dwellings. In accordance with guidance, the simultaneous flow calculations presented are based on the summation of both hot and cold loading units but, as was the case for both BS EN 806[1] and BS 8558[2]/BS 6700[3], data are also presented for which the hot and cold loading units have *not* been added together.

### 4.2.4 Background information: Danish Standard DS 439

Danish standard DS 439: 2009[4] specifies an empirical method to calculate the design flow representative of the random use of appliances. The standard also presents a diversity factor used to calculate the simultaneous hot water demand from multiple dwellings that is used alongside the calculation to determine the heating demand for district heating systems.

According to DS 439: 2009[4], the design flow is calculated using the following equation:

$$q_d = 2\, q_m + \theta\, (\sum q_f - 2\, q_m) + A\, \sqrt{(q_m\, \theta)}\, \sqrt{(\sum q_f - 2\, q_m)} \quad (1)$$

where $q_d$ is the design flow of the relevant section based on randomly used appliances (l/s), $q_m$ is the weighted mean flow for several appliances connected to the distribution pipe, $\sum q_f$ is the sum of intended flow rates of appliances (l/s) and $A$ and $\Theta$ are constants.

Recommended intended flow rates ($q_f$) are specified in the code for both hot and cold water systems; alternatively any other value that assures the satisfactory operation of appliances may be used. The values for $q_m$, $A$ and $\Theta$ should be selected based on the type of building, and further definitions to calculate the value of $q_m$ illustrate that it is based on the frequency, tapping times[2] and mean flow rate of appliances. Recommended values are given ($q_m$ = 0.1 l/s, $A$ = 3.1, $\Theta$ = 0.015) for residential and similar buildings where relatively low and random use of appliances is predicted.

### 4.2.5 Background information: ISSO Publicatie 55 (ISSO-55)

ISSO Publicatie 55: 2013[5] is the Dutch standard for the calculation of hot and cold water requirements for residential buildings. This is based on a twofold approach whereby 'calculation rules' are specifically applicable up to the connection to an apartment, and for flows *within* the apartment, the '$q \sqrt{\sum \text{TE}}$' rule is said to apply. For the latter, a nominal demand of 0.083 l/s is used for $q$ and, based on the design flow rate of the appliance ($q_v$), the tap unit (TE) is calculated as shown in equation 2:

$$\text{TE} = (q_v / 0.083)^2 \quad (2)$$

For the former, i.e. apartments, the 'calculation rules' were developed based on simulations performed using SIMDEUM, a stochastic model that uses statistical information gathered on water-using appliances and on household user demographic and behaviours[3][16–18].

Calculation rules are specified in order to determine the maximum hot and cold water flow rates and the maximum hot water volumes for different time periods: 10 minutes, 1 hour, 2 hours and 1 day, for six types of apartments as a function of the number of apartments of a particular type ($n$), and as shown in Table 3.

[2] 'Tapping' is a literal translation but taken here to mean duration.

[3] Includes data gathered from: Dutch water companies (3200 respondents), Netherlands Institute for Social Research (social survey), public information from the Statistics Bureau CBS, and technical information on appliances (provided by manufacturers).

| Apartment type | Cold water maximum flow (l/s) | Hot water maximum flow (l/s) |
|---|---|---|
| Studio | $0.227 + 0.109\ (\sqrt{n}) + (0.00366\ n)$ | $0.272 + 0.0373\ (\sqrt{n}) + (0.00359\ n)$ |
| Luxury two bedroom ($100\ m^2$) | $0.578 + 0.146\ (\sqrt{n}) + (0.01\ n)$ | $0.270 + 0.107\ (\sqrt{n}) + (0.00325\ n)$ |
| Seniors' apartment ($120\ m^2$) | $0.331 + 0.064\ (\sqrt{n}) + (0.007\ n)$ | $0.25 + 0.0052\ (\sqrt{n}) + (0.00259\ n)$ |
| Three bedroom ($120\ m^2$) | $0.348 + 0.00902\ (\sqrt{n}) + (0.00803\ n)$ | $0.246 + 0.0523\ (\sqrt{n}) + (0.0034\ n)$ |
| Luxury three bedroom ($160\ m^2$) | $0.563 + 0.171\ (\sqrt{n}) + (0.013\ n)$ | $0\ 323 + 0.0924\ (\sqrt{n}\ ) + (0.00637\ n)$ |
| Luxury four bedroom ($250–300\ m^2$) | $0.449 + 0.191\ (\sqrt{n}) + (0.0118\ n)$ | $0.359 + 0.0795\ (\sqrt{n}) + (0.0068\ n)$ |

**Table 3** Calculation rules according to ISSO-55

The assumed number and type of appliances in each type of apartment are also specified within the code. Furthermore, a correction factor is applied for calculating the total maximum flow for different types of apartment, see Table 4, where $n$ is the number of apartments of a particular type, and:

$$f_{x,\,corr} = \frac{1}{(0.2\,f_x - 0.2)\,n_{type} + 1.2 - 0.2\,f_x} \qquad (3)$$

where $n_{type}$ is the number of different types of apartments.

| Factor | Cold water maximum flow (l/s) | Hot water maximum flow (l/s) |
|---|---|---|
| $f_x$ | $3.96\ n^{-0.17}$ | $4.38\ n^{-0.17}$ |

**Table 4** Correction factors for maximum flow rate according to ISSO-55

This empirical approach specified in the Dutch standard hence recommends design flow rates based on the number and type of different apartments within the selected building. It is also worth noting the stochastic aspect of this approach.

### 4.2.6 Background information: DIN 1988-300

German standard DIN 1988-300: 2012-05[6] recommends an empirical method for calculating the peak flow for the simultaneous use of appliances using the following equation:

$$V_s = a\,(\sum V_R)^b - c \qquad (4)$$

For $0.2 \leq \sum V_R \geq 500$, where $\sum V_R$ is the sum of the calculated flow rates for installed appliances (l/s), $V_s$ is the peak flow (l/s), and $a$, $b$, and $c$ are constants. The calculation flow rates are specified in the standard for different appliances and are applicable for both hot and cold water systems. Manufacturers' specifications for the calculation flow rates can also be used. The values of $a$, $b$ and $c$ are specified for seven types of buildings, where $a = 1.48$, $b = 0.19$ and $c = 0.94$ are recommended for residential buildings.

