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Article

Identifying the Physical Properties of Showers That Influence User Satisfaction to Aid in Developing Water-Saving Showers

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Abstract: This research was conducted with the goal of clarifying the required conditions of water-saving showerheads. In order to this, the research analyzes the mutual relationship between water usage flow, the level of satisfaction and the physical properties of spray of showerheads. The physical properties of spray were measured using physical properties test apparatus of standard or scheme for water-saving showerheads issued in several water-saving countries, and satisfaction evaluation data was acquired through bathing experiments. The evaluated showerheads were separated into three groups according to usage water flow and the level of satisfaction. The relationships between usage water flow, the level of satisfaction and physical properties were compared. The results identified that Spray Force and Spray Force-per-Hole were physical properties that influence usage water flow. Spray force-per-hole, water volume ratio in Spray Patterns within φ 100 and φ 150, Temperature Drop and Spray Angle were identified as physical properties that influenced the level of satisfaction. The level of satisfaction and usage water flow has a spurious correlation through the physical properties of Spray Force-per-Hole and Temperature Drop. It is possible to improve the level of satisfaction independent of amount of water usage through designs that set an appropriate value for water volume ratio and Spray Angle for Spray Patterns within φ 100 and φ 150.

Keywords: shower; satisfaction; flow rate; physical property; standard

1. Introduction

In recent years, the shortage of water resources due to climate change and the concentrating of populations in urban areas has become a serious global issue, requiring water-saving measures on a global scale. In addition, using water consumes energy required to transport and purify water, as well as for sewage treatment. This consumption of energy also results in the emission of CO_2. Several studies have reported that there are large amounts of CO_2 emissions from bathrooms, where a large amount of water is used [1,2]. As a result, the use of water-saving showers, which are expected to reduce the amount of water used daily, is thought to not only preserve water resources, but also effective in reducing the volume of CO_2 emissions. On the other hand, unless water-saving showerheads that users can satisfy of shower feeling are developed, they will not be accepted by the market, which means that unless these types of showers are developed, it will not lead to a reduction in the amount of water used. Water-saving showerheads that can be satisfied of shower feeling are required in order to promote the efficient use of water through the popularization of water-saving showerheads. However, it is note that the satisfaction of shower feeling is virtually dependent on usage water flow [3]. In other words, there is a trend where as usage water flow decreases, satisfaction also decreases, making the combination of satisfaction and water-saving difficult.

In previous studies regarding the satisfaction of water-saving showerheads, subjective evaluations of items that affect the satisfaction of shower feeling based on bathing experiments can be seen [4,5]. In other studies can also be seen that analyze the physical factors that affect satisfaction through the analysis of the relationship between satisfaction evaluations and the physical property values of the spray of showerheads [6–14]. The author has analyzed the physical properties of the water-saving showerheads and also has its results of satisfaction evaluations in Japan and Vietnam [15,16]. However, none of the study takes into account the relationship between usage water flow and the physical properties of thes pray of showerheads, making it insufficient to discuss showerheads that can increase the satisfaction without affecting usage water flow.

The purpose of this study is to propose a method of analyzing the relationship between satisfaction of shower feeling, usage water flow, and the physical properties of the spray of showerheads. This is a report on the basic data obtained in order to develop water-saving showerheads that provide a high level of satisfaction with little water consumption.

2. Methods

2.1. Selection of Showerheads

Showerheads to be used in the experiments were selected from among those marketed in Asia, Europe, and the U.S. We chose four parameters: spray hole diameters, numbers of spray hole, faceplate sizes and spray velocity as may influence on shower feeling. In order to prevent bias in four parameters, nine showerheads were selected. Since spray velocity determined by flow rate, flow rate was adjusted during the experiments by attaching valves on the showerheads. Table 1 and Figure 1 shows four parameters and flow rate of showerheads.

Table 1. Design parameters and flow rate of showerheads.

