

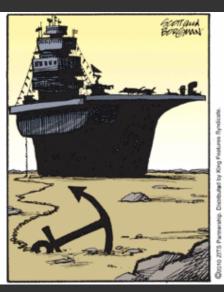




Showerheads experience: statistical analysis of the individual behaviour of the users





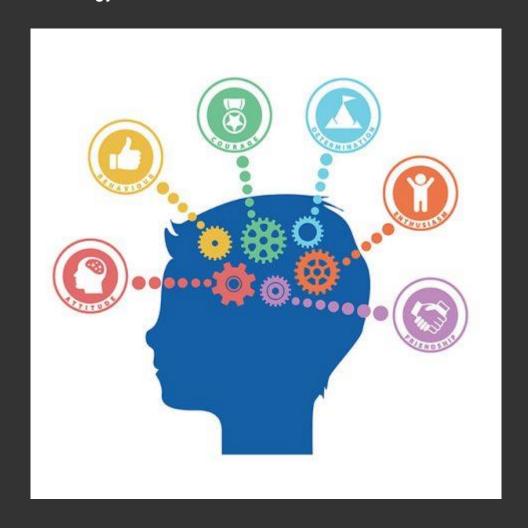




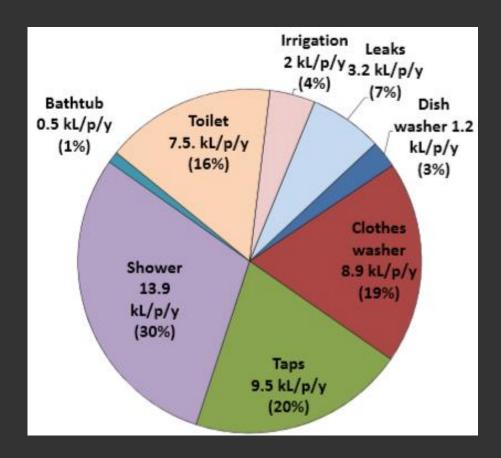
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Framework

According to several studies, user's decisions, behaviours and habits have a major effect on resource use be it energy or water.



Beal et al. (2011) found that shower use contributes an average of around 30% of the total household consumption in Australia and the UK.



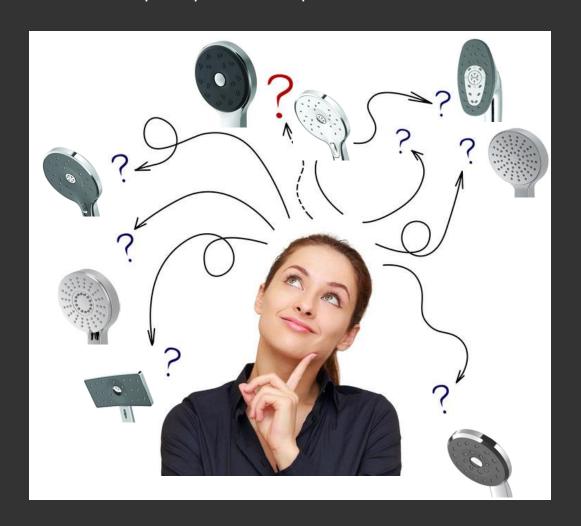
Framework

This makes engineered / higher efficiency water using devices such as water efficient showerheads an important strategy for delivering effective reductions in water consumption.



Aim of the study

This paper sits within a wider body of work which aims to understand the technical efficiency of showerheads as well as the extent to which it is efficient-in-use based on other qualitative metrics such as the user, perceptual and experiential factors.



Aim of the study

Statistical study to investigate the correlations and differences between water use factors such as duration and volume (discharge), against user and water efficient showerhead types.

This paper also provides insights into how quantitative methods and analysis can be beneficial for understanding the qualitative implications of water efficiency interventions; such as the tendency for users to make behavioural adjustments according to the perceived performance of water efficient products.

Methodology

Analysis of data from 12 users, in 10 showerheads, for 10 weeks. Further details found in Adeyeye et al (2017).

Statistical tests were applied to evaluate:

- i) If there are differences in the shower event durations and amounts of water used as a result of using the different showerheads.
- ii) The possible explanations underlying the distinct behaviours from the various users when using the same showerhead.

The methodology comprises the following steps:

- i) Data preparation, including the codification of the non-numerical information in the dataset.
- ii) Preliminary data analysis and assumption checking.
- iii) Testing the difference between the shower events durations and volumes changes.