It should be noted that the previous version of this Standard dates from 1988, and that this was superseded by the current version in 2012. A notable inclusion as part of this revision was to adjust the design flow calculation, thus reducing the design flow across a range of building occupancy types, including a significant reduction relating to residential applications, which we presume was based on data/experience from live buildings. This would suggest that the design method in this Standard has been proven to be effective over time.

### 4.2.7 Background information: SANS 10252-1

SANS 10252-1 (2012)[7] is the South African standard for calculating the design (probable) flow of installations. This empirical method provides the following equation:

$$Q_p = (\sum Q)^n \tag{5}$$

where $Q_p$ is the probable flow (l/min), $\sum Q$ is the sum of the design flow rates of appliances (l/min) and $n$ is a factor related to the probable simultaneous use of appliances. The range of the value of $n$ is specified for ten types of building. For economic dwellings and low-cost dwellings, the recommended ranges of $n$ are 0.5–0.7 and 0.5–0.75 respectively. The only guidance offered for the selection of $n$ value is to use, in general for larger installations, a lower value for the main supply pipe than is used for the branch pipes. Design flow rates of appliances are specified in the standard and are used for both hot and cold water systems.

### 4.2.8 Background information: SNiP 2.04.01-85

SNiP 2.04.01-85: 1986[8] is the Russian standard for calculating the design water flow for supply systems. This uses an empirical method, with the maximum design water flow ($q$) determined using equation 6:

$$q = 5\, q_o\, \alpha \tag{6}$$

where $q_o$ is the water used by an appliance in l/s. Recommended $q_o$ values for nine categories of residential buildings are given in the standard; $\alpha$ is a coefficient based on the total number of appliances ($N$) and the probability of their usage ($P$). $P$ is calculated as follows:

$$P = \frac{q_{\mathrm{hr,u}}\ U}{q_{\mathrm{o}}\ N\ 3600} \tag{7}$$

where $q_{\mathrm{hr,u}}$ is the water consumption within the hour of maximum consumption per user (in litres) and $U$ is the number of persons.

### 4.2.9 Differing notation used by international standards

It is worthwhile highlighting the difference in notation used by international codes and standards. This is shown in Table 5 which confirms the terminology used. This terminology is of importance when comparing predicted (design) flows and measured (peak) flows.

| Standard | Notations used for recommended flow |
|---|---|
| BS EN 806 | Design flow rate (accounting for probable simultaneous demand) |
| BS 8558 | Peak design flow rates/simultaneous design flows |
| CIPHE/IoP | Maximum simultaneous design flow rate |
| DS 439 | Local design water flow* (assuming all taps are used randomly) |
| ISSO-55 | Volume flow rate* (referred as instantaneous peak demand or maximum momentary flow in other literature) |
| DIN 1988-300 | Probable simultaneous demand* |
| SANS 10252-1 | Probable flow demand |
| SNiP 2.04.01-85 | Maximum consumption |

* translated notation

**Table 5** Differing notation used internationally

# 5 Application of codes and standards to case study buildings

## 5.1 Case studies and primary/secondary data

In order to effect a comparison between the range of codes noted in Table 2, examples of system design were required. Bearing in mind that this phase of the project dealt only with medium-to-large scale residential buildings, sample drawings of this kind were provided by the wider LUNA team. For the purposes of confidentiality, drawings have been deliberately omitted from this report, however Table 6 provides an indication of type and scale.

| Case study reference | Number of apartments | Details |
|---|---|---|
| A | 9 | 1 and 2 bedroom apartments |
| G | 101 | 1 and 2 bedroom apartments |
| I | 165 | 1, 2 and 3 bedroom apartments |
| M | 289 | 1, 2 and 3 bedroom apartments |

**Table 6** Case study buildings provided by the LUNA team

With the exception of that for Case Study A, these drawings were, by definition, detailed and complex, and required significant analysis and interpretation to allow for an estimation of design flow. A number of assumptions were made in doing so, some with assistance from the consultant(s). In addition, it can be seen from section 4 that each national code adopts a slightly different design approach. In terms of practical application this meant that a degree of interpretation was also required in order to ensure best comparability. The assumptions made when applying codes to these buildings, and to the extended dataset, are noted below. Overall, although this part of the work was time consuming and required the identification of a high level of detail, we believe that the assumptions made are all valid and allow comparisons to be drawn. Although this was a smaller sample size than we had hoped, additional comparisons were facilitated, as explained below.

Application of the codes noted in Table 2 yields a clear comparison between the design flow rates for the case study examples documented in Table 6. This is useful information but does not necessarily offer a comparison against 'actual' flows. Resourcing for this first phase of the LUNA project did not allow for data collection, or for the gathering or purchase of any existing data. The initial plan proposed a comparison of outcomes from codes, coupled with an analysis of the statistical validity of each however, we were keen to enable, as a minimum, an indication of any difference between estimated and actual values. Very few data sets exist where not only validated flow data can be accessed but also where information on the installed appliances in the buildings under consideration is available. Further to discussion, it was agreed that the dataset for comparison would be that established by Tindall and Pendle[19] and by their collaborator and LUNA project team member Aquatech Pressmain. Conditional permission to use these data was granted and the datasets obtained.

These data comprised two components: the primary data gathered from two local authority multi-storey residential buildings, and secondary data supplied by Aquatech Pressmain. For the primary data (Case Studies H and F), volumetric flow data for the cold water incoming main was recorded over a week-long period in April 2014. Case study 'H' of the primary data is for a 26-storey residential block comprising 125 two-bedroom apartments. It was constructed in 1966 and had recently been renovated. Building occupants are restricted to over 55s. Case study 'F' represents a 17-storey building built in 1961, with 60 two-bedroom apartments and 30 single-bed apartments, also recently modernised, but with a mixed range of occupants. It is understood that both buildings were fully let. Although no data on the installation or use of dishwashers and washing machines for case studies H and F were available, it was assumed that both were used in each apartment so as to allow comparability across datasets.