Shower No.	S1	S2	S3	S4	S5	S6	S7	S8	S9
Flow Rate (L/min)	6.5	5.5	6.9	8	4.9	5.5	7.5	13	9.5
Spray hole diameter (mm) × Number of spray holes	φ 1.15 × 42	φ 0.5 × 33 φ 1.0 × 20	φ 0.3 × 236	φ 0.8 × 47	φ 0.6 × 36	φ 0.65 × 32	φ 1.3 × 90	φ 1.3 × 90	φ 0.7 × 86
Total area of spray holes (mm^2)	44	13	17	24	10	11	119	119	33
Spray velocity (m/s)	2.98	8.20	6.89	5.64	8.02	8.63	1.81	1.05	4.78
Face plate size (mm)	Lh: 34, 30 Lw: 42	36	50	26	48	32	120	120	120

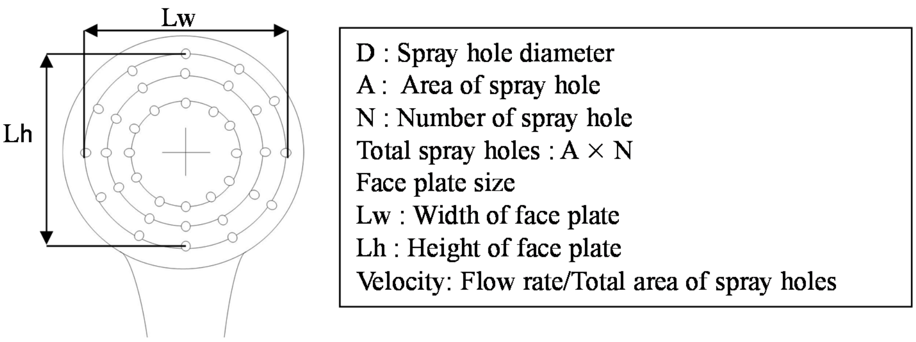

Figure 1. Design parameters of showerheads.

2.2. Physical Property Measurement Methods

2.2.1. Physical Property Test Apparatus

Methods used to determine the physical properties of the spray, focused on the physical properties test procedures of standards or schemes for water-saving showerheads issued in several water-saving countries [17–22]. These test procedures indicated the use of dedicated physical property test apparatus to determine the physical properties of spray. Determinations of the physical properties were conducted using these test apparatus. Although there were minute differences in the procedures of determining physical properties and test apparatus adopted by each country, these are broadly four types of determination items: Spray Force, Spray Pattern, Temperature Drop, and Spray Angle. This paper involved the manufacture of a test apparatus according to blueprints disclosed in AS/NZS3662:2013 [16], an Australian/New Zealand standard that encompasses all of these determination items.

2.2.2. Measurement of Physical Properties

Test apparatuses were used to observe the physical properties of spray of selected showerheads. Measurement methods were conducted in accordance with AS/NZS3662:2013 [16]. However, for water usage flow was as specified in Table 1. Additionally, with regards to the distance for measurement of physical properties, in consideration of both hand-held and wall-mounted usage conditions, the distance from the face plate of showerhead to the equipment was set to 450 mm. The following is a summary of measurement methods for each physical property.

Spray force was measured with an apparatus consisting of a water receptor plate attached to a digital force gauge. The force value when spraying water vertically down onto the receptor place was used as the measurement value for spray force.

Spray force is the total force received by the entire water receptor plate. However, consideration was given to the fact that the stimulus received from the shower is not only the total force, but also the local force received by individual streams sprayed. Thus, the researchers also calculated the value of "spray force per hole" by dividing the force received by the water receptor plate by the number of holes in the showerhead.

Spray pattern measurements were made with a water collector that had a central ring (diameter ø50) with concentric rings around it, each ø50 larger in diameter. Researchers measured the amount of water collected within each ring when spraying vertically down onto the collector. The ratio of the overall water amount collected within each ring was calculated. Figure 2 shows the results of spray pattern measurements. Differences in water amount ratios for each showerhead were particularly notable for the ratio collected within the 100 mm and 150 mm rings. Thus, the ratio of the amount of water distributed within ø100 mm and ø150 mm in comparison to the total amount of water was used as the value for spray pattern measurements.

