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Citation for published version:
Adeyeye, K, She, K & Meireles, I 2018, 'Thermal and flow distribution of showerheads as a method for understanding water user preferences' Paper presented at Water Efficiency Conference 2018: , Aveiro, Portugal, 5/09/18 - 7/09/18, .

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link to publication

University of Bath

Proceedings of the 4th Water Efficiency Conference 2018

Date: 5-7 September, 2018
Venue: University of Aveiro, Portugal

Citation: {Authors surname, Initials…} (2018), {Paper title}, Silva-Afonso, A and Rodrigues-Pimental, C. (Eds.), *Proceedings of the Water Efficiency Conference 2018*, 5-7 September, Aveiro PORTUGAL: WATEF Network/University of Bath

ISBN-13: 978-0-86197-198-5. ISBN-10: 0-86197-198-1

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COVER IMAGE: a city skyline with several large water pipes above ground by Gratuit.
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Thermal and flow distribution of showerheads as a method for understanding water user preferences

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ABSTRACT

Water efficient products such as showerheads provide a useful means to manage and deliver water use efficiency. They are now prevalent in the market, however there remains gaps in the understanding of these products in terms of user interaction and use and the extent of how these affects user perception, and experience. These unknowns still exist since user experience of eco products influences the extent to which they consistently achieve water use efficiency beyond the short term.

This study was therefore undertook to study important parameters that define the technical efficiency of showerheads as it is associated with the perceived performance and experience of (and therefore the satisfaction with) showerheads. Technical parameters were measured in a laboratory environment and the findings were triangulated against in-home user feedback.

This study is significant because it presents a useful methodology for understanding user preferences for such water products, as well as the degrees of affordance that need to be factored into their design, deployment and use.

Keywords: Flow distribution, Thermal range, Showerheads, Water efficiency, Water user

1. INTRODUCTION

This unsustainable water use relative to population growth is an increasing cause for concern and attention. Water use habits have also evolved in line with sociological and economic factors, and less in line with environmental/resource constraints. Although water challenges are less apparent in developed countries, particularly due to advancements in municipal water supply systems, the need for water use efficiency remains important. Technological solutions, behavioural interventions and financial incentives targeted at users has been shown, to varying degrees of success, to help deliver water use efficiency in homes (e.g., [1-4]). In addition to water efficient behaviours, promoting use of water efficient fixtures have been successful in some communities resulting in up to 35% of indoor water savings [5].

Water technologies and products are useful for achieving targeted water savings in domestic and personal water use. Taps, showers, baths and toilets are necessary for sanitation and health but can also promote water waste due to poor design, installation and use. However, some like Lee and Tansel [5] have found that the satisfaction levels of the participants in water efficiency trials including retrofitted high efficiency fixtures were closely correlated with the achieved water savings.

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Therefore, this study focuses on the technical efficiency of showerheads as a determinant for its efficiency in-use. It presents laboratory findings of temperature and flow distribution of showerhead as an indicator of the potential to propagate due to water loss, and the perceived satisfactions that could potentially be derived by the user as a result of using these products.

A sample of 10 showerheads was used in this study. All the showerheads were water efficient discharging water at between 5-11 litres per minute (Table 1).

Table 1. Characteristics summary of the showerheads in the sample.

Ref No.	S-01	S-02	S-03	S-04	S-05	S-06	S-07	S-08	S-09	S-10
Shape	Round	Oblong	Round	Round	Round	Round	Round	Rectangle	Curved rectangle	Round
Height	90	157	106	100	100	106	135	67	65	135
Width	90	82	106	100	100	106	135	182	120	135
Height incl. handle	215	270	239	230	230	239	246	227	219	246
Sprout Type	Recessed twin	Recessed twin	Recessed twin	Protruding single soft rubber	Protruding single soft rubber	Recessed twin	Recessed twin	Triple central, recessed twin	Recessed twin	Recessed twin
Sprout Layout	3 x 3 double sprout clusters	Two long double-sprout oval rows	Two concentric double sprout circles	Central core and radial rows	Central core and radial rows	3 x 3 double sprout clusters	Random x 3 clusters	Central triple clusters, random rows	Random	Random x 3 clusters
Working pressure (bar)	0.3 - 5.0	1.5 - 5.0	0.35 - 5.0	0.3 - 5.0	0.3 - 5.0	1.0 - 5.0	0.35 - 5.0	1.5 - 5.0	0.35 - 5.0	0.35 - 5.0
Regulated flow rate @ 2 bar pressure (l/m)	8.7	8.7	7.9	13.2	12.9	5.1	7.6	7.4	8.3	7.6
Measured Regulated flow rate @ 2 bar pressure	10.3	7.2	7.2	9.2	8.7	5.1	11.3	7.2	8.1	9.6
Number of functions	1	4	1	3	1	1	2	2	1	2
Mode of operation	Colliding twin jets	Colliding twin jets	Colliding twin jets	Mixing with Air	Mixing with Air	Colliding twin jets	Colliding twin jets	Colliding twin jets	Colliding twin jets	Colliding twin jets
Image										

Studies such as this contribute to the better understanding of sustainability mismatch in water efficient products against user preferences and use behaviours. The laboratory and user experiments on showerheads makes it possible to further determine factors that promote the efficiency of design and use of the showerhead; in turn promoting sustainable development.