Table 7 below shows a summary of the details for the secondary data.

| Case study | Period of flow measurement | Occupancy | Comments |
|---|---|---|---|
| B | 5 days: Thursday 07/05/2009 (14:15) to Tuesday 12/05/2009 (12:42) | Only 18 flats appear to be occupied (concluded from water meter readings for each apartment) | Built to provide 2.7 l/s at 3.4 bar.<br>Refers as maximum flow.<br>The described original appliance list (362 LU, according to CIPHE 'low' usage) was later changed to 308 LU. (No information available on how appliances were changed. Hence the calculated values show clear oversizing.)<br>Daily average water use: 292 litres/flat. |
| C | 7 days: Friday 24/04/2009 to Friday 01/05/2009 | | Built to provide 4 l/s at 4.5 bar.<br>Refers as maximum flow.<br>Daily average water use: 241 litre/flat. |
| D | 5 days: Tuesday 10/09/2009 to Saturday 14/09/2009 | | Pump set sized to supply 0.82 + 0.82 l/s at 4 bar.<br>Refers as maximum flow.<br>Daily average water use: 200 litre/flat. |
| E | 7 days: Monday 17/03/2008 to Monday 24/03/2008 | | Refers as maximum flow.<br>Consultant required 5.8 l/s at 8.2 bar.<br>Daily average water use: 297 litre/flat |
| J | 7 days: Thursday 12/06/2008 to Thursday 19/06/2008 | | Refers as maximum flow.<br>Daily average water use: 85 litre/flat. |
| K | 7 days: Thursday 4/06/2009 to Wednesday 10/06/2009 | | Refers as maximum flow.<br>Built to provide 12 l/s at 5 bar.<br>Daily average water use: 286 litre/flat. |
| L | 8 days: Wednesday 26/11/2008 to Wednesday 3/12/2008 | | Refers as maximum flow.<br>3 pumps that can produce 20 l/s at 8 bar had been installed.<br>Average of 215 litre/flat/day water used |

**Table 7** Secondary dataset details showing peak flow (source: Aquatech Pressmain)

Reviewing the data from Tindall and Pendle[19], it is seen that the secondary data were used to increase the sample size and also to confirm the validity of the primary dataset, as the duration for data gathering for the primary dataset was limited. The same principle has been applied within the LUNA project.

Details provided for the secondary dataset allowed for an estimate of the design flow for all the codes and standards noted in Table 2. As before, this required a number of assumptions to be made, some of which are documented below, see section 5.2.

It is worth noting that Tindall and Pendle[19] found BS EN 806[1] to offer the best of the three sizing methods used as part of their study (i.e. BS EN 806, BS 6700 and the CIPHE/IoP guide), but all three demonstrated oversizing. They also note a comparison between the trend of the measured versus estimated data that allows for an approximate extrapolation of apartment scale. This suggests that some, but not all, methods can be used for larger buildings without excessive oversizing.

## 5.2 General assumptions made in the application of codes

As noted above, when applying the codes to the case study examples (from the LUNA team, and from the primary and secondary datasets), it was necessary to make a number of assumptions in order to enable a suitable degree of comparability. Only those assumptions that may have particular impact are detailed in this section.

When calculating the design flow rate, only the demand arising from the apartments was considered. Hence the calculated design flow values exclude the demand for sprinklers, rainwater tanks, pools, cold water retention tanks and isolated taps (e.g. cleaner's store sink), as well as district heating loads. Additionally, it was assumed that, in general, only cold water is supplied to washing machines and to dishwashers.

Due to the way that apartment types are specified, the application of the Dutch code required a significant number of specific assumptions. For example, only the 'calculation rules' were applied here, and each apartment required categorisation under one of the six types recommended in the code despite some differences in installed appliances. Maximum flow rates for hot and cold water systems were derived for the total number of apartments of the same type. When several types of apartment were included in a single case study, the $f_x$ and $f_{x,corr}$ values were calculated for each and the maximum flow rates multiplied by the appropriate correction factor to obtain the modified flow rates. In order to obtain comparable results with other design methods, hot and cold water design flow rates were added to yield a total flow.

Application of the South African code required the selection of a coefficient from the range $n$ = 0.5–0.75. It is unclear which value of $n$ was best suited for comparative purposes. For this reason, values selected were: $n$ = 0.5, 0.6, 0.7 and 0.75, and are each shown in the results.

For the Russian code, the residential building category of 'with baths of lengths from 1500 to 1700 mm, equipped with showers', yielding recommended $q_o$ and $q_{hr,u}$ values of 0.3 l/s and 15.6 litres respectively, was used. All case studies where baths were installed are considered to fit within this category. Apartments where no baths were installed are considered under the heading 'with centralised hot water supply, equipped with sinks, wash-basins and showers'. Furthermore, the number of persons occupying different apartment types was assumed as 1, 2, 4 and 6 for a studio, and 1–3 bed apartment types, respectively.

# 6 Results and discussion

The calculated design flow rates from the range of standards noted above are shown in the appendix as Table A.1. This table also shows measured peak flow rates available from primary and secondary data sources. The calculated design flow rates for each case study are plotted against the corresponding number of apartments and shown in the appendix as Figure A1. For the purposes of clarity, Figure A.1 omits the highest SANS 10252 dataset. Furthermore, it should be noted that Figure A.1 *does* include BS EN 806, BS 8558 and CIPHE 'low use' data for which hot loading units have not been included in the calculation; however these are provided for comparative purposes only and should be regarded as purely indicative. The inclusion of these curves should not be interpreted as suggesting an alternative design approach, as the summation of cold loading units *only* does not represent the true system loading. The following text highlights points that should be noted when interpreting both Table A.1 and Figure A.1.

Case Study A represents a high-end apartment scheme and therefore when calculating its design flow rate using the Dutch code, the 'calculation rules' for 'luxury apartments' were applied. In all other methods, the impact of 'high end' apartments/appliances was neglected as the design flow rate calculation does not account for this difference. Case Study F represents 30 one-bedroom apartments (with one wash-hand basin, one WC, one bath, one shower and one sink installed) and 60 two-bedroom apartments (with an identical list of appliances). The difference in type of apartment is again considered only in ISSO-55 (the Dutch code) as the type and number of installed appliances are otherwise identical. Case Study H represents 125 two-bedroom apartments for residents over 55 years of age. This type of accommodation has been considered specifically only in ISSO-55 as a two-bedroom apartment for senior citizens and hence is shown as an outlier in Figure A.1 with a noticeably lower design flow rate (for this method only).

For Case Study B, it is worth noting that the measured flow data point may be marginally low as meter readings suggest that only 18 of 22 apartments were occupied. This would have the effect of slightly 'flattening' the measured data curve at the lower end of the scale.

For Case Studies F and H, design flow data includes that for washing machines and dishwashers, although it was not possible to ascertain whether or not both were installed in each apartment.

