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Quantifying the Potential of Voluntary Energy Efficiency Measures: The Case of Flow Restrictors

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Abstract: Aside from regulatory measures and price-based instruments, many governments use voluntary energy efficiency measures as a means to reduce greenhouse gas emissions, both in the commercial and residential sector. In the domain of water heating -- the second largest domestic energy end use -- flow restrictors in showers are being contemplated as a dual-purpose policy instrument, to conserve energy and to tackle water scarcity. While the implementation of regulatory measures often faces fierce resistance by consumers and industry, also in the context of voluntary measures it is still unclear whether individuals do not simply compensate for low flow rates by taking longer showers (rebound effects). ICT can help to create more realistic estimates of the savings potential of these instruments. Based on a dataset of 5,610 individual showers, we assess the real-world influence of the flow rate on energy and water use and compare these numbers to the 45% reduction anticipated by engineering calculations. We find that users of low-flow shower heads do, indeed, take longer showers; nevertheless, they consume 38% (1.0 kWh) less energy per shower compared to the baseline level of 2.6 kWh. While more research on acceptance issues and potential biases is needed to assess the savings potential in case of mandatory measures, the findings have first important implications for policy makers and industry.

Keywords: Regulation, voluntary efficiency standards, rebound effect, energy consumption, water heating, flowrate, flow restrictors, energy efficiency

1 Motivation and Context

Today's life highly depends on energy of which demand is mostly covered by fossil fuels. The environmental (e.g., carbon emissions) and geopolitical problems (e.g., energy security) related with that are well known. The international community therefore strives for effective energy efficiency measures. Private households in Switzerland, UK and the US account for around a third of carbon emissions associated with energy production [Sc14, BN08, GS08]. Although smart meters can provide a much better data basis to

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determine effective efficiency measures, surprisingly little field data is still available in many domains.

In general, there are two different approaches to promote energy efficiency: technological upgrades (e.g., replacing light bulbs by energy-saving bulbs), further referred to as *efficiency* actions on the one hand; and *curtailment* actions on the other hand, which focus on prompting human behavior toward an energy reduction (e.g., turning off lights when leaving a room) [GS08]. The authors state that "efficiency-improving actions generally save more energy than curtailing use of intrinsically inefficient equipment" (p. 22).

In the residential sector, a promising candidate for energy efficiency measures is water heating: With 18% of energy demand of private US households and 13% for European households, respectively [Re13, De13], it is the second largest domestic energy use after space heating. In water-stressed regions, reductions in hot water consumption even serve the dual purpose of energy conservation and tackling water scarcity.

In many countries and several U.S. states, legislators have therefore enacted or are currently considering bills requiring plumbing fixtures sold to meet certain water efficiency standards [Wa15]. Given the large share of hot water that is consumed in the shower, shower heads with an integrated flow restrictor have moved into the focus of policy makers as a technical solution to simultaneously meet energy efficiency goals and address water scarcity. Some regions impose stringent regulatory measures, while others opt for voluntary industry standards (eco-labeling schemes). In Europe, shower heads that curb the flowrate to a maximum of 6 liters per minute are entitled to the carry the label "eco" or "energy-saving" [Th15]. Yet in many regions, low-flow showerheads face severe resistance by consumers and industry [Ba09, Po10] as a paternalistic intrusion in the individual's scope of action. Economists also criticize that that kind of imposed behavior change does not take into account individual differences in the costs of changing behavior [see, e.g., Fr92]. Yet, it is still unclear whether an installation of flow restrictors results in the desired resource savings.

One of the key arguments that is often brought forward against flow restrictors is that individuals will simply compensate by taking longer showers. Different reasons are put forward for that argument: First, from a practical point of view, certain actions like rinsing one's hair simply require a certain quantity of water; a reduced flow rate thus merely results in a longer shower duration. Second, reduced flow rates tend to reduce perceived comfort; individuals might compensate for that by extending the duration of their shower. Third, from an economics point of view, flow restrictors may generate rebound effects, as has been shown for the purchase of efficient vehicles ("Buy a more fuel-efficient car, drive more. " – [GRW16, p. 68]): as the cost per minute of showering decreases, the individual may respond by taking longer showers.

