Saving water in showers

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Abstract. This project is part of a programme aimed at reducing water consumption. Power showers are water inefficient, but in order to persuade the user to accept a lower water use it will be necessary to sustain the “shower experience” to maintain user satisfaction. Previous work has indicated that users’ requirements include temperature stability, adequate water volume and distribution, and skin pressure, all of which are substantially controlled by the showerhead. In the present phase of the project several commercially available domestic showerheads have been examined to determine pressure-volume characteristics, radial spray distributions at different flow rates, direct and indirect measures of “skin pressure” and measurements of vertical temperature profiles. Part of the practical work at LJMU has supported extensive theoretical studies by CFD carried out by staff at Arup (consulting engineers) for the Market Transformation Programme. A future phase will study user satisfaction in their own homes where user satisfaction will be surveyed and linked to the physical performance of the shower.

1. Introduction
It is usually asserted that a shower takes less water than a bath. Figures from the UK Government’s Office of Water Services [Ofwat 2006] quote 35 litres for a shower compared with 80 litres for a bath. However, these figures are questionable partly because the rate to the electrically heated instant shower with a typical flow of 4-8 litres per minute and because so much depends on showering duration and on the depth of water used in a bath. The increasing use of power showers with flow rates of 8-15 litres per minute and changing personal habits may well increase water requirements. The water industry is under increasing pressure to pursue policies of reducing water consumption. With this in mind, United Utilities plc has sponsored a project at Liverpool John Moores University. The project aims to reduce water consumption while maintaining acceptable performance. The initial phase of the project [McClelland et al 2005] used focus groups to address the issue of a ‘good shower’. It was found that the main requirements were temperature stability, adequate water volume and distribution, and perceived skin pressure. These requirements were found to be substantially independent of gender, age, and other variables, whilst the pattern of usage did vary substantially. Earlier experimental work [Woolf 2005] has addressed the issue of temperature stability. In the present work, we will address water volume and distribution, and skin pressure, with the aim of reducing water flow while maintaining acceptability.

2. Experimental Measurements
The basic experimental shower rig (Figure 1) was set up to copy as far as possible the standard low-pressure plumbing practices in the United Kingdom. Cold water was supplied from a tank only slightly higher (1.5m) than the rest of the installation. Water was heated in a conventional vertical copper
cylinder with a 3kW immersion heater, and was supplied at the same pressure as the cold water. Hot and cold water were supplied separately to two pumps on the same shaft driven by the same motor (Figure 2). The pump motor was electronically controlled, allowing the supplied pressure to be adjusted over the range 1 to 2 bar. The existence of a pump in the set-up defined the shower, according to MTP, as a ‘power shower’, and is typical of modern shower installations in those houses in the UK which have low-pressure hot water systems fed from a loft tank. From the pumps, the water supplies went to a mixer valve with a fluidic thermostat, with separate controls for flow volume and mixed temperature. It was possible to exchange the mixer for others of a different design, so as to allow for comparisons. From the mixer, the thermostatted water went through a flexible to the showerhead, which could be exchanged for others of differing design, again to allow for comparisons. A typical shower head used in the project is shown at the end of this paper, together with its pressure/flow characteristic.

![Figure 1. Experimental shower rig Note I have better one.](image1)

![Figure 2. Pump supplying shower.](image2)

The flow rate of water was measured by turbine meters in the two separate hot and cold supplies, and then by a visual rotameter in the flexible pipe from the mixer valve to the showerhead. To allow absolute calibration, the combined flow volume could also be measured by a timing the collection of a known volume. The pressure of water supplied to the shower head was initially measured using a simple Bourdon tube gauge, but later a solid state electronic pressure gauge was used. The diameters and distribution of holes in the showerheads was measured photographically, allowing an estimate to be made of the total area of free cross section in the head. The “skin pressure” was measured using a flat diaphragm pressure sensor linked to an electronic manometer. This is discussed in detail in section 5 of this paper.