Case Study J has three types of apartment: 140 two-bedroom apartments (each with two wash-hand basins and two WCs, a bath, shower, kitchen sink, washing machine and dishwasher); 14 two-bedroom apartments (with two wash-hand basins and two WCs, two baths, two showers, a kitchen sink, and a washing machine and dishwasher) and 12 three-bedroom apartments (with three wash-hand basins and three WCs, a bath, shower, kitchen sink, washing machine and dishwasher). The available data on appliances have been used for all methods except that for the Dutch code ISSO-55. In the ISSO-55 method, the difference between the two types of two-bedroom apartments was neglected and instead 154 two-bedroom apartments and 12 three-bedroom apartments were modelled in line with the recommendations laid out in the code. It is also worth noting that, for Case Studies J and K, the design flow rate calculated in accordance with BS 8558 is greater than 30 l/s, and hence cannot be properly estimated as this lies outside the range specified.

Case Study L is a scheme with 255 one-bedroom apartments with only a wash-hand basin, WC, shower and kitchen sink installed. With only basic appliances (and no bath, dishwasher and washing machine), the calculated design flow values appear as outliers when compared with others. Furthermore, when applying the Russian method (SNiP 2.04.01-85), only this case was deemed to fit the 'with centralised hot water supply, equipped with sinks, wash-basins and showers' category as there are no baths installed. This case study has therefore been neglected when constructing the approximate demand profiles for each of the calculation methods.

Finally, the design flow rates calculated in accordance with the BS EN 806, BS 8558 and the CIPHE/IoP *Design Guide* (low) methods for Case Study M fall outside the range specified within the codes and hence cannot be properly estimated.

From the calculated design flow rates, approximate power-based design flow curves for each method have been developed and are shown in the appendix as Figure A.2. It should be noted that, overall, there is a degree of uncertainty in trends for measured data, as values were not available across the whole range of the number of apartments.

In general, as shown by Figure A.2, the German standard (DIN 1988-300) seems to be the method that most closely estimates the peak demand within the range of apartments considered, with the exception of the lower boundary of the South African method (where $n$ = 0.5). Overall, the German method slightly overestimates demand, but does display some under-estimation in the higher range, although there is some uncertainty in this conclusion due to the difficulty in predicting trends for measured data at this scale. It is worth noting however that the Russian method (SNiP 2.04.01-85) estimates demand better than the German method up to around 30 apartments, as illustrated by Figure A.3. When the number of apartments is greater than about 30, the Russian method does appear to notably overestimate.

Examining data established using the South African method, it may be seen that the estimated peak demand profile for $n$ = 0.5 is comparable to the measured flow rate in schemes with less than 150 apartments, but this method slightly underestimates when the number of apartments is lower than about 50 (Figure A.3). Above around 150 apartments, the estimated demand profile slightly underestimates but this is again relative to the uncertainty of the estimated measured demand curve (Figure A.2). For $n$ =0.6, the South African method slightly overestimates and is comparable to the German method below 50 apartments, as illustrated by Figure A.3. Figure A.2 also shows that when the number of apartments is greater than 100, the South African method (where $n$ = 0.6) overestimates the demand more so than the German and Dutch methods. The remaining two scenarios selected, $n$ = 0.7 and $n$ = 0.75, estimate peak demands that deviate significantly from the range of results obtained using other methods, and Table A.1 shows that the overestimation at $n$ = 0.75 is greater than that for BS 8558 for schemes with more than 120 apartments.

Case Study H was deliberately neglected when constructing the demand profile for the Dutch method as it estimates a comparatively lower demand for the senior citizens' apartments. Overall the Dutch method overestimates the peak demand but it seems to better predict the demand with an increasing number of apartments (Figure A.2).

As the peak demand for Case Study M using BS EN 806 could not be established, the demand curve as presented in Figure A.2 incorporates some level of uncertainty. This same graph also shows that generally BS EN 806 overestimates the peak demand but provides a better estimate than the methods defined in BS 8558 and the CIPHE/IoP *Design Guide* (low category).

The Danish method (DS 439) slightly overestimates the peak demand for schemes with less than around 100 apartments and provides results comparable to those from the German method, as illustrated in Figure A.3. However, with an increasing number of apartments, it overestimates the peak demand more so than BS EN 806 (Figure A.2).

Although three curves shown on Figure A.2 represent design methods that have been adapted such that both cold and hot loading units are not added, it is important to stress that these curves are indicative only. As noted above, the inclusion of these curves should not be interpreted as suggesting an alternative design approach, as the summation of cold loading units *only* does not represent the true system loading. The issue of adding loading units (or not) is complex, and depends on the installation detail. However, it may be seen that some of the empirical methods discussed above overcome the challenges of representing both supplies by representing 'apartment-scale' loading models.

# 7 Statistical validity of techniques

The following section outlines the relative characteristics of the statistical methods adopted by the codes noted above. It explains the principles in relation to the sizing techniques adopted and gauges the validity of each.

## 7.1 Probability models

Despite their weaknesses, as alluded to above, probabilistic approaches have the advantage that instead of giving one single outcome, models estimate a range of possible outcomes and their associated probability (i.e. likelihood of occurrence). This provides a greater flexibility to the user by allowing them to select a desired level of confidence in decision making/designing solutions.

The statistical validity of probabilistic models relies upon various factors such as:

- *Availability of good quality data*: In general, probabilistic models are highly sensitive to extreme values and any inadequacy of available data points to model extreme events can result in a poor fit of the probability model in the 'tail' regions of the distribution. Extreme values are mostly attributed to rare events, and to effectively model extreme values, one should incorporate a suitable extreme value distribution within the probability model, as failing to do so can result in a poor estimation.

- *Factors included in the modelling procedure*: Probability models do not account for several important factors such as number of users, user behaviour/habits etc., thus providing only a general estimation. It should be noted that to account for these user-specific factors effectively, technically complex joint probability models should be considered.

- *Various assumptions made during the modelling process*: Probability models rely on various underlying assumptions that are based on the modeller's personal judgement of the problem/situation and thus can easily overlook specific details. For example, as mentioned in Hunter[20], in the development of the binomial probability model 'the choice of values employed in evaluating the probability function and in converting estimates in number of fixtures flowing to estimates in gallons per minute represents the *author's judgement.*'

Interestingly, Hunter's binomial probability model uses a failure factor of 1% to construct loading unit curves for different types of appliances. This provides guaranteed satisfactory service for up to 99% of the time during the congested period. Thus, this approach will naturally overestimate water demand when used for modelling water demands of residential/small buildings.