Spray angle was calculated using spray pattern measurement values and the following formula (defined within AS/NZS3662:2013 [16]).

Temperature drop values were calculated as the difference in temperature in heated water measured at 100 mm and 750 mm below the showerhead.

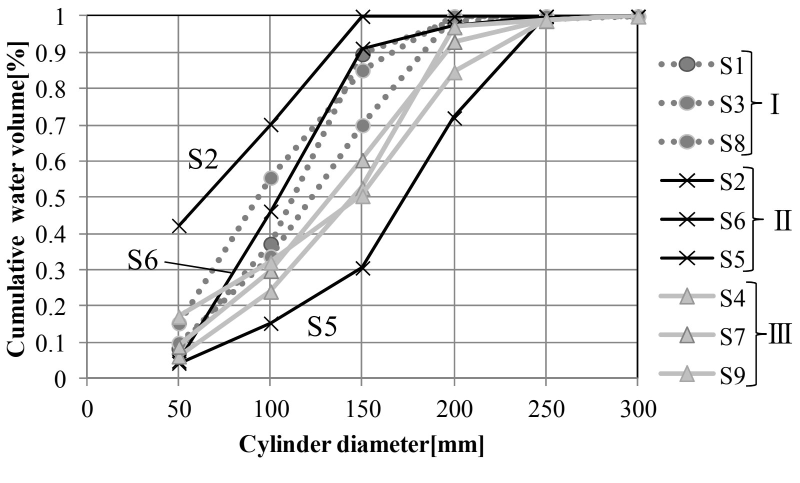

Figure 2. Results of spray pattern.

2.3. Satisfaction Evaluation

2.3.1. Evaluation Method

Bathing experiments were conducted and sensory evaluations for satisfaction of shower feeling were performed for the showerheads indicated Table 1. Although evaluations of satisfaction for showerheads may include exterior design, weight, and ease of handling, in this paper, evaluation was limited to the satisfaction of the sprayed water as the objective is to develop a showerhead spray that provides a high level of satisfaction.

Showerheads adjusted using valves to dispense the spray flow rate predetermined in Table 1 were set in advance in the bathrooms used for the experiment. Subjects held the showerheads in their hands in the bathroom, adjusted the spray so that the water sprayed their chests, and then evaluated satisfactions. Evaluations of the satisfaction of the spray were based on seven levels: very unsatisfied, unsatisfied, slightly unsatisfied, cannot say either way, slightly satisfied, satisfied, very satisfied. The evaluations were assigned grades of 1 through 7 and the results tabulated. When evaluation of one showerhead was completed, it was replaced with another showerhead, and the evaluations repeated using the same procedure.

The order of showerheads was set randomly, so as to prevent rating contaminations. Moreover, before testing, subjects were made to feel the spray from sample showerheads with their hands and create axes of evaluation. Testing was carried out after familiarizing the evaluators beforehand with the details of the testing, the meaning of evaluation terms, and the details of the evaluation.

2.3.2. Experiment Location, Experiment Period, Subjects

The experiments were conducted in Kitakyushu-shi in April 2013. There were 12 subjects (healthy Japanese nationals between the ages of 25 and 50 consisting of 6 males and 6 females).

3. Results and Discussion

3.1. Grouping Showerheads

Figure 3 indicates the relationship between the satisfaction levels and usage water flow. The correlation coefficient between the two was 0.526. This was shown to be significant ($p < 0.01$) through uncorrelated tests. It is believed that satisfaction levels increased as the usage water flow increased.