Parametric or non-parametric tests can be carried out in order to compare if the mean values between two distributions are statistically distinct.

Parametric tests are considered more powerful than non-parametric, but require the data to be normally distributed across each group and to be without outliers.

The Shapiro-Wilk and Kolmogorov-Smirnov tests reveal that the duration and the water consumption of the shower event are not normally distributed for several users.

Example of user 1:

Variable	Showerhead	Kolm	ogorov-Smi	rnov ^a	Shapiro-Wilk			
Variable	Snowerneau	Statistic	df	Sig.	Statistic	df	Sig.	
	2	0.360	7	0.007	0.664	7	0.001	
	3	0.484	12	0.000	0.465	12	0.000	
	4	0.293	6	0.117	0.915	6	0.473	
Duration	5	0.421	7	0.000	0.646	7	0.001	
(min)	7	0.414	7	0.001	0.630	7	0.001	
	8	0.285	6	0.140	0.711	6	0.008	
	9	0.504	7	0.000	0.453	7	0.000	
	10	0.367	5	0.026	0.684	5	0.006	
	2	0.360	7	0.007	0.664	7	0.001	
	3	0.484	12	0.000	0.465	12	0.000	
Motor	4	0.293	6	0.117	0.915	6	0.473	
Water	5	0.421	7	0.000	0.646	7	0.001	
consumption	7	0.414	7	0.001	0.630	7	0.001	
(I)	8	0.285	6	0.140	0.711	6	0.008	
	9	0.504	7	0.000	0.453	7	0.000	
	10	0.367	5	0.026	0.684	5	0.006	

^{*.} This is a lower bound of the true significance.

a. Lilliefors Significance Correction

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Variable	OSEI	Statistic	df	Sig.	Statistic	df	Sig.	
	2	0.367	5	0.026	0.684	5	0.006	
	4	0.268	6	,200	0.862	6	0.197	
	5	0.322	8	0.014	0.753	8	0.009	
Duration	6	0.251	8	0.148	0.924	8	0.459	
Duration (min)	8	0.492	6	0.000	0.496	6	0.000	
(111111)	9	0.228	7	,200	0.934	7	0.582	
	10	0.192	8	,200	0.926	8	0.477	
	11	0.175	3		1.000	3	1.000	
	12	0.233	5	,200	0.884	5	0.329	
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a. Lilliefors Significance Correction

As such, only non-parametric tests were used in the analysis:

- the Mann-Whitney U test, for comparing two groups;
- the Kruskal-Wallis test, for comparing three or more groups.

I - Analysis of each user separately

User profiles:

Gender	Λαe	Highest	Height	Weight	Income	Ethnicity	Pelationship	Peligious	Employment
Geriuei	Aye	_	neigni	vveignt	ancome	Ethilicity	Kelationship	beliefs	Employment
Female	35 - 44	•	156-160cm (to 5ft	51-55ka	£40.000 -	Polish Catholic	Married or domestic	All	Employed (full-
			,						time)
Female	25 - 34	Bachelor		51-55ka	£20.000 -	White	Married or domestic	No religion	Employed (full-
		Degree	1inches)		£29,1004		partnership	3	time)
Female	35 - 44		171-175cm (to 5ft 9	71-75kg		White	Married or domestic	No religion	Employed (full-
		Doctorate	inches)	J	more		partnership	J	time)
Female	35 - 44	PG degree,	151-155cm (to 5ft	56-60kg	£20,000 -	White	Single, never married	No religion	Employed (full-
		Doctorate	1inches)		£29,1003			ŭ	time)
Female	45 - 54	PG degree,	156-160cm (to 5ft	56-60kg	£20,000 -	White	Divorced	No religion	Employed (part
		Doctorate	3inches)		£29,1000				-time)
Female	25 - 34	PG degree,	151-155cm (to 5ft	90Kg +	£30,000 -	White	Married or domestic	No religion	Employed and
		Doctorate	1inches)	_	£39,999		partnership	•	studying (part -
									time)
Male	35 - 44	PG degree,	171-175cm (to 5ft 9	76-80kg	£60,000 or	Mixed/Multiple	Married or domestic	Christian	Employed (full-
		Doctorate	inches)		more	ethnic groups	partnership		time)
Male	25 - 34	PG degree,	180cm and more	76-80kg	£20,000 -	White	Single, never married	Christian	Employed (full-
		Doctorate	(6ft +)		£29,999				time)
Male	25 - 34	Currently	166-170cm (to	76-80kg	£20,000 -	White	Married or domestic	No religion	Student
		studying	5ft7inches)		£29,1001		partnership		
Male	45 - 54	Professional	166-170cm (to	71-75kg	£60,000 or	White	Married or domestic	No religion	Employed (full-
		qualification	5ft7inches)		more		partnership		time)
Male	35 - 44	Professional	`	66-70kg	£60,000 or		Married or domestic	No religion	Employed (full-
		qualification	inches)		more	British	partnership		time)
Male	35 - 44	Further	176-180cm (to 5ft	66-70kg	£50,000 -	White	Married or domestic	No religion	Employed (full-
		Education/	11inches)		£59,999		partnership		time)
		College							
	Female Female Female Male Male Male Male Male Male	Female 35 - 44 Female 25 - 34 Female 35 - 44 Female 35 - 44 Female 45 - 54 Female 25 - 34 Male 35 - 44 Male 25 - 34 Male 25 - 34 Male 35 - 44 Male 35 - 44 Male 35 - 44	Female 35 - 44 PG degree, Doctorate Female 25 - 34 Bachelor Degree Female 35 - 44 PG degree, Doctorate Female 35 - 44 PG degree, Doctorate Female 45 - 54 PG degree, Doctorate Female 25 - 34 PG degree, Doctorate Male 35 - 44 PG degree, Doctorate Male 25 - 34 PG degree, Doctorate Male 25 - 34 Currently studying Male 45 - 54 Professional qualification Male 35 - 44 Professional qualification Male 35 - 44 Further Education/	qualification Female 35 - 44 PG degree, Doctorate 156-160cm (to 5ft 3inches) Female 25 - 34 Bachelor 151-155cm (to 5ft 9inches) Female 35 - 44 PG degree, Doctorate 171-175cm (to 5ft 9inches) Female 35 - 44 PG degree, Doctorate 151-155cm (to 5ft 9inches) Female 45 - 54 PG degree, Doctorate 156-160cm (to 5ft 9inches) Female 25 - 34 PG degree, Doctorate 151-155cm (to 5ft 9inches) Male 35 - 44 PG degree, Doctorate 171-175cm (to 5ft 9inches) Male 25 - 34 PG degree, Doctorate 180cm and more (6ft +) Male 25 - 34 Currently Studying 166-170cm (to 5ft7inches) Male 45 - 54 Professional qualification 166-170cm (to 5ft7inches) Male 35 - 44 Professional qualification 171-175cm (to 5ft 9inches) Male 35 - 44 Further Education/ 176-180cm (to 5ft 11inches)	qualification Female 35 - 44 PG degree, Joctorate 156-160cm (to 5ft 51-55kg 3inches) Female 25 - 34 Bachelor Degree 151-155cm (to 5ft 51-55kg 1inches) Female 35 - 44 PG degree, Doctorate 171-175cm (to 5ft 9 inches) 71-75kg 15-55kg 15-5	Pemale 35 - 44 PG degree, 156-160cm (to 5ft 51-55kg £40,000 - £49,1003 Emale 25 - 34 Bachelor 151-155cm (to 5ft 51-55kg £20,000 - £29,1004 Emale 35 - 44 PG degree, 171-175cm (to 5ft 56-60kg £20,000 - £29,1004 Emale 35 - 44 PG degree, 151-155cm (to 5ft 56-60kg £20,000 - £29,1003 Emale 45 - 54 PG degree, 156-160cm (to 5ft 56-60kg £20,000 - £29,1003 Emale 25 - 34 PG degree, 156-160cm (to 5ft 56-60kg £20,000 - £29,1000 Emale 25 - 34 PG degree, 151-155cm (to 5ft 56-60kg £20,000 - £39,999 Emale 25 - 34 PG degree, 151-155cm (to 5ft 56-60kg £30,000 - £39,999 Emale 25 - 34 PG degree, 171-175cm (to 5ft 9 76-80kg £60,000 or more Emale 25 - 34 PG degree, 180cm and more 6ft 166-170cm (to 5ft 56-60kg £20,000 - £29,999 Emale 25 - 34 Currently 166-170cm (to 5ft 56-80kg £20,000 - £29,1001 Emale 25 - 34 Professional 166-170cm (to 5ft 71-75kg £60,000 or more Emale 35 - 44 Professional 171-175cm (to 5ft 9 66-70kg £60,000 or more Emale 35 - 44 Professional 171-175cm (to 5ft 9 66-70kg £60,000 or more Education 11inches Emale 250,000 £59,999 Emale 250,000 £50,000 £59,999 Emale 250,000 £50,000 £50,000 £59,999 Emale 250,000 £50	Female 35 - 44 PG degree 156-160cm (to 5ft 51-55kg £40,000 - £49,1003 & 2 Jewish	Female 35 - 44 PG degree, 156-160cm (to 5ft 51-55kg £40,000 Polish Catholic partnership partnership partnership Pemale 25 - 34 PG degree, 171-175cm (to 5ft 51-55kg £20,000 E29,1004 partnership partnership partnership partnership partnership partnership Pemale 35 - 44 PG degree, 151-155cm (to 5ft 51-55kg £20,000 degree 171-175cm (to 5ft 51-55kg £20,000 degree 151-155cm (to 5ft 51-60kg £20,000 degree 156-160cm (to 5ft 51-60kg £20,000 degree 156-160cm (to 5ft 51-60kg £20,000 degree 156-160cm (to 5ft 51-60kg £20,000 degree 151-155cm (to 5ft 51-155cm £30,000 degree 151-155cm (to 5ft 51-60kg £20,000 degree 151-155cm degree 151-155cm (to 5ft 51-60kg £20,000 degree 151-155cm degree 151-155cm	Female 35 - 44 PG degree 156-160cm (to 5ft 51-55kg £40,000 E29,1004 E29,1004 E29,1005 E29,1004 E29,1005 E29,1006 E2