2. RESEARCH CONTEXT

There 5R principle (below - [6]) is typically proposed for achieving water, and energy efficiency as shown below.

Reduce consumption
Reduce loss and waste
Re-use water
Recycle water
Resort to alternative source

→ Water Efficiency in buildings

Domestic buildings which typically include individualised, and multiple architectural spaces such as kitchens and bathrooms provide the opportunity and scope for targeted water efficient product solutions, and this has been the case. A wide range of different types of taps, showers etc. are now readily found in the market with increasing additional functionalities, and characteristics, all designed to meet user needs, preferences, and demands as highlighted by market studies of various kinds. Showerheads in particular have become increasingly complex over time and this in turn informs their water use consumption. Even eco- or water efficient-showerheads come in varying types and offer different flow rates/patterns, pressure, temperature ranges etc. as shown below.

Type of shower heads [7]:

- Single head: This type of showerhead may have a single setting or more than one setting. Settings often include more and less focused sprays and a pulsating spray.
- Multiple-head Shower: These fixtures may have two or more spray nozzles connected to one pipe. They can easily replace a single head fixture.
- Cascading Showerhead: They often are mounted overhead such that the water drops straight down. They typically give a softer spray and have diameters of 6 to 8 inches.
- Shower Panel or Shower Tower: These are designed to spray water from more than one location having more than one showerhead. They may operate sequentially.
- Rain Systems: Rain systems simulate rain by allowing water to fall from an overhead fixture.
- Body Spas: Body spas consist of multiple showerheads and are described by some as the vertical equivalent of a spa. The showerheads may be activated sequentially or intermittently.

Biermayer [7] also postulated that the amount of water used by showers could be reduced in several ways if information were available regarding both the water efficiency and performance of showerheads.

- Results of testing showerheads can provide an enforcement function, whereby showerheads that exceed the standard for water flow are identified and removed from the market.
- Showerheads that use even less than the standard and also provide a good shower experience can be identified and promoted.
- Providing consumers with information about which showerheads they are most likely to find satisfactory will encourage them to switch to effective low-flow showerheads and discourage them from installing non-compliant showerheads.
- Identifying low-flow showerheads that provide an adequate shower also may prevent consumers from purchasing multi-head shower fixtures.
- Additional research into ways to encourage consumers to turn off the water while lathering also could save water.
- Perceived or real safety considerations may prevent utilities from promoting very low-flow showerheads and therefore, these issues must be researched.

A previous study by Adeyeye *et al.* [8] showed that the environmental performance of resource using products such as showerheads, are affected by product design and use. Use factors are also influenced by the extent to which the product satisfies user performance expectations in addition to meeting environmental benchmarks and standards. Therefore, it is important to understand water efficient product design and performance standards individually and in conjunction with user preferences in order to determine the extent to which it is wholly water efficient.

This study aims to satisfy this assertion by presenting product performance findings of 10 water efficient showerheads in conjunction with user feedback on the specific criteria being studied. The 10 showerheads were supplied by the same manufacturer and 12 volunteer participants participated in a 12 week study where they were able to use each showerhead at home for one week. They completed a feedback sheet of each showerhead after their first and last use during the week. Therefore, it is possible to compare their initial and final feedback. Conclusions are then presented to highlight the importance of the showerhead performance characteristics in informing the user perception and feedback of the product.

3. THE EXPERIMENTAL SETUP

A study by McClelland *et al.* [9] used focus groups to address the issue of a 'good shower'. They found that the main requirements were temperature stability, adequate water volume and distribution, and perceived skin pressure. Alkhaddar *et al.* [10] followed up these findings with laboratory experiments which proposed useful measurement methods as well as determined the relative dependencies of performance metrics such as flow rate and skin pressure. This study builds on this work. The research design is summarised as below (Figure 1).

