

An Experimental Study of Shower Spray Properties and Shower Comfort

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Abstract—Shower comfort influences the adoption of water saving showerheads, and thus the implementation of sustainable water conservation programs. This study investigates the shower spray properties of 7 sampled showerheads experimentally and evaluates their relationships with user satisfaction according to shower comfort feedback. The feedback from 30 participants showed that spray force and water flow rate were the two most influential factors determining shower comfort. It was found that if either the spray spread angle (e.g. 17°, 40°), spray coverage area (e.g. 0.122 m², 0.232 m²) or spray force (e.g. 1.67 N, 2.43 N) was too large, the level of shower comfort would decrease. Moreover, shower comfort may be independent of spray velocity and flow rate.

Keywords—Showerhead; Shower spray properties; Shower comfort; Optimum flow rate.

I. INTRODUCTION

Improving shower water efficiency leads to energy savings and carbon emissions reduction. To encourage shower water conservation in Hong Kong, a voluntary Water Efficiency Labelling Scheme (WELS) on showers for bathing has been implemented by the Hong Kong Water Supplies Department (HKWSD) since 2009 [1]. A study by Okamoto et al. [2] reported that shower spray properties, including water distribution pattern, temperature drop and spray spread angle, influenced user satisfaction with showerheads. To efficiently promote the WELS rated showerheads in Hong Kong, a local study of shower comfort is necessary.

This study investigates the shower spray properties of 7 sampled shower heads experimentally and evaluates their relationships with user satisfaction according to shower comfort feedback.

II. EXPERIMENTAL STUDY

Fig. 1 shows a schematic diagram of the laboratory-made water circulation system used in the experiments. An electronic scale was placed underneath a showerhead to measure the force exerted by the spray on the body. The top

of the scale was 0.4 m from the showerhead faceplate. The scale was replaced by an annular gauge when measuring water distribution patterns within the spray cross-section. As shown in Fig. 2, the annular gauge had four circles of graduated cylinders. A high speed camera was prepared for taking photos of the discharging showerheads. Fig. 3 exhibits the 7 showerheads sampled.

Based on the measurement method by the HKWSD [1], the flow rates of all showerheads were measured over an inlet pressure range of 0.5 – 2.5 bar. The spray velocity, spray spread angle, spray coverage, force exerted by the spray on the body and water distribution pattern within the spray cross-section were measured at a pressure of 1 bar.

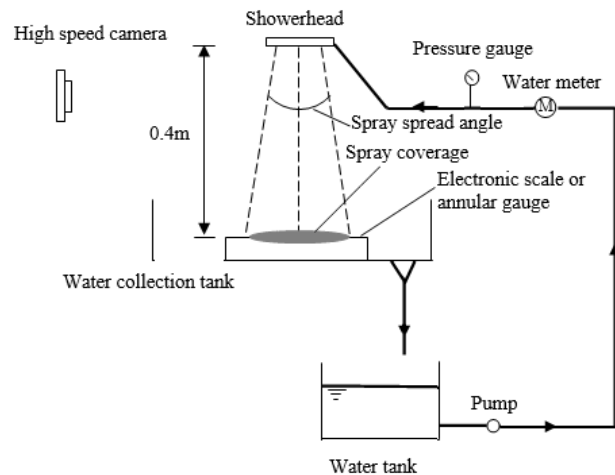


Figure 1. Schematic diagram of experimental setup.

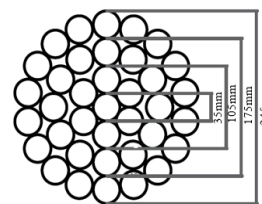


Figure 2. Annular gauge.

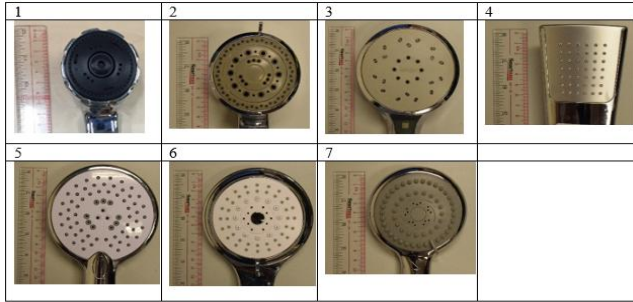


Figure 3. Showerheads sampled.