Therefore, it is important to quantify the actual energy (and water) saving potential of flow restrictors. Aside from acceptance issues, the key question is what fraction of the savings anticipated by engineering calculations (i.e., reduction in flow rate translates entirely into energy savings) is actually realized in practice and what fraction is compensated by increases in shower duration. The ubiquity of ICT and the “seamless integration of the physical and digital worlds through networked sensors, actuators, embedded hardware” [De15, p.4] increasingly makes it possible to collect this kind of data for better-informed policy decisions.

This paper aims to shed light on these questions based on a large set of individual shower data comprising 5,610 individual showers. The dataset was collected by 636 smart shower meters in Swiss households. We analyze the data regarding the interplay of flowrate, shower time and energy consumption. Based on this, we run a simulation with a fictive flowrate restriction. After presenting methodology and results, we discuss implications for politics and industry. In this context, the portability of the results from a voluntary setting into a regulatory setting is discussed in detail. Please note that other articles based on the same data set have been published so far; parts of the context, methodology and limitations sections therefore correspond to our previous work [Ti16].

2 Study Design, Data Collection and Sample

We conducted a large-scale field study in cooperation with a local utility that gave the study device (smart shower meter) as a gift (unconditional of participating in our study) to 5000 customers. Among these, 1- and 2-person households who agreed to answer two surveys and to make their shower data available to the researchers were eligible for the energy efficiency study with a limitation of 700 participating households (due to budget and logistics reasons). In the following 2-months of winter 2012/ 2013, study participants installed the smart meter in their showers. The technology tracks all water extractions with the help of a flowrate and a temperature sensor and stores the data on the internal memory. At the end of the study, participants sent in their devices in order to have them manually read out before they were returned to the participants for good. The course of study was split into two periods: the baseline period, which tracked shower behavior and during which the devices displayed only water temperature (first ten tracked showers on the device) and the intervention period, during which participants were provided with real-time information on their resource use (from shower eleven on). This paper focuses on the baseline data, which are not affected by the subsequent manipulations in the intervention period. Our goal is to investigate the interplay of flowrate, shower time, and energy consumption in the blindly measured baseline data[4].

Overall, we collected shower data from 636 Swiss households located in the region of Zurich. In total, we analyze shower behavior of 975 individuals, 50% of which are female. The mean age of study participants is 46.3 years, with a standard derivation of 15.6 years. The smart meter dataset comprises shower data of a total of more than 46’000 showers.

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[4] We will not further discuss capabilities of the technology and the study period intervention. The energy savings – the main purpose of the study – are not subject of this paper but are discussed in other articles (blinded for review).

As mentioned in the previous section, baseline showers only (up to ten showers) are considered in this paper. Water extractions of below 4.5 liters were not considered a shower. With this we ensure that water extractions for cleaning or watering the plants will not distort average consumption values. Data points with more than 200 liters per shower or an average temperature of above 47°C were excluded as extreme outliers or measurement errors (85 showers). We discarded the first data point of every dataset, as its temperature and volume distribution strongly deviated from all other showers recorded. We assume that in many cases, the first water extraction was not an actual shower; instead, participants who had just completed the installation turned on the water for several seconds to see if the device worked and what information it displays. This leaves us with up to nine data point per household for our data analysis (N = 5,610) with the variables flowrate in liters per minute (M = 11.0, SD = 2.52), temperature in degree C (M = 36.0, SD = 4.09), shower time in minutes (M = 4.04, SD = 3.04) and water volume in liters (M = 43.9, SD = 33.7). Energy consumption is calculated using the standard engineering formula for heat energy ($E = m * cp * \Delta T / \eta$, with heat energy E, mass of water m, heat capacity cp, ΔT the difference between the measured water temperature and cold water temperature, and η the coefficient of energy efficiency. The latter depends on the type and age of the heating system. A study for the Swiss Office of Energy [De13] gives a detailed breakdown of residential water heating systems for Switzerland. The vast majority use fossil fuels (40% oil, 25% electric resistance heaters, 21% gas), with an average conversion efficiency of 65%. The resulting energy use per shower is (M = 2.60, SD = 2.15). To the best of our knowledge, this is the largest shower data set worldwide to date.