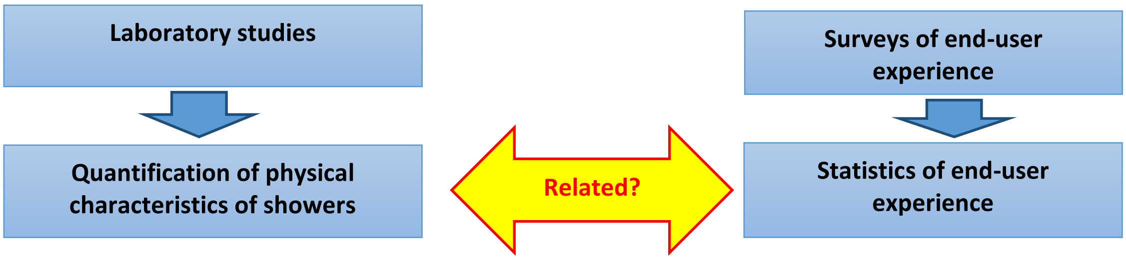


Fig. 1. Research design.

Figure 3 shows the laboratory setting and the schematic configuration of the instrument setup in the shower cubicle. The cubicle has provision for three shower heads to be mounted at the same time. The mounting position for this study is indicated in the figure and the mounting wall is referred to as the north wall for the purpose of orientation.

3.1 Showerhead Spray diffusion/ distribution

The measurement of the showerhead spray diffusion and distribution is derived from the method employed by Alkhaddar *et al.* [10] and a comparison is shown in Figure 4. Alkhaddar *et al.* [10] assumed that the spray has a circular pattern and the spray centre coincides with that of the collector unit. As such, their collector system consists of nine radial zones with water collected and measured for each zone to give a distribution map of the spray. In reality, the spray pattern is not symmetrical in the radial direction due to spray-hole asymmetry or simply the presence of showerhead installation angle. This means that a collector system of circular zone may not truly map the actual spray distribution.

Refinement to the circular zone design is needed, ideally with each circular zone subdivided into smaller zones. This would however significantly increase the manufacturing and operational difficulties. The spray collector design adopted in the current study overcomes the asymmetry issue by using a series of plastic containers (cups) arranged in a configuration as shown in Figure 2. A precision template is laser-cut out of an 8 mm Perspex sheet, ensuring repeatability and consistency of container positions between tests of different shower heads. The position of the collector unit in the shower cubicle can be seen in Figure 3. Initial trials show that the centre of the shower spray is generally not the same as the centre of the container array, depending on the showerhead being tested. For consistency and improved spray area coverage, each shower head is tested three times with the template placed at a distance of 0.55 m, 0.60 m and 0.66 m from the north wall, respectively. In addition to increased spray area being measured, the gapping area between the container arrays is also covered. The spray collector unit serves to obtain the flow distribution and temperature variations across the spray. The unit collects water over a fixed time of 60 seconds. Over this time, a sufficient amount of water is collected without overflowing any of the cups. The volume of water in the cups can be easily derived using a digital scale while the water temperature at each cup is obtained by means of a thermal camera. Four thermal images are taken for each test, each covering 1/4th of the container array.

3.2 Showerhead temperature range

Thermal imaging is now widely used in the construction industry and for the purposes of this study temperature differentials can be used to define temperature ranges and heat transfer from water being dispensed from the showerhead. Thermal imaging cameras work by recording Infrared Radiation (IR) which directly relates to the objects' temperature. The thermal imaging camera used for this study is Thermo View Ti30 by Raytec, which comes with a software tool that coverts recorded thermal images into temperature.