The spray velocity v_s ($m s^{-1}$) at the location $20 \pm 5mm$ underneath the showerhead can be obtained from a series of photos taken by the high speed camera. Similarly, the spray spread angle θ_s ($^\circ$) can be determined by the photos.

The force exerted by the spray on the body F_s (N) can be determined using the following formula, where M (kg) is the mass reading from the electronic scale when the showerhead is operating, m_0 (kg) is the mass of the water left on the electronic scale after showering, and g ($m s^{-2}$) is the gravitational acceleration,

$$F_s = (M - m_0)g \quad (1)$$

The shower head resistance factor K ($kPa \text{ min}^2 L^{-2}$) is expressed by the following equation, where P (kPa) is the pressure loss and Q ($L \text{ min}^{-1}$) is the water flow rate,

$$K = \frac{P}{Q^2} \quad (2)$$

III. SUBJECTIVE ASSESSMENT

A total of 30 Hong Kong residents were recruited in this study. They washed the back of their hands using the setup as shown in Fig. 1 and their feedback on the sampled showerheads was collected.

The optimum pressures of the sampled showerheads, i.e. the shower spray pressures that were most satisfying to the participants, were determined. Participants' feedback on the spray properties, including water flow rate, spray angle, spray coverage and spray force, was evaluated using a four-point semantic differential scale ('1' indicates the most influential factor and '4' indicates the least influential factor for shower comfort). The showerheads sampled were ranked by the participants based on shower comfort via a seven-point semantic differential scale ('1' indicates the most satisfactory showerhead and '7' indicates the least satisfactory showerhead).

IV. RESULTS AND DISCUSSION

Table 1 summarizes the characteristics and spray properties of the 7 shower heads sampled.

The feedback results shows that spray force (average scale 1.5) was considered by the participants as the most

influential factor determining shower comfort, followed by water flow rate (average scale 2.1).

Relationships between satisfaction ranking of the showerheads sampled and resistance factor K , spray spread angle, spray coverage, spray velocity, spray force and optimum flow rate are graphed in Fig. 4.

TABLE I. SUMMARY OF CHARACTERISTICS AND SPRAY PROPERTIES OF SHOWERHEADS SAMPLED.

Specification	Showerhead						
	1	2	3	4	5	6	7
Type	Conventional	Conventional	Conventional	Aerating	WELS*	WELS*	WELS*
Showerhead diameter (m)	0.045	0.080	0.150	0.067(U) [†] 0.057(L) [†] 0.067(H) [†]	0.115	0.107	0.085
Number of 0.5mm nozzles	0	48	0	0	59	0	52
Number of 1mm nozzles	48	0	36	42	0	52	15
Number of 2mm nozzles	9	19	8	0	9	10	0
Number of 3mm nozzles	0	10	0	0	3	0	0
Ratio of total nozzle area to showerhead faceplate area	0.0415	0.0278	0.0030	0.0079	0.0059	0.0080	0.0039
Resistance factor K ($kPa \text{ min}^2 L^{-2}$)	1.90	1.82	0.19	0.63	16.50	11.99	3.36
Spray spread angle θ_s ($^\circ$)	2	11	40	17	11	13	9
Spray coverage A_s (m^2) $\times 10^{-2}$	0.56	1.64	12.20	2.35	23.20	2.36	1.50
Spray force F_s (N)	1.05	0.75	2.43	1.67	0.34	0.39	0.62
Spray velocity v_s ($m s^{-1}$) [*]	0.66	0.78	0.72	0.43	0.18	0.27	0.24
Water pattern	Circle 1 (%)	6	23	15	8	4	1
	Circle 2 (%)	28	61	52	21	39	62
	Circle 3 (%)	36	14	24	35	42	37
	Circle 4 (%)	30	1	9	36	15	0

Note: *WELS*: Water Efficiency Labelling Scheme rated Grade 1 showerhead; 'U': upper base length of the trapezoid; 'L': lower base length of the trapezoid; 'H': height of the trapezoid.

Figure 4(a) shows that for resistance factor K , either small values (e.g. $\leq 1.82 \text{ kPa min}^2 L^{-2}$) or a large value (e.g. $16.50 \text{ kPa min}^2 L^{-2}$) would decrease the level of shower comfort. According to Figure 4(b), shower comfort level would decrease when the spray spread angle was too large (e.g. 17° , 40°). Similarly, when the spray coverage area (e.g. 0.122 m^2 , 0.232 m^2) and spray force (e.g. 1.67 N , 2.43 N) were too large, the level of shower comfort would decrease, as shown in Figures 4(c) and 4(d). The inconspicuous relationships presented in Figures 4 (e) and 4 (f) indicate that shower comfort may be independent of spray velocity and flow rate.