Kruskal-Wallis test reveals that for the different showerheads:

- -the duration and water consumption are statistically distinct for users 1, 2, 5, 8 and 10;
- for users 4, 6, 7, 9 and 12 the duration is not statistically distinct but the water consumption is;
- no statistically significant difference was found either for duration or water consumption for users 3 and 11.

User	Variable	Duration (min)	Water consumption (I)
	Total N	57	57
1	Test Statistic	25,342a	33,561a
	Degree Of Freedom	7	7
	Asymptotic Sig.(2-sided test)	0.001	0.000
	Total N	47	47
2	Test Statistic	19,303ª	43,429a
-	Degree Of Freedom	7	7
	Asymptotic Sig.(2-sided test)	0.007	0.000
	Total N	12	12
3	Test Statistic	4,780 ^{a,b}	5,313 ^{a,b}
ľ	Degree Of Freedom	2	2
	Asymptotic Sig.(2-sided test)	0.092	0.070
	Total N	39	39
4	Test Statistic	11,354 ^{a,b}	25,457ª
	Degree Of Freedom	6	6
	Asymptotic Sig.(2-sided test)	0.078	0.000
	Total N	61	61
5	Test Statistic	29,373a 8	42,383ª
	Degree Of Freedom	0.000	0.000
	Asymptotic Sig.(2-sided test) Total N	67	67
	Test Statistic	6,190 ^{a,b}	23,105ª
6	Degree Of Freedom	0,190-	23,103
	Asymptotic Sig. (2-sided test)	0.626	0.003
	Total N	47	47
	Test Statistic	5.865 ^{a,b}	20.133ª
7	Degree Of Freedom	5	20,133
	Asymptotic Sig.(2-sided test)	0.320	0.001
	Total N	77	77
_	Test Statistic	25,939ª	43.775ª
8	Degree Of Freedom	8	8
	Asymptotic Sig.(2-sided test)	0.001	0.000
	Total N	66	66
_	Test Statistic	8,460 ^{a,b}	24,729a
9	Degree Of Freedom	9	9
	Asymptotic Sig.(2-sided test)	0.489	0.003
	TotalN	67	67
10	Test Statistic	15,754ª	34,394
10	Degree Of Freedom	7	7
	Asymptotic Sig.(2-sided test)	0.027	0.000
11	Total N	36	36
	Test Statistic	12,177 ^{a,b}	13,817 ^{a,b}
	Degree Of Freedom	7	7
	Asymptotic Sig.(2-sided test)	0.095	0.055
	Total N	45	45
12	Test Statistic	11,416 ^{a,b}	26,542ª
14	Degree Of Freedom	8	8
	Asymptotic Sig.(2-sided test)	0.179	0.001
a The test static	stic is adjusted for ties		

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Discussion:

Duration

- the majority of the users do not change their showering pattern, enabling the lower discharge showerheads to produce a statistically significant reduction in water consumption;
- these results are indications that these water efficient devices provide most users an equivalent level of comfort so that they do not change their showering habits.

