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Examination of Domestic Cold Water Systems

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The design of domestic cold water systems is inherently based upon the fixture unit or demand unit method. Therefore, it is fundamentally necessary to understand these water demand units and how to interpret them in order to design efficient water systems that enable a balance between capital cost (where oversizing leads to elevated capital cost) and engineering good practice. Recent sustainability initiatives aimed at reducing water usage encourage the uptake of devices such as flow limiters, spray and percussion taps and low flow appliances and have driven peak water demands down in buildings. Maintaining water movement within the cold water system prevents overheating and helps to maintain a healthy hygienic system. Stagnation exacerbates overheating and may contribute to contamination by micro-organisms. To promote movement of cold water within pipework systems there has been a recent move towards adopting strategies that were not traditionally incorporated into cold water pipework design such as, a secondary cold water return circuit and end of line solenoid flush (dump) valves. These are an added expense, contribute to wasted water or energy and should therefore be carefully considered when incorporating into domestic cold water systems taking cognisance of the other contributory factors such as the building water usage and turnover, building air tightness standards and sanitary ware specification. Also water conservation in buildings is another reason to have an appropriately sized system for the potential water consumption as older appliances had larger flow rates than present; this subsequently has a knock-on-effect on the buildings drainage pipework, system selections and sizing, for example WCs.

This paper presents an examination into the importance of sizing a cold water distribution system appropriately and the effect of modern building design standards on operational performance. Finally, through the experience of multiple engineers from many consultancies over several years, a summary of cold water services issues caused in modern buildings is presented and potential strategies to mitigate against excessive temperatures and promote water movement and turnover is given.

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1. INTRODUCTION

It would be reasonable to assume that the '*out of sight out of mind'* adage often applies to building services systems which may potentially lack the appropriate design and maintenance attention they deserve until an apparent defect or issue with system performance transpires. In most buildings, domestic water services represent a small percentage of the total construction cost, however their design and installation should not be underestimated given the potential cost and disruption from future remedial works and retrofit measures required in the event of the system failing to provide a hygienic potable water source.

This paper will look at issues with domestic cold water systems (DCWS) in recent years, through the experience of several building services engineers. There has been a growing trend in rising cold water temperatures in systems and a number of examples where temperatures greater than 20℃ have been recorded which exceed Health and Safety Executive requirements. Generally, the Health and Safety Executive's L8 document [1] as well as UK Water Regulations and EU legislations are seen as the authoritative documents within the construction industry, setting a maximum permissible temperature of 20℃ within domestic cold water systems. In a number of instances it has proven difficult to achieve temperatures of less than 20℃ due to the temperature of the incoming mains water supply and the associated heat pick-up from the site boundary to the points of connection within the building.

This paper starts by summarising the current design methodologies and codes of practice, followed by a review of the relevant standards and regulatory requirements with respect to cold water temperatures and the contributing circumstances and risk factors that would enable bacteria to proliferate within the domestic cold water system. Finally, causes of elevated temperatures are acknowledged and potential mitigation measures presented.

2. DESIGN METHODOLOGY

The design of domestic cold water systems should always be in accordance with UK Water Regulations and local Water Bylaws guidance, current design guides and industry good practice. However, it is acknowledged that sometimes the quality of the potable water has degraded due to one or many external influences. Tracing the domestic cold water systems pipe routes can help highlight the potential parameters that could affect water quality. The potable water supply will originate from the local water authorities 'town' main. The point of connection of a buildings potable water supply is normally at the water authority meter located at the site boundary, where it will then be routed to the potable water storage tanks or supplied directly to mains water outlets within the building. From the cold water storage tank, the cold water feed normally serves a cold water booster set which distributes 'boosted' cold water around the building to the various cold water outlets and cold water feeds to hot water generation plant. Additionally, direct mains water may be distributed throughout a building to appliances or outlets deemed to be 'potable' such as drinking fountains, water coolers and boiling water taps; this is deemed as industry good practice and often a requirement to satisfy sustainability assessment methods such as BREEAM (Building Research Establishment Environment Assessment Methodology).