Most codes that are based on a probability modelling approach utilise a 99% level of confidence, though there is no evidence or study conducted to support the selection of this 1% failure rate (or 99% of confidence level) for estimating the various loading unit curves for different types of appliances. Arguably, it appears that the selection of a '1% failure rate' is adopted from Hunter's original work that clearly suggests an arbitrary selection of a '1% failure rate' to demonstrate the methodology. It should be noted that setting up a high level of confidence such as 99% (which is purely the modeller's choice) can significantly impact the issue of overestimation of water demand, specifically in residential/small buildings where the chances of experiencing congested water demand periods are considered to be low. To avoid oversizing issues using a probability model, it is therefore recommended that careful investigation should be undertaken to identify the appropriate criteria for selecting an acceptable level for the underpinning failure rate, whilst also considering the impact of=factors such as the size of the building, types of building, users' behaviour, peak demand periods etc. Dissatisfaction should of course be considered, and low flows are discussed in more detail by Morooka *et al.*[25]

## 7.2 Stochastic models

Stochastic models have the advantage of being able to generate the most realistic scenarios representative of the dynamic behaviour of the process or system being considered. They provide the most effective means of investigating and factoring-in the effect of the various forms of naturally occurring uncertainty and variability. In contrast to empirical models that allow only for a few key variables, stochastic models provide the most effective environment for incorporating the effects of various factors within a single robust framework. Additionally, model sensitivity is a less of a problem with stochastic modelling schemes.

The statistical validity of stochastic models relies upon the following factors:

- Stochastic models are structurally complex and can demand significant amounts of quality data/information to generate input probability distribution files. Thus, the validity of models strongly depends on the quality and quantity of information available.

- In general, stochastic models can integrate complex algorithms and be comparatively more difficult to calibrate. They therefore rely significantly on the modeller's ability to effectively handle large amounts of data, various technical challenges and available resources. Stochastic models can also lead to the wrong conclusion if not developed or applied effectively.

- Stochastic models yield a range of possible solutions and thus interpreting the outcomes is not always straightforward. These models often require the development of additional tools (depending on the individual requirements) to effectively interpret the outcomes in a meaningful way.

## 7.3 Empirical models

Empirical models have the advantage of being technically much simpler to set up and apply. In addition, the model generates one possible outcome or solution for a given set of parameters. Thus, it is easy to use and apply within the application scenarios discussed herein.

The statistical validity of the empirical modelling approach relies upon the following factors:

- Empirical models are sensitive to certain sets of parameter/boundary value conditions, i.e. models can demonstrate completely unexpected behaviour for critical values (commonly known as 'chaotic' behaviour). Thus, model performance can be highly unreliable outwith these critical (threshold) values or conditions.

- Empirical models can be highly sensitive to outliers (i.e. to the boundary conditions of parameter in the model).

- No confidence levels can be attached with the outcomes of the model.

- The efficiency of empirical models strongly depends on the data quality, quantity and the number of variables included in the model.

- Robust model validation exercises should be considered in order to establish the statistical validity of the model.

- Empirical modelling frameworks are restricted to those parameters for which determinants are established. In other words, they cannot be retrospectively 'improved' through the inclusion of additional variables.

For most of the codes listed herein that are based on an empirical modelling approach, no information can be found on the data/measurements used for calibration of the core empirical formulae listed for the estimation of water demand. Furthermore, there is no information on how robust the model validation procedure has been in establishing the statistical validity of each model.

Interestingly, for all empirically-based codes used as part of this study, the relevant modelling framework features appropriate parameters to account for the variation in different building types (such as residential/non-residential) and appliance/fixture types. However, only the Dutch method introduces a wider range of variables than this, although none has a framework suited to accounting for the influence of the full range of key factors that determine water demand, such as users (number of users/type of users/lifestyle/daily activity etc.), peak time of use, frequency of use, duration of uses, influence of climate variability etc.

# 8 Alternative options and recent code changes

Looking forward to possible new approaches, Oliveira *et al.*[21] suggest that dynamic profiles for design flow may be generated by integrating fuzzy logic within the Monte Carlo simulation scheme[22,23]. This method explores various aspects of subjectively addressing user behaviour as a determinant of the duration of sanitary appliance usage. The Monte Carlo model determines the instance of usage of various appliances and the inclusion of fuzzy logic accounts for user behavior in determining the duration of shower use[21]. Here, two case studies were used to set up the model and results show that the design flow rate obtained by the stochastic modelling scheme are 23% lower than the flow rate obtained using the deterministic model, and 13% lower than that obtained using the probabilistic model. The paper presents a number of graphs to demonstrate the efficiency of the model in estimating the shower duration by comparing actual measurements with the simulated values, though no formal statistical measures have been used to demonstrate the statistical significance of these comparison/validation graphs.

As discussed above, in the Netherlands, in order to address the issue of the overestimation of design flow rate, the previously-used square root method of calculation of hot and cold water requirements has been modified using simulation results from SIMDEUM — a stochastic model. Here, statistical data on water-using appliances and users have been integrated to account for the various factors that influence peak flow rate. However, the method has been presented within the national code as an *empirical* model, with less detailed information required at the design stage. Although an improvement on the previous method, it is unclear as to whether there is a longer-term objective to use, or further integrate, outcomes from the stochastic model.

In the United States, an improved method has recently been developed to address the issue of oversizing using Hunter's method, and is based on the normal approximation of the binomial distribution proposed by Robert Wistort in 1994[24]. As for Hunter's method, the number of busy fixtures (*x*) is considered as a random variable with a binomial distribution but this proposed approach eliminates the use of 'fixture units' to estimate the peak demand and instead uses the probability and flow rate of the installed appliances. A poor fit at the tails of the binomial distribution leads to inaccuracies when estimating the 99th percentile and most households lie in this region of the distribution where the number of appliances and probability of 'fixture' use is low. Hence the conditional distribution of busy appliances in any building including single family homes has been approximated using a zero-truncated binomial distribution (ZTBD) which allows for an extension of the Wistort method to smaller systems. Also, appliances that operate within a common room such as kitchen and bathroom have been bundled as a room group and a unique probability (*p*) and flow rate (*q*) assigned to them. This work is currently ongoing and not yet published, but is anticipated as ultimately feeding through to codified documents.