3 Results

In a first data analysis step, we examine whether flowrate is a predictor for shower time and energy consumption. Tab. 2 shows the regression estimation for both independent variables; Fig. 1 helps to interpret the results with a visualization.

	DV: Shower Time	*DV: Energy Consumption*
IV: Flowrate	-0.0946***	0.1681***
Constant	4.0440***	2.6000***
R-sq	.0062	.0387
N	5583	5583

DV: Dependent variable, IV: Independent variable, *** p<0.001

Tab. 1: Regression Output for Flowrate as Predictor of Shower Time and Energy Consumption

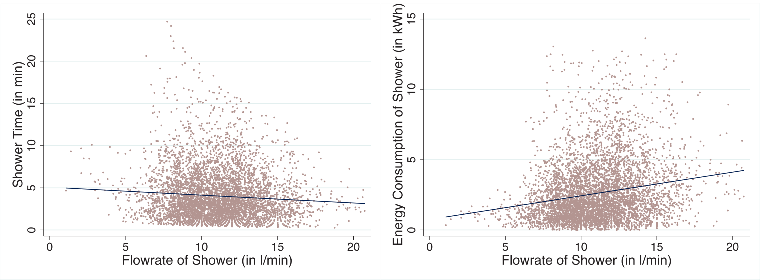

Fig. 1: Regression Plots with Trends for Shower Time and Energy Consumption

As can be seen from Tab. 1, flowrate has indeed a highly significant influence both, on shower time (negative) and energy consumption per shower (positive). Our data indicates that increasing the flowrate by 1 liter per minute decreases shower time by 0.09 minutes and increases energy consumption by 0.17 kWh. Thus, we find that individuals who have a shower head with a lower flowrate do indeed consume substantially less energy, yet they do take somewhat longer showers. Yet, the effect of combining both factors has to be determined.

To quantitatively derive the energy saving potential of low-flow shower heads, we run a simulation in which we estimate the effect of flow restrictors based on our data set. We set the flowrate to 6 liters per minute for all showers that exceed this threshold (upper margin for low-flow shower heads). First, we conduct the “engineering calculation” (i.e., assessing the impact of the technically imposed threshold, without considering rebound effects on shower duration). Thus, we calculate a new water volume with the help of shower time and the fictive flowrate and get a new energy value ((2) in Tab. 2). Taking the above presented regression results into account, however, we also have to consider that individuals adapt their shower behavior to the flowrate (i.e, they would take longer showers). Hence, in a next step, we adjust shower time according to the regression coefficient. This results in a time surcharge (water flow reduction in liters per minute multiplied by 0.09 minutes, the beta-coefficient from Tab. 1). Again, water volume is calculated with the new flowrate and – this time – the new shower time. The resulting values for energy consumption are presented in (3) in Tab. 2. Tab. 2 presents descriptive data of the original energy value (1) and the newly derived energy values (2) and (3).