3. Water flow and supply pressure

It was found that although the pressure-flow relationship varied widely between heads, the curves were of a consistent shape, with flow proportional to the square of the pressure, as required by the theory of turbulent flow (Figure 3 below). More surprisingly, the relationship between the free cross section of the head (the total whole area) and the maximum flow rate is weak (Figure 4), perhaps
indicating that the nature of the holes (e.g. roughness, degree of slope in the sides etc) is more important than the impedance of the measured hole diameter, the pipe-work, etc. This is an unexpected result, and further work is needed to clarify the issues involved.

\[ Q = f(P) \]

-0.2

0

0.2

0.4

0.6

0.8

1

1.2

2.5

3.5

4.5

5.5

6.5

7.5

8.5

9.5

10.5

11.5

12.5

Flow (l/min)

Pressure (bar)

Figure 3. Pressure flow relationship

Figure 4. Relationship between hole area in the shower head and maximum flow rate

4. Flow distribution

Flow distribution was measured using a set of concentric cylinders, either close to the shower head (Figure 5) or at shower tray level (Figure 6). Typical results (Figures 7 and 8) show that for some shower heads, the flow distribution can be maintained adequately over a range of flow rates, while for other shower heads, the flow distribution suffers significant degradation at reduced flows.

Figure 5. Flow distribution measurement device for measurement close to the shower head

Figure 6. Flow distribution measurement device for measurement at shower tray level.
Figure 7. Shower head with adequate maintenance of distribution over a range of flow rate

Figure 8. Shower head with inadequate maintenance of distribution at lower flow rates.

5. Skin pressure
The pressure exerted by a shower on the skin of the user has been estimated [Woolf, private communication] at about 50 Pa, or about 5 mm water gauge. Pressures of this order can be measured using the impact of a shower on a microbalance [British Standards, 1983] but this technique is difficult to use except for vertical impact, and is not useable outside the laboratory. In principle it is possible to make measurements in arbitrary positions in non-ideal conditions using an electronic manometer connected to a sealed capsule with a thin diaphragm, a method which has been deployed in geriatric nursing [Rithalia and Kenney, 2001].

In the present work we have used a method shown in Figure 8. A thin rubber diaphragm is sealed on to a plastic funnel, and connected with a thin plastic pipe to an electronic manometer with a 2000 Pa full scale and 0.1 Pa resolution.
Absolute calibration of the device, by putting weights on the diaphragm, has proved it to be linear over the working range of pressure. Results have been quite consistent, with a clear relationship between the skin pressure and the square of flow rate.

With a measuring technique established for skin pressure, it was now possible to relate skin pressure from a particular head to flow which is of course itself related to supply pressure. Not surprisingly, therefore the skin pressure varies with pressure of water supplied to that head. A set of results for 8 different heads is shown in Figure 9 below.

The dimensionless ratio $P_{\text{s}}/P_{\text{supply}}$ is independent of flow for a given showerhead, but varies widely between different showerheads. This parameter ($P_{\text{s}}/P_{\text{supply}} = HF$) which we have termed the ‘Head Factor’ will be of great significance in shower head design, see Figure 10. At the time of writing, this work is continuing. It is hoped that the results will help manufacturers to design heads which preserve the ‘feel-good’ factor of showering with a water flow sufficiently reduced to be a significant factor in saving water if implemented nationally.
6 Assessment of results
This is a continuing project, and results are at an early stage. However, it is clear that the measurement methods developed in the laboratory are able to measure the variables which shower users in the focus groups have said are important, and are able to do so in the conditions likely to be encountered in domestic conditions. The project is thus well placed to move to the next phase, which is to install experimental water saving devices and showerheads in people’s homes and to assess the acceptability experimentally and by user testing.

7 Conclusions
It is clear that the design of the showerhead can have a major effect on how the flow distribution changes with flow rate. Thus it will not suffice simply to install a flow restrictor in an existing domestic shower without at least some consideration of the shower head itself.
It is also clear that because skin pressure is related in a non-linear manner to flow rate, there will be a very considerable change in skin pressure for a comparatively small change in flow rate. If skin pressure is indeed a variable about which people care, this fact may make it difficult to maintain user satisfaction while reducing flow. It may be necessary to look at alternative methods of improving the showering experience with low flows, perhaps by redesign of shower heads, in which the Head Factor may well prove to be important, or alternatively by technological changes, such as enforced droplet formation by sonic agitation.

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