# 9 Conclusion

It can be readily seen from the results presented within this report and from the context provided by the discussion on statistical validity of the models used in the codes applied, that all methods integrate advantages alongside limits of applicability. The final decision on a new statistical framework is hence a judgement that is based on the evidence provided herein, but one that does appear to strongly suggest that an empirical model is best suited to the sizing of pipework and pump systems for mid-large size residential buildings[4]. It is worth noting however that this conclusion is conditional upon the limitations imposed by the data used and upon the assumptions made when representing water-using appliances and household user demographic and behaviours. For example, it was found by Ilha *et al.*[26] that probabilistic methods perform better than empirical methods when sub-metering is addressed.

It is important to stress that the scope of this first phase of the work did not extend to data gathering or monitoring. The aim was to draw comparisons between relevant statistical frameworks and to discern from this comparison of theoretical values, a trend towards a particular framework, thus allowing us to learn from other approaches how best to estimate flows.

[4] This conclusion is based on the assumption that development of a fully stochastic model, potentially integrating fuzzy logic, although able to present the most accurate representation of loading, lies outwith the timescale and resources available to the LUNA team.

Access to third-party measured data, albeit limited, has helped significantly and is a key element in supporting the decision. However, the measured data were gathered over a limited timescale and from a limited number of buildings. Since the measured data used in the study were obtained from secondary sources, there is a level of uncertainty regarding their representation of peak flow, and adequate information on occupancy levels within the buildings is not available.

Therefore, in moving to Phase 2 of this work, it is recommended that an appropriate level of data gathering be undertaken and these data used to support the development of, or to validate the application of, a new empirical model. This will also allow for confirmation of the applicability and limitations of any new approach.

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# Appendix A: additional tables and graphs

| Case study | Number of apartments | Measured flow rate (l/s) | Data source | Design flow rate (l/s) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | BS EN 806 | BS 8558 | CIPHE 'low' | ISSO-55 | DS 439 | DIN 1988-300 | SNiP 2.04.01-85 |
| A | 9 (1 and 2 bed) | | LUNA | 1.5 | 3.3 | 2.15 | 1.5 | 0.9 | 1.4 | 0.8 |
| B | 22 (2 bed) | 0.9 | Secondary | 2.6 | 7.0 | 4.5 | 2.3 | 1.8 | 1.9 | 1.7 |
| C | 27 (2 bed) | 1.1 | Secondary | 2.8 | 8.0 | 5.2 | 2.4 | 2.0 | 2.0 | 1.9 |
| D | 33 (2 bed) | 1.1 | Secondary | 3.1 | 9.2 | 5.8 | 2.7 | 2.2 | 2.1 | 2.1 |
| E | 45 (2 bed) | 1.0 | Secondary | 3.4 | 10.4 | 6.6 | 3.1 | 2.5 | 2.2 | 2.5 |
| F | 90 (1 and 2 bed) | 1.3 | Primary | 5.3 | 18.0 | 11.5 | 4.2 | 4.5 | 2.7 | 3.5 |
| G | 101 (1 and 2 bed) | | LUNA | 5.3 | 18.5 | 11.5 | 3.7 | 4.6 | 2.6 | 3.0 |
| H | 125 (2 bed) | 2.3 | Primary | 6.5 | 23.0 | 14.8 | 2.6 | 5.84 | 2.9 | 4.9 |
| I | 165 (1, 2 and 3 bed) | | LUNA | 7.2 | 25.4 | 17.5 | 5.1 | 7.0 | 3.5 | 5.2 |
| J | 166 (2 and 3 bed) | 2.0 | Secondary | 8.4 | >30 | 19.0 | 5.9 | 8.6 | 3.3 | 6.1 |
| K | 180 (1 and 2 bed) | 3.3 | Secondary | 8.3 | >30 | 18.5 | 6.3 | 8.3 | 3.3 | 5.7 |
| L | 255 (1 bed) | 3 | Secondary | 6.3 | 19.5 | 14.5 | 4.7 | 5.9 | 3.0 | 3.8 |
| M | 289 (1,2,3 bed) | | LUNA | >9 | >30 | >30 | 8.5 | 14.1 | 3.9 | 7.4 |

**Table A.1** Design flow rates for different approaches — part 1 of 2

| Case study | Number of apartments | Measured flow rate (l/s) | Data source | Design flow rate (l/s) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SANS 10252-1 (*n* = 0.5) | SANS 10252-1 (*n* = 0.6) | SANS 10252-1 (*n* = 0.7) | SANS 10252-1 (*n* = 0.75) | BS EN 806 (cold LUs only) | BS 8558 (cold LUs only) | CIPHE low (cold LUs only) |
| A | 9 (1 and 2 bed) | | LUNA | 0.5 | 1.1 | 2.1 | 3.0 | 1.25 | 2.2 | 1.42 |
| B | 22 (2 bed) | 0.9 | Secondary | 0.9 | 2.1 | 4.6 | 6.9 | 1.85 | 4.75 | 3.1 |
| C | 27 (2 bed) | 1.1 | Secondary | 1.0 | 2.3 | 5.2 | 7.8 | 2.05 | 5.5 | 3.6 |
| D | 33 (2 bed) | 1.1 | Secondary | 1.1 | 2.5 | 5.7 | 8.6 | 2.2 | 6.0 | 3.8 |
| E | 45 (2 bed) | 1.0 | Secondary | 1.1 | 2.7 | 6.2 | 9.4 | 2.45 | 6.8 | 4.3 |
| F | 90 (1 and 2 bed) | 1.3 | Primary | 1.7 | 4.4 | 11.0 | 17.6 | 3.9 | 11.7 | 8.0 |
| G | 101 (1 and 2 bed) | | LUNA | 1.7 | 4.4 | 11.1 | 17.7 | 4.0 | 12.5 | 8.25 |
| H | 125 (2 bed) | 2.3 | Primary | 2.0 | 5.3 | 13.9 | 22.5 | 4.8 | 15.3 | 10.2 |
| I | 165 (1, 2 and 3 bed) | | LUNA | 2.4 | 6.3 | 17.0 | 27.9 | 5.5 | 17.5 | 11.5 |
| J | 166 (2 and 3 bed) | 2.0 | Secondary | 2.6 | 7.1 | 19.5 | 32.3 | 6.25 | 22.0 | 14.0 |
| K | 180 (1 and 2 bed) | 3.3 | Secondary | 2.5 | 6.9 | 18.9 | 31.3 | 6.2 | 21.0 | 13.5 |
| L | 255 (1 bed) | 3 | Secondary | 2.1 | 5.7 | 15.0 | 24.4 | 4.5 | 13.0 | 9.4 |
| M | 289 (1,2 and 3 bed) | | LUNA | 3.51 | 10.24 | 29.87 | 51.0 | 8.75 | >30 | 22.0 |