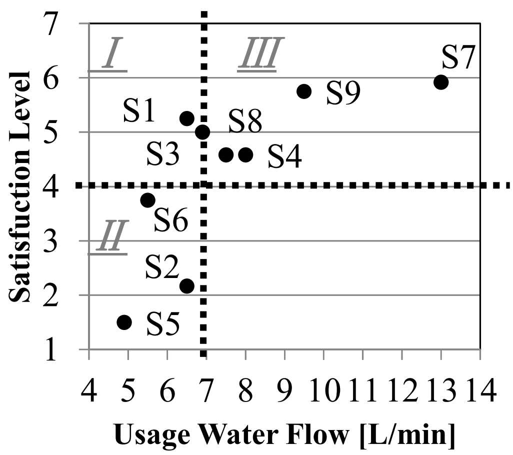

Figure 3. Relationship between usage water flow and satisfaction grade.

The aim of this research is to develop showerheads that use a small amount of water (*i.e.*, that are water-saving) and a high level of user satisfaction. Showerheads were divided into groups in order to analyze the differences between water-saving showerheads and standard flow amount showerheads, as well as the differences between high-satisfaction and low-satisfaction showerheads, from a viewpoint of physical properties. Four groups were created from among the combination of usage water flow and satisfaction levels. When creating these four groups, the threshold for water flow for water-saving showerheads and standard showerheads were set based on the labeling scheme for existing water-saving showerhead standards [21,22]. Showerheads with a usage water flow of 2 gpm (approx. 7.61 L/min.) or less are defined as high efficiency (water-saving) showerheads under ASME A112.18.1-2012/CSA B125.1-12. [21]. As showerheads with a usage water flow of 7.5 L/min. were rated with the highest water conservation rates under AS/NZS6400:2005 [22], this paper uses 7.5 L/min. as the threshold. In addition, as a seven-level method was used for sensory evaluations to measure satisfaction, the threshold was set at 4 (cannot say either way) and dividing the levels into a high satisfaction group and a low satisfaction group. Through this, the showerheads were divided into Group I—water-saving-high satisfaction group (three showerheads), Group II—water-saving-low satisfaction group (three showerheads), Group III—standard flow-high satisfaction group (three showerheads), and Group IV—standard flow-low satisfaction group (zero showerheads). As there were no showerheads that fit into Group IV, in actuality the showerheads were divided into three groups.

In order to analyze the difference in physical properties (Spray Force, Spray force per hole, Spray Pattern, Temperature Drop, Spray Angle) between these three groups, the measurement values for the showerheads in each group were averaged and a one-way variance analysis and multiple comparison (Tukey b method) was conducted. The results are shown in Table 2.

Table 2. Result of ANOVA and multiple comparisons (satisfaction).

Physical Properties		**I**	**II**	**III**	***F*-Value**	**Multiple Comparison**
		Low flow	**Low flow**	**Normal flow**	**** $p < 0.001$**	
		High satisfaction	**Low satisfaction**	**High satisfaction**	*** $p < 0.005$**	
Spray Force [N]	AVERAGE	1.0	1.0	1.2	38.472 *	III > I, II
	SD	0.2	0.1	0.1		
Spray Force (per-hole) [N]	AVERAGE	0.012	0.030	0.018	150.187 **	II > III > I
	SD	0.006	0.002	0.004		
Spray Pattern φ 100 [%]	AVERAGE	42	44	29	95.325 **	I, II > III
	SD	10	23	4		
Spray Pattern φ 150 [%]	AVERAGE	82	74	58	451.451 **	I, II > III
	SD	9	31	8		
Temperature Drop [°C]	AVERAGE	1.6	2.3	1.5	17.500 **	II > I, III
	SD	0.6	0.8	0.3		
Spray Angle [deg]	AVERAGE	4	6	5	8.687 **	II > I, III
	SD	1	2	2		

3.2. Physical Properties Thought to Affect Water Usage Flow

The researchers hypothesized about which physical properties affected water usage flow by comparing the physical property values of the two water-saving groups (groups I and II) and the standard flow group (group III). Significant differences were observed in spray force, spray force per hole, and spray pattern. It is generally known that spray force is proportional to spray velocity and water flow rate, so the researchers hypothesized that spray force had an effect on the water usage flow. Similarly, the researchers also considered that since a greater amount of water used equals a greater amount of water per hole, spray force per hole also possibly affects the water usage flow. On the other hand, spray pattern can be controlled to a certain degree by the angle of spray holes, making it possible to design spray pattern independently of water usage flow. Due to this, it is unlikely that there is a relationship between spray pattern and water usage flow. This led the researchers to believe that spray pattern does not affect water usage flow. Thus, the researchers hypothesized that the physical properties that affect water usage flow are spray force and spray force per hole.