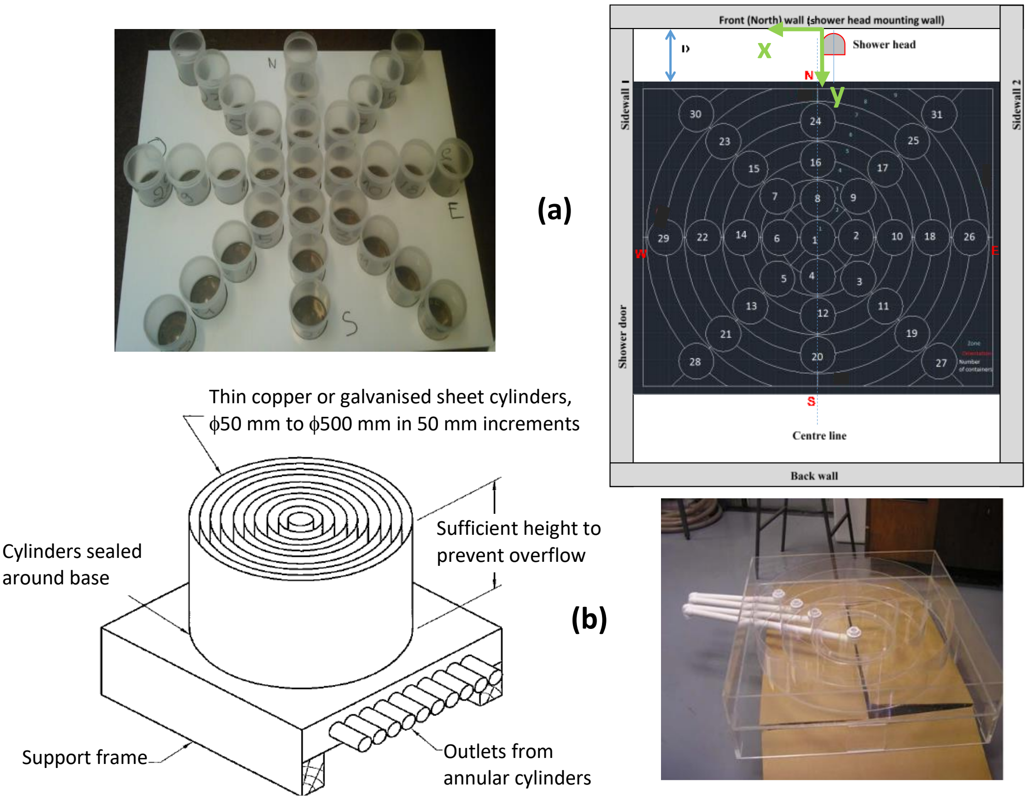
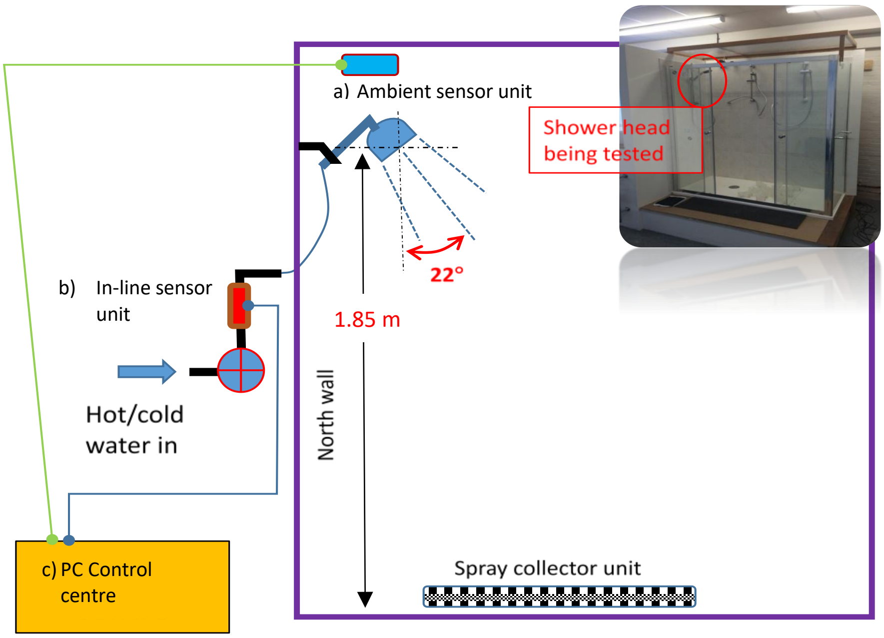


Fig. 2. Spray collector units (a) current study, with plan view and (b) Alkhaddar *et al.* [10].



a) Ambient sensor unit
This unit consists of 3 sensors to measure the air pressure, relative humidity, and sound level.

b) In-line sensor unit
This includes 3 sensors mounted in the pipework between the shower mixer and shower hose. The unit measures water pressure, temperature, and flow rate.

c) Control Centre
This is a PC with an A2D data logging system. All sensor outputs are connected to the control centre and all data are recorded simultaneously for later analysis.

Fig. 3. The shower cubicle and instrumentation layout.

4. USER FEEDBACK

As stated, participants of the 12 week shower challenge were asked to complete a feedback sheet which documented their showering habits as well as their feedback against a metrics of 23 different questions and a choice of 5 responses. The feedback sheet was explained to participants at a commencement workshop to ensure that the feedback questions are interpreted correctly when completing the feedback sheets.

Two stages of feedback were obtained: one on receipt of the showerhead at the beginning of the trial week, and second at the end of the trial week after the final showering event before the swap. Relevant excerpts of the average user feedback is presented due to the space constraints of this paper (Table 2). A further paper will better articulate the findings based on participant demographic and discuss correlations against other user and showerhead metrics.

In summary, it was found that users were able to discern differences in the showerhead performance in terms of the consistency of flow and temperature as well as the spray coverage. Further, user judgemental and experiential perceptions of the showerheads differed throughout the trial. Therefore, and depending on the showerhead, the mean value for the showerhead increased or decreased throughout the trial. This showed that there could be significant differences in findings from water efficiency studies that are based on experiential data compared to other 'passive' methods.