V. CONCLUSION

A voluntary Water Efficiency Labelling Scheme (WELS) on showers for bathing has been implemented by the Hong Kong Government since 2009 for sustainable water use. This study experimentally examined the shower spray properties of 7 sampled shower heads. The feedback from 30 participants showed that spray force and water flow rate were the two most influential factors determining shower comfort. It was found that if either the spray spread angle (e.g. 17° , 40°), spray coverage area (e.g. 0.122 m^2 , 0.232 m^2) or spray force (e.g. 1.67 N , 2.43 N) was too large, the level of shower comfort would decrease. Furthermore, shower comfort may be independent of spray velocity and flow rate.

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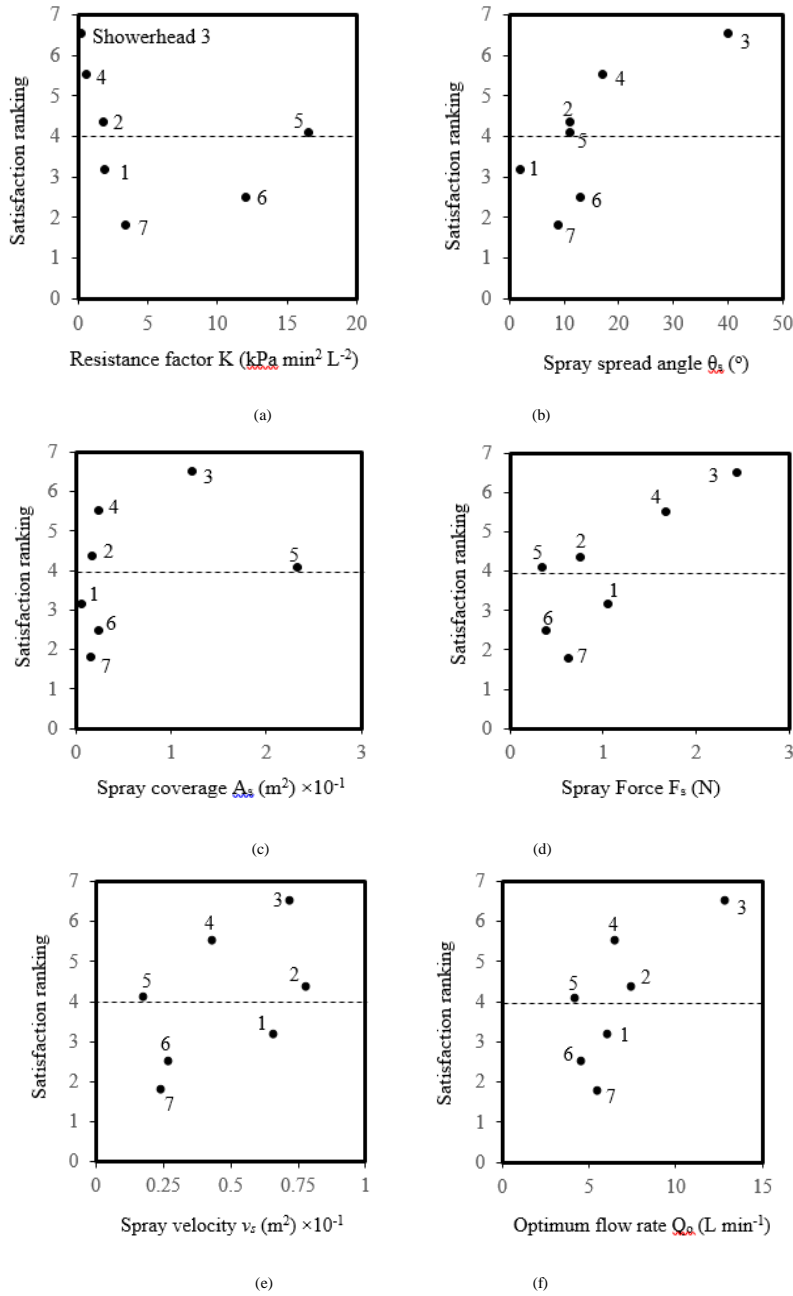


Figure 4. Relationships between satisfaction ranking, resistance factor K and spray properties.