**Table A.1** Design flow rates for different approaches – part 2 of 2

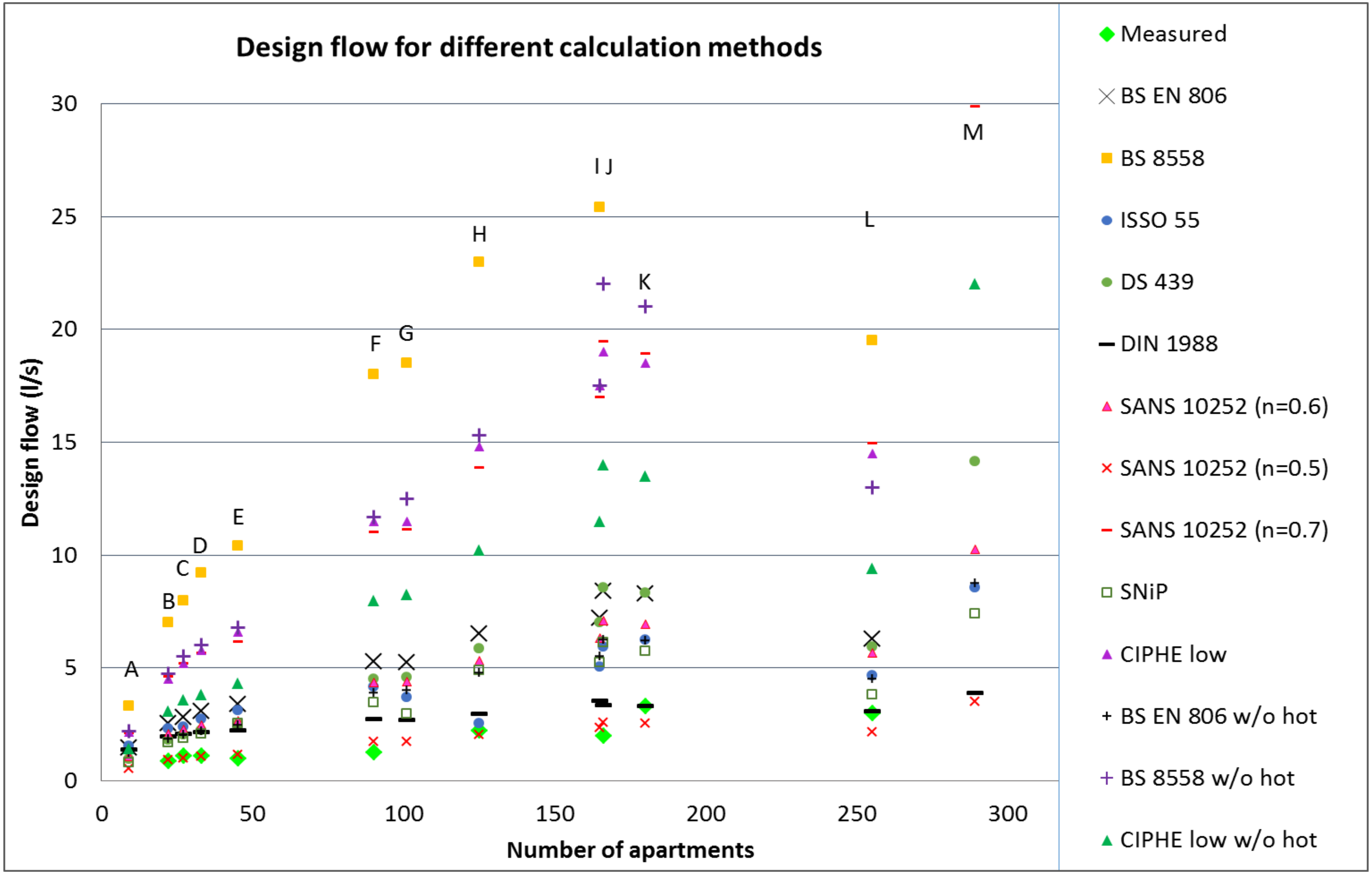


**Figure A.1** Design flow rates according to different calculation methods

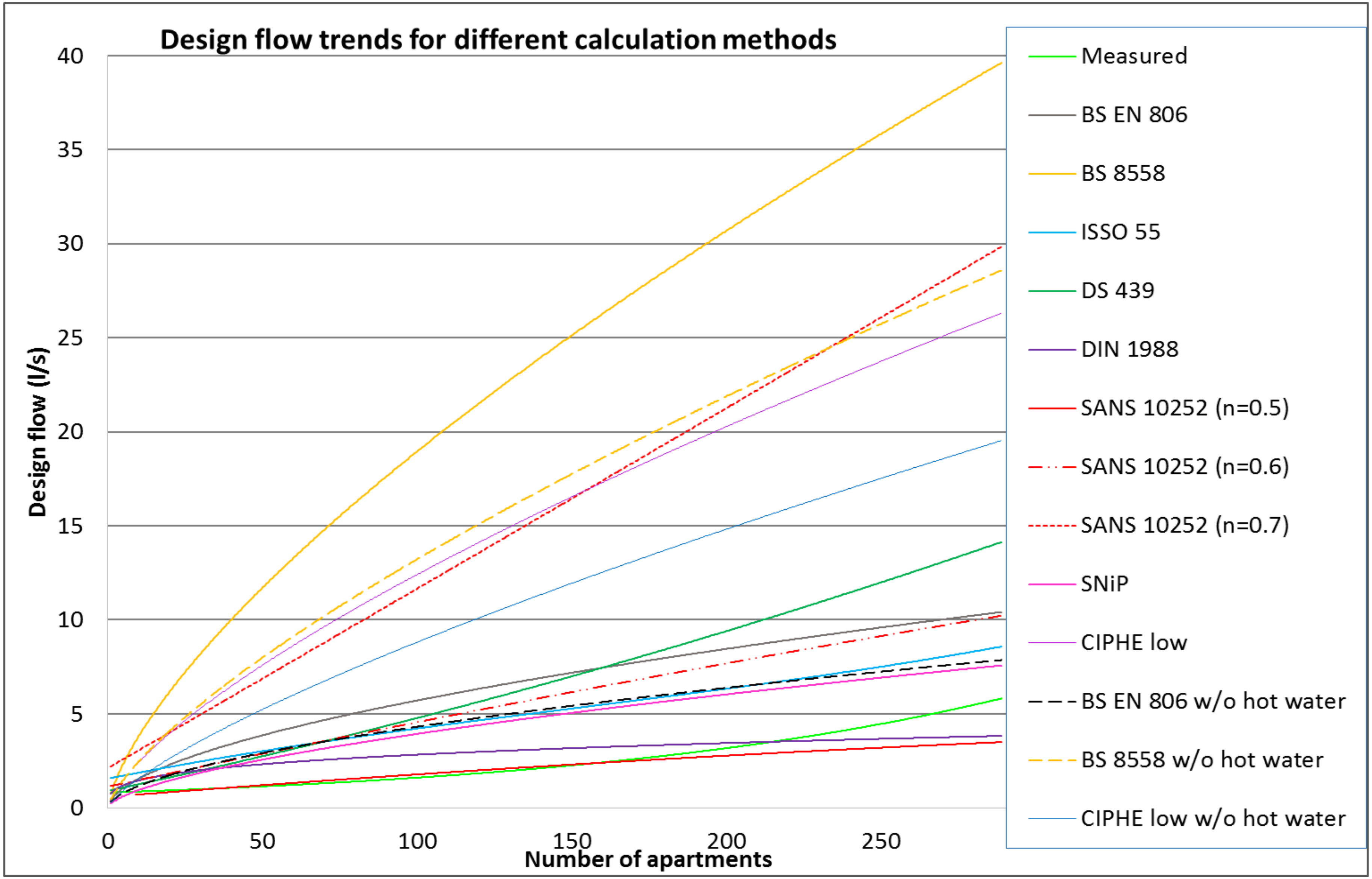


**Figure A.2** Approximate design flow curves for different calculation methods (*Note*: curves without the addition of hot water loading