Feedback are provided on a scale of 1 to 5, and the notional mean for acceptable, positive feedback was defined as 3.5 in line with the median, rather than the arithmetic mean which is not robust for outliers and variance. On consistency of water flow, the majority of the showerheads performed the notional mean. With the exception of showerheads 1 and 10, all the showerheads were rated higher at the end of trial week compared to the beginning of the week. Showerhead 7 received the same overall mean value for both feedback stages. It should be noted that showerheads 7 and 10 are identical in all aspects except colour (*see images in Table 1*). This was done as an additional indicator of consistency in the user feedback of each product.

Table 2. Average feedback summary from study participants.

		S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10
The water flow was consistent	Start of Week	4.67	4.55	4.11	4.60	4.38	4.33	4.75	4.67	4.50	4.75
	End of Week	4.56	4.67	4.38	4.70	4.55	4.44	4.75	4.83	4.60	4.58
I like the coverage of the spray	Start of Week	4.22	4.25	4.00	4.30	4.23	3.44	4.25	4.00	4.20	4.50
	End of Week	3.67	4.42	4.38	4.40	4.55	3.44	4.63	3.83	4.40	4.42
The water temperature was consistent	Start of Week	4.00	4.27	4.00	4.20	4.38	3.33	4.38	4.17	4.10	4.50
	End of Week	4.00	4.42	4.00	4.20	4.36	3.44	4.13	4.08	4.00	4.42
This showerhead meets all my expectations	Start of Week	4.00	4.55	3.89	4.00	4.08	3.67	4.13	3.83	4.20	4.25
	End of Week	3.89	4.33	3.75	4.20	4.09	3.44	4.00	3.83	4.10	4.33
I will be happy to buy this showerhead	Start of Week	2.67	2.27	2.33	2.70	2.62	2.67	2.75	3.00	2.70	2.67
	End of Week	2.11	1.83	2.38	2.90	2.73	2.78	2.75	3.25	2.40	2.83
This showerhead was enjoyable to use	Start of Week	2.78	3.09	3.00	3.60	3.08	2.89	3.75	3.50	3.30	3.92
	End of Week	2.89	3.17	3.00	3.30	3.00	2.56	4.25	3.58	3.00	3.83
	Total (top 3 criteria)	25.12	26.58	24.87	26.40	26.45	22.42	26.89	25.58	25.80	27.17
	Average (top 3 criteria)	4.19	4.43	4.15	4.40	4.41	3.74	4.48	4.26	4.30	4.53
	Total	34.23	36.6	34.73	37.8	37.12	31.66	39.02	37.07	36.4	39.67
	Average	3.42	3.66	3.47	3.78	3.71	3.17	3.90	3.71	3.64	3.97

User feedback on the spray coverage were more varied. Most of the showerheads received higher ratings at the beginning of the week compared to the second feedback at the end of the week. All except showerhead 6 (*see images in Table 1*) which was rated lower than the notional average at 3.4. Showerhead 6 is a round showerhead with recessed twin sprout types laid out as 3X3 double sprout clusters. This shower delivered the least regulated flow rate of 5.1 l/min @ 2 bar pressure of all the showerheads. Although showerheads 1 and 8 performed better, their ratings dropped at the end of the trial week compared to the initial feedback. Showerhead 1 is also round, whilst 8 is rectangular. The design of showerhead 1 is similar to that of 6, but with more sprouts. Whilst showerhead 8 has triple central, recessed twin arranged from the centre in triple clusters and random rows (*see images in Figure 1*). They deliver regulated flow rates of 8.7 and 7.4 l/min @ 2 bar pressure respectively. All 3 showerheads work by delivering colliding twin jets of water that turn into thousands of tiny droplets. At the end of the trial week, showerheads 1, 6 and 8 received good feedback for consistency of water flow at mean values of 4.56, 4.44 and 4.83 respectively. However, this fell to mean values of 3.67, 3.44 and 3.83 for flow distribution.

The preceding feedback did not apply to the temperature consistency delivered by the showerheads. All the showerheads were rated well above the notional mean, except showerhead 6. Showerheads 1, 3, 4 and 9 stayed within the same feedback range at the start and end of the trial week. However, the mean rating for showerheads 5, 7, 8 and 10 dropped at the end of the trial week. Showerhead 5 is also round but distinct in its mode of operation. Showerhead 5 has 1 function unlike the similar showerhead 4 which has 3 functions. Like showerhead 4, it has a protruding sprout arranged in radial rows around a central core. Their mode of operation is also significantly different from the others as they are the only two showerheads that mix water with air – hence some participants complaining that they are noisy.