In the UK the Institute of Plumbing (IoP) – Plumbing Engineering Services Design Guide [2], British Standard 6700 [3], BS EN 806 [4] and BS 8558 [5] are the recognised methods for designing and sizing domestic cold water systems. The industry practice of using loading units to size pipework is based on the 1940s methodology created by Hunter of the USA. These loading units are based upon; probability theory, time between uses of an appliance, duration of use and flow rates when in use. Dr Hunter knew most appliances are intermittently used, from this he theorized the loading of a single appliance didn't just depend on the rate of flow to the appliance but also the frequency of use and duration of use [6]. Konen [7] reviewed part of the Hunter method based on the probability theory and also established that the frequency of use is the most critical parameter for water turnover rather than flow rate. However at present, with the use of water conservation measures, the flow rate may now become just as important, if not more than, the frequency of use if we are to size pipes appropriately to the lower volumes, but potentially higher pressures due to residential pressure drops across the taps/outlets of water now being used.

From a building services industry perspective it is important to highlight that many of the design guides for domestic pipe sizing have not been updated to reflect current domestic water services approaches particularly with regards to water conservation measures and building design standards and strategies. This has been investigated by Tindall et al. [8] where the study undertaken compared three typically used design guides and found that one more than doubled the over sizing of pipework when compared to the actual recorded site data in relation to water consumption and frequency of use. They also highlighted BS EN 806-3 as the more accurate standard in predicting DCWS flow rates.

In academia, Goncalves et al. [9] presented a paper that summarised the mathematical models of the design of water systems within buildings. This included, a review of Webster 1972 (a generalized binomial distribution function), Courtney (1976) a probabilistic model to determine flow rate but also the use of different types of appliances. Konen (1980) and Holmberg (1981) a dimensioning formula. Nowhere within his study did Goncalves highlight microbial contamination as an issue or if design consumptions changed would the models verify. However if design demands change then consideration should be given to reviewing pipe sizes. As such, if pipe sizing does not consider potential consumption and turnover within a building, the potential of water stagnation increases and associated issues of elevated temperatures in services distribution voids may contribute to cold water overheating and bacterial growth within the cold water system.

3. WATER QUALITY STANDARDS AND REGULATIONS

To give some context to the health issues regarding water quality there are several standards and regulations that are applicable to cold water supply temperature within the UK, these are:

- UK Health and Safety Executives L8: 2013, Approved Code of Practice and Guidance, *'The control of Legionalla Bacteria in Water Systems'* [1].
  This requires that temperatures between 20°C and 45°C are to be avoided.
- UK Water Regulations (WRAS) [10].
  This requires temperatures to be kept below 25ºC and within recent amendments to Local Bylaws in Scotland of 25℃.
- BS 8580:2010 '*Water Quality – Risk Assessments for Legionella Control'* [11].
  This requires the temperature of a cold water outlet to be below 20℃ after the outlet has been opened for 120 seconds.
- CIBSE TM13:2013, '*Minimising the Risk of Legionnaire's disease'* [12].
  This requires the temperature of a cold water outlet to be below 20℃ after the outlet has been opened for 120 seconds.

For bacteria such as Legionella to proliferate within cold water systems several factors need to be present; these include a suitable temperature and a source of nutrients, e.g. sludge, scale algae and other organic matter. The Chartered Institute of Building Services Engineers Technical Memorandum TM13 '*The Control of Legionella'* [12] identifies the following as temperatures for Legionella growth:

- Dormant; 0℃ to 20℃;
- Will multiply; 20℃ to 45℃;
- Will not multiply and will die in time; 50℃ to 70℃;
- Not active; 70℃ to 100℃.

The ideal temperature, based on empirical data suggests that the ideal microbial growth and proliferation is 36℃. Typical appliances such as, WHBs, sinks, Water closets (WCs), drinking fountains, bib taps and urinals are not typically associated with aerosol sprays which is the understood transfer route for Legionella bacteria through inhalation. Also, certain groups of people are known to be more susceptible, for example; men are more open to contract the disease than women, as are over 45 year olds, smokers, alcoholics, diabetics, immune compromised and those with cancer or respiratory or kidney disease. Therefore, the obvious building where infection would prove catastrophic and potentially fatal is a hospital. The Department of Health have the Technical Memorandum HTM 04-01 [13] for their own facilities to ensure a hygienic water source to the patients, it states there should be no greater than a 2℃ rise between the storage tank and the appliance within 2 minutes. BS 8580:2010 provides detailed guidance on how to conduct a Legionella risk assessment; the risk assessor should however have an in depth understanding of water systems.