units are indicative only and do not suggest an alternative design approach)

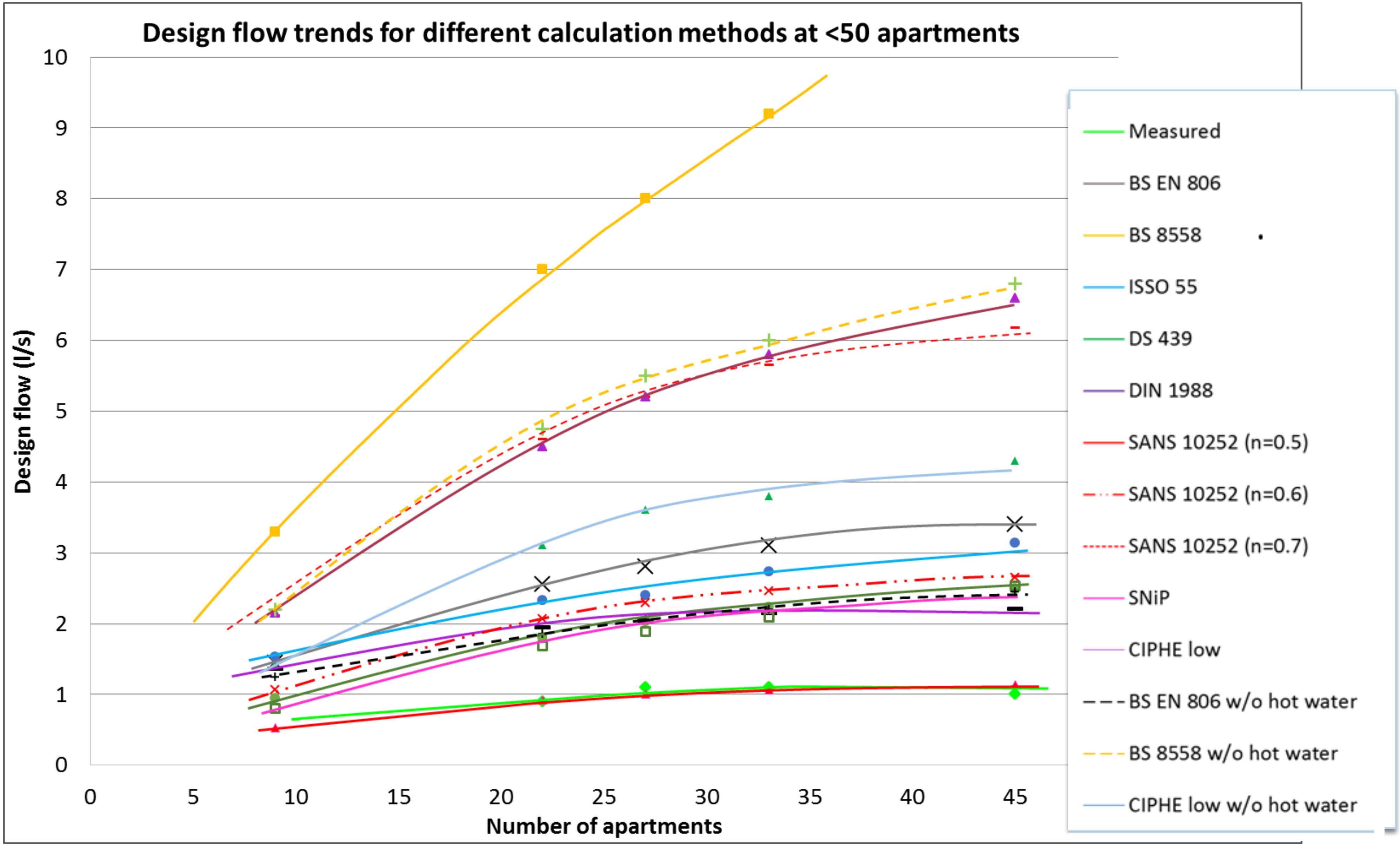


**Figure A.3** Design flow rates for different calculation methods for flow <10 l/s; number of apartments < 50 (*Note*: curves without the addition of hot water loading units are indicative only and do not suggest an alternative design approach)