Participants stated that most of the showerheads met their expectations except for 6 which fell just below the notional mean. However, most of the participants – mean 1.83 – stated that they will not buy showerhead 2, the most expensive multifunctional showerhead in the sample. It should be noted that most of the participants did not identify that it had multiple functions until they were told at the end of the challenge as these functions were not obvious or intuitive. Showerheads 7 and 10 ranked highest for enjoyability – they were the largest showerheads in the sample and had just 2 functions which were obvious and easy to use.

In considering the flow, distribution, and temperature of the showerheads in this study sample, showerheads 7 and 10 were ranked highest by the participants, followed by 2, 5, 4, 9, 8, 1, 3 and 6 in that order. These findings compared with that in Adeyeye *et al.* [8] prove the importance of user perceptions and feedback of design and performance considerations in determining the degrees of suitability, adoption, satisfaction and water use efficiency of water products such as showerheads.

5. LABORATORY RESULTS

As the spray water is collected in individual cups at known positions over a fixed time of 60 seconds, the relative volume of spray water at these positions can be calculated with respect to the total amount of water released from the showerhead, which is recorded by the data logging system. Figure 4 gives an example of the spray water distribution in different directions (Refer to Figure 2, **N**orth-**S**outh, **E**ast-**W**est etc.). Note that the spray water measurement is repeated 3 times for each showerhead with the spray collect unit respectively placed at 0.55m, 0.60m and 0.66m from the north wall. There is good consistency between the 3 tests. It is clear that the centre of the spray is not easily identifiable during the experiment. It can however be estimated using the measured spray volumes. With the positions of the cups defined in terms of x-y coordinate (refer to Figure 3), the centre of the spray can be calculated in the form of centre of gravity of the measured masses:

$$x_c = \frac{\sum V_i x_i}{\sum V_i}, \quad y_c = \frac{\sum V_i y_i}{\sum V_i}$$

Where $\{x_i, y_i, V_i\}$ represent the position (x_i, y_i) and volume (V_i) of i-th cup. Not all cups are included in the calculation. A measurement is included if $V_i \geq 0.3V_{max}$, where V_{max} is the maximum volume per cup collected in a showerhead test. This is based on the fact that all showerhead tests have a spray collector coverage of at least 70% of the total spray. The approach has the effect of alleviating potential bias and inaccuracy caused by low spray water area that extends to outside the bounds of the collector unit.

An examination of the spray volume measurement indicates that the per-cup volume is up to 4% of the total spray volume. For purpose of mapping the spray distribution, the measured per-cup volumes are grouped into 5 ranges of 0.001-0.5%, 0.5-1%, 1-2%, 2-3% and 3-4%. These are colour-coded and shown along with the cup positions, thus providing a visual indication of the varying spray intensity over the spray area.

Figure 5 shows the results for showerheads 1, 4, 6, and 10. It was shown in Section 4 that 4 and 10 were among the showerheads that attracted the highest overall ratings in user feedbacks while 1 and 6 were among those that received the lowest. The mapping provides an insight into three aspects of the spray, i.e., spray form or pattern, magnitude and variation of spray intensity and effective spray area or coverage. It can be seen that the spray form is generally non-symmetrical with respect to the centre of the spray irrespective of the showerhead design. The dashed curves approximately enclose the central areas where the collected spray water exceeds 1%. It can be seen that showerhead 10 shows a pattern that is the nearest to radial asymmetry. The percentage volume of water collected in each cup can be viewed as the intensity of the flow at the cup position. A higher intensity of spray means a higher flow rate and velocity over the cup area. A higher flow velocity in turn means a greater impact force felt on the body due to the momentum principle. As the distance from the centre of the spray increases, the spray intensity reduces.

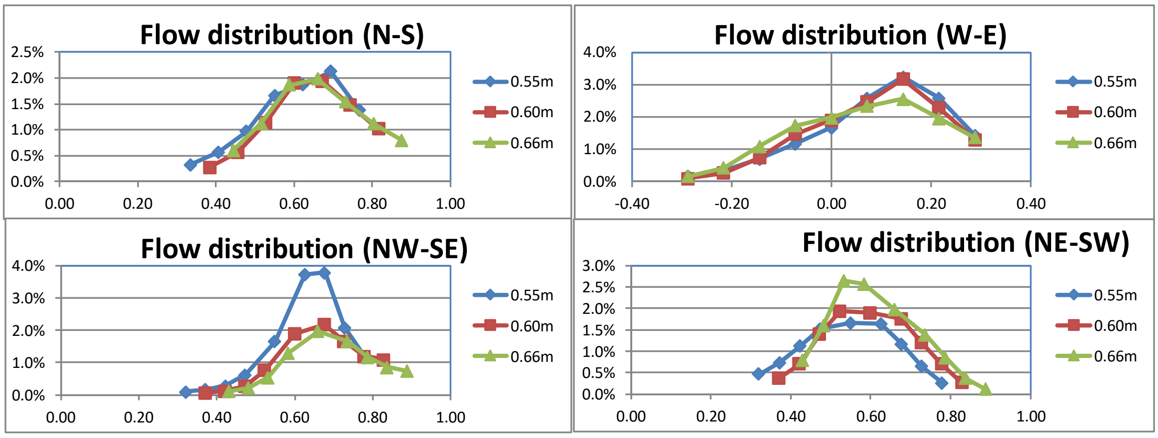


Fig. 4. Variation of spray volume as a function of floor position for showerhead S-1.