Water consumption

- even if some users change their showering pattern, a statistically significant reduction in water consumption is still observed but for 2 users;
- these results are indications that even if these water efficient devices force the users to change their showering habits, the discharge reduction still compensates this change in behaviour, contributing to save water.

II - Analysis of each showerhead separately

showerhead characteristics:

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 (mm)	90	157	106	100	100	106	135	67	65	135
Width (mm)	90	82	106	100	100	106	135	182	120	135
Height incl. handle (mm)	215	270	239	230	230	239	246	227	219	246
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
Number of functions	1	4	1	3	1	1	2	2	1	2
Image						6		•		

Mann-Whitney U test reveals that:

- the duration and water consumption for males and females are statistically distinct for showerheads 1, 4, 6, 9 and 10.
- no statistically distinct water consumption was found for showerheads 2, 3, 5, 7 and 8.

Showerhead	Variable	Duration (min)	Water consumption (I)
4	Total N	56	56
	Mann-Whitney U	142.000	142.000
	Test Statistic	142.000	142.000
1	Standard Error	56.811	56.811
	Standardized Test Statistic	-3.520	-3.520
	Asymptotic Sig.(2-sided test)	0.000	0.000
	Total N	78	78
	Mann-Whitney U	792.500	792.500
2	Test Statistic	792.500	792.500
2	Standard Error	99.576	99.576
	Standardized Test Statistic	0.326	0.326
	Asymptotic Sig.(2-sided test)	0.744	0.744
	Total N	55	55
	Mann-Whitney U	297.000	297.000
3	Test Statistic	297.000	297.000
3	Standard Error	58.693	58.693
	Standardized Test Statistic	-1.363	-1.363
	Asymptotic Sig.(2-sided test)	0.173	0.173
	Total N	63	63
	Mann-Whitney U	207.000	207.000
4	Test Statistic	207.000	207.000
4	Standard Error	72.226	72.226
	Standardized Test Statistic	-3.987	-3.987
	Asymptotic Sig.(2-sided test)	0.000	0.000
	Total N	71	71
	Mann-Whitney U	476.000	476.000
5	Test Statistic	476.000	476.000
3	Standard Error	83.846	83.846
	Standardized Test Statistic	-1.407	-1.407
	Asymptotic Sig.(2-sided test)	0.159	0.159

Showerhead	Variable	Duration (min)	Water consumption (I)
	Total N	49	49
	Mann-Whitney U	143.500	143.500
	Wilcoxon W	468.500	468.500
6	Test Statistic	143.500	143.500
	Standard Error	49.488	49.488
	Standardized Test Statistic	-3.162	-3.162
	Asymptotic Sig.(2-sided test)	0.002	0.002
	Total N	48	48
	Mann-Whitney U	223.500	217.500
7	Test Statistic	223.500	217.500
′	Standard Error	47.919	48.101
	Standardized Test Statistic	-1.304	-1.424
	Asymptotic Sig.(2-sided test)	0.192	0.154
	Total N	72	72
	Mann-Whitney U	577.500	577.500
8	Test Statistic	577.500	577.500
0	Standard Error	88.102	88.102
	Standardized Test Statistic	-0.778	-0.778
	Asymptotic Sig.(2-sided test)	0.437	0.437
	Total N	57	57
	Mann-Whitney U	52.500	52.500
9	Test Statistic	52.500	52.500
3	Standard Error	60.777	60.777
	Standardized Test Statistic	-5.570	-5.570
	Asymptotic Sig.(2-sided test)	0.000	0.000
	Total N	72	72
10	Mann-Whitney U	379.000	379.000
	Test Statistic	379.000	379.000
	Standard Error	83.128	83.128
	Standardized Test Statistic	-2.370	-2.370
	Asymptotic Sig.(2-sided test)	0.018	0.018

Discussion:

Duration & Water consumption

- the difference found between water consumption for males and females in some showerheads might indicate that these water efficient devices do not provide to female users an equivalent level of comfort as to male users, probably causing a change on their showering habits.

Conclusion

This paper uses statistical methods to investigate the individual behaviour of the users when using different showerheads.

Water savings are possible using water efficient showerheads for the large majority of users, since the eventual duration adjustment from behavioural change may affect but do not hinder the potential savings completely.

There seems to be distinct behaviour from males and females to the different showerheads, particularly when the discharge is high or low.

Scientific Research and Technological Development Project

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