4. POTENTIAL CAUSES OF COLD WATER OVERHEATING

There are several potential factors within new-build constructions that may contribute to overheating of DCWS. The main factors generally relate to the modern day drive to conserve energy, these factors include:

4.1 From the Mains Water Supply Network

- Mains water authorities should have a requirement to provide water at less than 20℃;
- A rural location of a building on a radial service, due to the distribution routes from the reservoir/pumping station and potential low rates of water draw-offs water temperatures can increase;
- In a new-build there is a standard burial depth for the incoming water mains however sometimes in older buildings incoming mains water pipeline from the site boundary to the cold water tank room can be at a shallower burial depth, as such during a warm day the incoming water could receive heat pick-up;
- Water storage tanks located above ground or in semi-buried configurations.

4.2 From Water Conservation Measures

- The introduction of rainwater/grey water/ black water recycling provided for water conservation;
- The use of percussion taps and low-flow fittings;
- A lack of regular flushing of the system as a management procedure.

4.3 From Higher Void Temperatures

With the drive to reduce energy costs, changes in the building standards and client aspirations to reduce carbon emissions, buildings have become very well insulated and constructed to a higher level of air tightness compared to older buildings. This can result in higher services distribution-void temperatures. In a non-ventilated void, in a well sealed building, temperatures could easily elevate to 30^{o}C and above. Although the change to reduce carbon emissions by reducing water consumption and insulating buildings is seen to be good for the environment, there is evidence to suggest they can have a negative effect on the quality of building potable water supplies. The result is that buildings cannot guarantee to keep cold water temperatures below 20℃ during spells of low or no use unless sufficient design mitigation measures are implemented.

4.4 From Design and Management

There are design and management/operational factors that also contribute to potential elevation of DCWS temperatures:

- A lack of temperature monitoring within the cold water tank, incoming mains and at the extremities of cold water pipe distribution;
- The possibility of over sizing the cold water storage tank;
- Reduced periods of occupancy and demand such as at weekends and holidays. Seasonal variations in the occupancy of the building can result in longer standing times of water within the cold water storage tanks;
- Heat generating plant and equipment within ceiling voids such as recessed light fittings, current carrying cables, radiant panels and heating pipework. Although heating pipework and plant may be insulated, over time this will emit heat to the void space if adequate ventilation is not provided;
- The DCWS pipelines should be kept a minimum distance from any hot water and LTHW heating pipelines within void spaces, however spatial restrictions for building services often result in DCWS pipes running in parallel heating pipelines;
- If the plant room where the cold water storage tanks are located and unventilated there may be the potential for cold water storage temperatures to increase when there are periods of low usage;
- A lack of quality control of legislation particularly with regards to thermal insulation of plant and equipment may contribute to elevating plant and void space temperatures if sections remain un-insulated;
- Insufficient separation between the heat generating plant and equipment e.g. boilers, hot water storage cylinders and the cold water storage tank room and a lack of appropriate ventilation within the plantroom housing heat generating plant and equipment;

- If the occupancy levels within the building after handover is less than envisaged at design stage a lack of domestic water draw-off due to unoccupied spaces and infrequently used outlets may cause elevated temperatures;
- The end user not implementing risk assessments and procedures to control the risk of Legionella.

It is possible that the above factors may, in some part, contribute to elevating water temperatures in any domestic water installation. The above list summarises the main factors, there may be more which are unique and still unknown to us but specific to an individual installation or building.

5. MITIGATION MEASURES

The previous section discussed several factors that may contribute to an elevated domestic cold water services temperature. The following highlights the potential mitigation measures that could be considered and adopted where appropriate and also areas where further investigation would be recommended:

- Ensure pipe sizing is carried out as close as possible to the expected demand to ensure good flow, to minimize stagnation and potential heat gain;
- Implement an appropriate management strategy which includes manual or automatic flushing of mains and cold water pipework to all remote outlets on a daily routine or time schedule if automatic and identifies infrequently used outlets that should be included within a regular flushing regime;
- Conduct a detailed testing and commissioning of DCWS and LTHW systems to monitor domestic cold water temperatures and ensure heating system set points and time schedules are set appropriately;
- External MWS pipework between the site boundary and plant room should be at a depth of 750 mm in accordance with industry standards. Also, avoid if possible running under asphalt surfaces or surfaces with a low albedo, to minimise heat gains to below ground pipework;
- Isolate and check the infill against the actual demand of a single water storage tank section and drain down one cold water storage tank section if it is a sectional tank as in hospitals. This will improve water turnover-to-demand;
- The addition of chlorine dioxide tablets to the domestic water services systems. This is an eco-friendly micro biocide. This solution will assist in eliminating Legionella within systems but will not address the issue of water temperature. However, it is recognised water temperature is directly related to the ability of microbial bacteria to exist within water supplies. Therefore by eliminating the bacteria increased water temperatures may be acceptable;
- Improve quality control on site with regards to thermal insulation of pipes, valves, flexible pipe connections and LTHW radiant panels;
- Increase the thickness of insulation on the cold water system pipework. Whilst this may eliminate overheating of pipework it will also help to further delay the temperature pick-up over time;
- Provide a delayed action adjustable height ball valve within water storage tanks to allow stored volumes to be adjustable;
- Ensure appropriate controls and sensors are provided for monitoring domestic cold water consumption and cold water temperatures throughout the system:
- Consider reducing cold water storage levels within buildings appropriate to the building type and anticipate demand (reduce from 24 hr to 12 hr storage);
- Incorporate a ‘soft landings’ approach to help building users and operators adjust to their new facility and help them understand the building and associated systems design intent and operation;
- Include for seasonal commissioning within the contract to allow the systems to be adapted to seasonal variations and changes in user need, and perhaps enforce the user by law to ensure this happens;
- Enhance void ventilation movement by introducing high and low level grilles to induce airflow through the ceiling voids. This may be achieved by installing natural or automatic ventilators to reduce heat build-up and resulting temperature elevations to cold water pipework, particularly during periods of low water use. However this would not mitigate the issue if high incoming mains water temperatures and storage tank temperatures were being achieved, an

analysis study may also be undertaken into whether void vents may increase temperatures within corridors or adjoining spaces;

- Introduce a cold water return circuit combined with automatic balancing valves to maintain water movement within the system or at least at the critical cold water services branches by adopting circulation venturi type valve;
- Install automatic dump valves at the system extremities/sentinel points. These operate by temperature controlled actuated valves which will remain open until acceptable temperatures are detected. This will result in water being wasted, however the dump valves will assist in water movement and subsequently cold water temperatures;
- Install a refrigeration system with pumps and a plate heat exchanger to chill water within the cold water storage tanks to ensure that the water is stored at an appropriate temperature or connect to a building chilled water circuit if one is available. This solution would deal with the issue if there is high incoming water temperature. This would require additional energy consumption and costs to the building. Remote outlets may still be flushed regularly as heat gains could still occur to cold water pipework in ceiling voids, as such a secondary cold water return loop could also be added;
- Encourage clients to include for post occupancy evaluation to learn how the systems and building are performing including encouraging the logging of live data which can be shared with the industry to help inform trends and future updates to standards and guidance;
- Industry review of current standards in relation to the design and sizing of cold water systems, drawing on the experience of industry professionals and available live data across a wide range of building types and sectors;
- Encourage an environment that would promote the sharing of data logged and lessons learned.

6. SUMMARY

This paper has reviewed potential causes of domestic cold water elevated temperatures, potential system mitigation measures to maintain water temperatures below 20℃ and recommendations for future investigation. The paper has outlined the history of the existing design methodology and presented the supporting guidance and legislation associated to maintain a hygienic cold water supply, potential causes of water degradation and proposed mitigation measures.

Additionally, in order to allow the client to make informed decisions on appropriate management strategies for the building water supplies the FM team need to be provided with sufficient training and background information relating to the running and operation of the DCWS systems. Also, the client should be made aware of potential obligations, restrictions as well as benefits of seasonal commissioning and soft landings.

Also, promoting a culture of collaboration and knowledge sharing with the ultimate goal of benefiting both the building services industry and our clients should be an objective for all. As such, harmonizing industry experience and academic research should be enforced if we are to achieve this objective.

COMPETING INTERESTS

The issues raised in this paper have accumulated through several resources and in no way reflect any one specific project or AECOM design. The issues and mitigation measures have been compiled through the experience of multiple engineers from many consultancies over several years.

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