Similar to spray volume distribution, the temperature of the spray may also be mapped as shown in Figure 6. Again, the temperature is grouped into 5 zones between maximum and minimum readings. It is interesting to note that the temperature variations follow a similar pattern as the spray volume distribution. There is a drop of about 2ºC between adjacent zones, indicating significant heat transfer from the spray to the surrounding air. It can also be seen that showerhead 6 contains only two cups in the two highest temperature zones, indicating that heat transfer of this showerhead is faster than others. This means that this particular showerhead, while being most water efficient, offers poor spray intensity and heat retention. Temperature variation for showerhead 1 shows no obvious difference to 4 and 10 apart from the stated asymmetry. Other factors may be in the play for the poor ratings of showerhead 1.

5.1 Limitations

The limitations of this study are the purposive sampling of the showerheads i.e. from the same manufacturer and the sample size of the study – 6 men and 6 women. However, the objective of the study was to investigate a range of water efficient showers types i.e. design, modes, functions, and this was achieved in spite of the showerhead samples being sourced from a single manufacturer. Also, the methodological aim was for depth rather than breadth hence the participant sample size. The challenge of recruiting and maintaining participants for studies such as this is also well documented. Nevertheless, the future studies will aim to further test and corroborate findings against a wider product and user sample range.

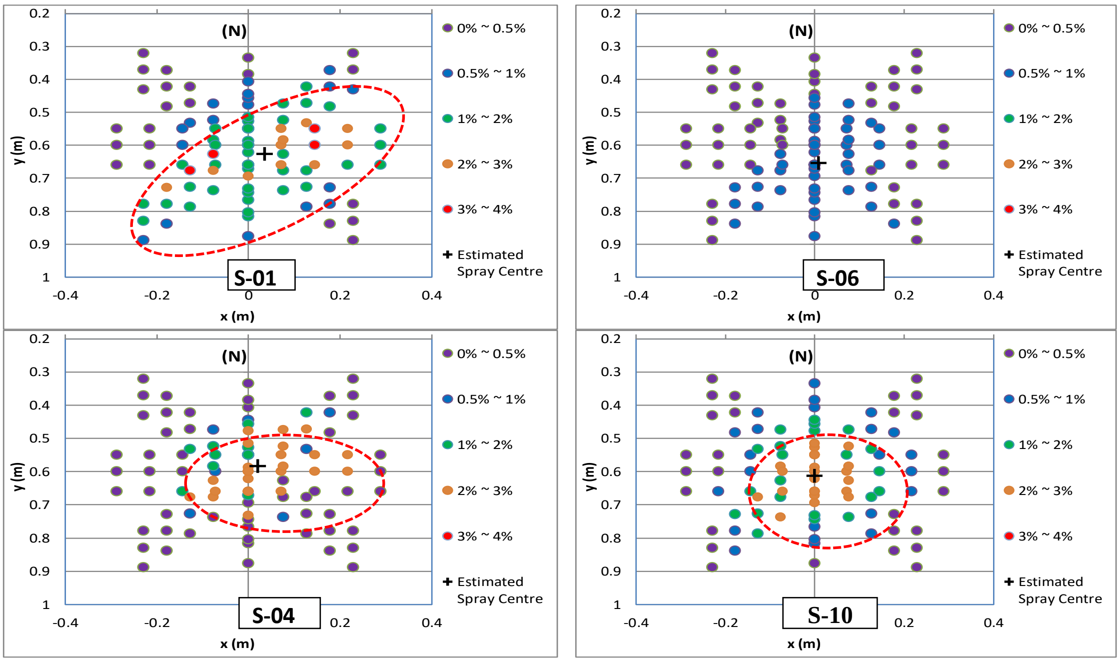


Fig. 5. Spray distribution for showerheads 1 & 6 of low overall ratings, 4 & 10 of high overall ratings.