3.3. Physical Properties Thought to Impact Satisfaction

The researchers hypothesized about which physical properties affected satisfaction by comparing the physical property values of the high-satisfaction group (group I) and the low-satisfaction group (group II). Significant differences were observed in spray force per hole, temperature drop, and spray angle. Smaller spray force per hole values correlated to higher evaluations for satisfaction. The researchers hypothesized that it was not spray force, but rather spray force per hole that affected satisfaction. This was thought to be because local force—the force from an individual stream—had a direct effect on stimulus to the skin. For temperature drop, smaller values correlated to higher evaluations for satisfaction. Water spray with a small temperature drop equates to warmer water spraying the body. Thus, the researchers believed that the warmth of water affected satisfaction. For spray angle, larger values correlated to lower evaluations for satisfaction. The researchers believed this was because the angle, which affects stimulus to the skin, affected satisfaction.

No significant differences were observed for the spray patterns. However, looking at the water distribution from showerheads in the low-satisfaction group (group II), Figure 3 shows a greater tendency of division into two types—showerheads with concentrated spray pattern (S2, S6) and showerheads with scattered spray pattern—when compared to the high-satisfaction group (group I). Due to this, the researchers deemed it possible that an over-concentration or over-scattering spray pattern negatively affected satisfaction. However, it will be necessary to further consider the issue with an increased number of showerheads in the future, the researchers hypothesized that spray pattern does affect satisfaction. Thus, from the above results, it was hypothesized that the physical properties that affect satisfaction are spray force per hole, temperature drop, spray angle, and spray pattern.

4. Conclusions

This study proposes methods to analyze the relationship between user satisfaction and usage water flow, and the physical properties of spray of showerhead, as well as discuss their mutual relationships. The physical properties of spray were measured using physical properties test apparatus of standard for water-saving showerheads issued in several water-saving countries and satisfaction evaluation data was acquired through bathing experiments. The evaluated showerheads were separated into three groups according to usage water flow and satisfaction, and the relationships between usage water flow, satisfaction, and physical properties were compared. The results identified that Spray Force and Spray Force-per-Hole were physical properties that influence usage water flow. Spray Force-per-Hole, water volume ratio in Spray Patterns within φ100 and φ150, Temperature Drop, and Spray Angle were identified as physical properties that influenced satisfaction. It is thought that satisfaction and usage water flow have a spurious correlation relationship through the physical properties of Spray Force-per-Hole and Temperature Drop, and through designs that set an appropriate values for water distribution and Spray Angle for Spray Patterns within φ100 and φ150, it is possible to improve satisfaction independent of usage water flow.

This paper is a result of satisfaction analyses for Japanese people. It is predicted that satisfaction will differ depending on country. Through the popularization of water-saving showerheads, and in order to contribute to the reduction of water usage volumes on a global scale, it is believed that requirements for water-saving showerheads settings can be considered by not just analyzing satisfaction for only one country, but comparing analysis results from multiple countries. An analysis satisfaction in other countries and a comparison of those results with the results presented here is something that is expected to be conducted in the future.

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Author Contributions

Minami Okamoto designed and performed the experiment, analyzed and interpreted the data and wrote the draft of the manuscript. Minoru Sato participated in study designed and interpreted the results. Yoshihiko Shodai analyzed and interpreted the data. Masayoshi Kamijo analyzed, interpreted the data and helped to draft the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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