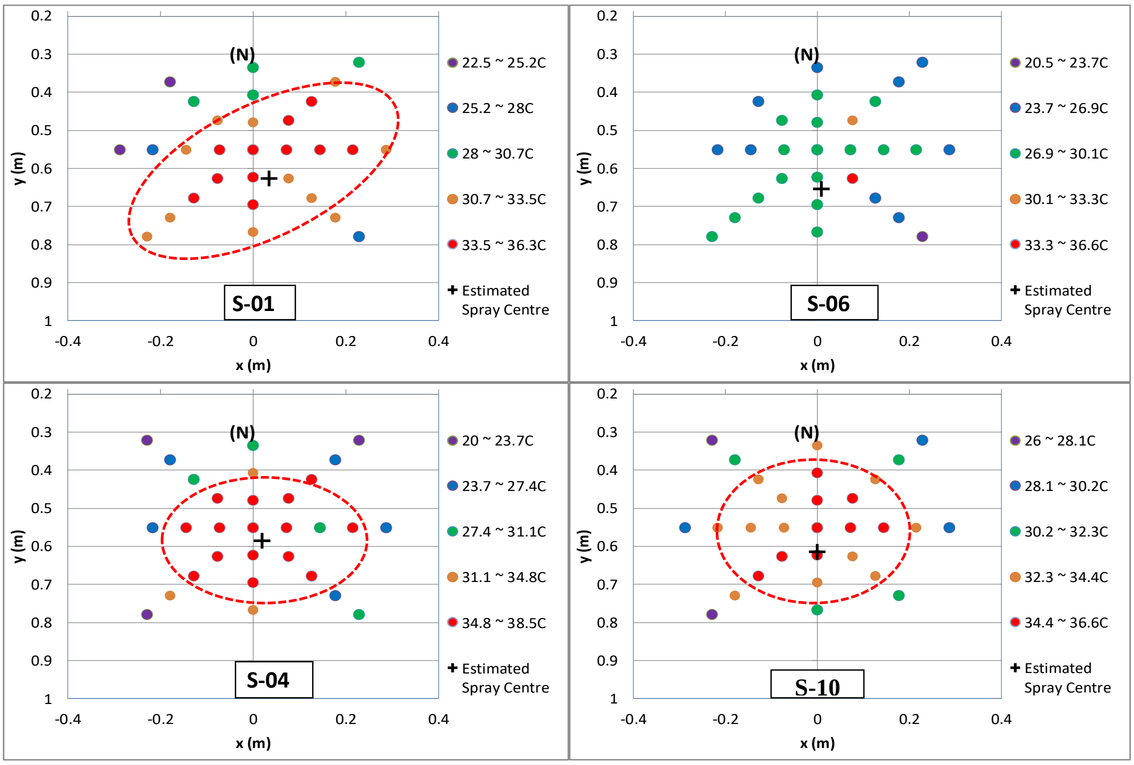


Fig. 6. Spray temperature distribution for showerheads 1 & 6 of low overall ratings, 4 & 10 of high overall ratings.

6. DISCUSSION AND CONCLUSION

Functionality matching as judged by the user, against his/her goal with the product [11] should be considered and understood when promoting water efficiency through the use of products such as showerheads. Functionality mismatch i.e. the desired functionalities and delivered functionalities, can occur and affect context in which the product is used [11], and can result in what can be referred to as unwanted or anticipated side effects [12]. This paper builds on Adeyeye *et al.* [8] in studying the sustainability mismatch between design/performance metrics of the sampled showerheads on one hand, and user feedback of experience on the other.

The first part of the results evaluated user feedback on flow and temperature parameters as two main parameters that can be used to understand user preference of one product against another, but also to understand how this preference is defined by their experience of the product. From the user feedback, the 10 showerheads can be clustered into two distinct groups; preferred and not preferred. Showerheads, 1, 3, 6 appeared to be distinctly non-preferred compared to the others. Showerheads 1, 3 and 6 have similar designs, with less sprouts compared to the others, and produce finer water flow i.e. deliver water as fine sprays.

The user feedback were then checked against findings from laboratory tests. This confirmed that the less rated showerheads can suffer from poor spray delivery along with temperature drops greater than other showerheads. Showerhead 1 for instance, seems to suffer from asymmetrical uneven spray distribution which may have contributed to its poor ratings. These showerheads can also suffer temperature variations following a similar pattern as the spray volume distribution. A drop of about 2ºC between adjacent zones was found, indicating significant heat transfer from the spray to the surrounding air. Therefore, the evidence from this product and user sample, can help to conclude that both volumetric and temperature distributions of the spray play a part in deciding the overall experiential performance of such products from the users' perspective. This means that the design of water efficient showerheads should avoid poor spray intensity and heat retention.

ACKNOWLEDGEMENTS

This project was funded by a University of Brighton SET RIF grant, with in-kind contributions from Methven and Chandlers Building Supplies, Lewes. A big thank you to all the participants for their commitment to the success of this study. IM acknowledges the support from FCT through the Sabbatical Leave Fellowship SFRH/BSAB/135243/2017 for her stay at the University of Bath in 2017/2018.

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