Energy consumption		*Mean*	*SD*	*Min*	*Max*
(1)	Actually consumed energy present in data set	2.60	2.15	0	13.6
(2)	Simulation with low-consuming shower head	1.43	1.17	0	9.58
(3)	Simulation with low-consuming shower head and adjusted shower time	1.60	1.18	0	9.67

Tab. 2: Energy Values per Shower based on different Simulations

Based on the engineering calculations (2) in Tab. 2, the replacement of inefficient shower heads results in energy savings of 45%. The average shower now consumes 1.43 kWh instead of 2.60 kWh. However, convenience needs of humans should not be neglected: if being exposed to a lower water pressure, humans tend to take longer showers to maintain their feeling of well-being. Taking this into account in our simulation model, energy consumption of the average shower is estimated for 1.60 kWh. Conclusively, human behavior harms the potential energy savings achieved by efficiency means by 15%. Yet, the final energy reduction in the magnitude of 1 kWh per shower, which corresponds to energy savings of 38% compared to the baseline energy use, would be a great achievement. Furthermore, we find that replacing inefficient shower heads by low-energy-consuming ones would cut down variances in energy values by around 45%. As a result, flowrate is one of the main predictors of original variance in energy consumption.

4 Discussion

This paper simulates the energy saving potential of shower heads with integrated flow restrictors based on 5,610 data points of individual showers in a voluntary setting. Analyzing existing shower data, we find that decreasing the flowrate by 1 liter per minute, increases shower time by approximately 0.09 minutes and decreases energy consumption of the shower by around 0.17 kWh. Based on these interdependencies, one could expect that replacing inefficient shower heads with low-flow models would generate energy savings of 38%. These numbers take into account that 15% of absolute savings are compensated by an increased shower time due to the new flowrate. This results in an average reduction of 1 kWh per shower (or per person if we assume one shower per person per day), which corresponds to the total amount of energy spent on daily lighting in an European household [LPS14].

This finding is of high importance for governments and industry. In fact, several governments have already started to reduce hot water consumption either by specifying labeling of shower heads (voluntary eco-labeling measures) or regulatory measures that ban the sale of showerhead above a certain flow rate threshold. Our results indicate that low-flow showerhead do indeed have a substantial potential for energy and water conservation in a voluntary setting. This can be meaningful particularly for regions affected by draughts and water scarcity. The sanitary industry also benefits from this finding. The quantitative energy saving potential certainly is a value proposition for the replacement of inefficient old showerheads that can be used for marketing purposes.

The results of this study provide a first estimate of the fraction of the (engineering calculation) savings that are likely to be offset, as individuals respond to increase their shower time. Nevertheless, caution is warranted with the generalization of the results, in particular when it comes to the savings potential of regulatory (mandatory) measures. The results are not based on an exogenous allocation of showerheads with different flow rates, but on the pre-existing heterogeneity in flow rates, energy consumption, and shower time we measured in an opt-in sample of 636 Swiss households. While these regression-based estimates are clearly informative, more research is necessary to evaluate in particular acceptance issues. After all, those individuals in our sample who had showerheads with lower flow rates had not been forced to install them, but chosen to do so (or at least accepted the existing infrastructure as it was). This raises two questions: First of all, are the individuals in our sample who had a low(er)-flow showerhead systematically different for instance in their environmental attitudes than the general population? And would the general population exhibit a similarly low degree of compensation behavior (i.e., only slightly increase their shower time), in particular in response to flow rate regulations imposed by legislators? Based on the discussion presented by [Ba09, Po10], a non-legible fraction of the population would clearly oppose that kind of regulation or try to tamper with the infrastructure if that kind of policy measure is enforced.

Another key question regards welfare analysis. Policy makers do not only need to consider what works and what does not, but also how those policies affect public welfare. Our data indicate that flow restrictors would clearly generate considerable energy savings, but the effect on overall welfare is less clear. Many individuals might perceive at least mandatory measures as an infringement of their personal freedom [Ba09, Po10].

In spite of these concerns, the results based on the dataset at hand already represent a first good estimate of the magnitude of rebound effects in that domain. The study shows that ICT can provide policy makers with large datasets from real households, which can serve as a valuable empirical foundation for better-informed policy decisions. We consider the results as a first step toward the quantification of the energy saving potential of flow restrictors. To assure generalizability and scalability of the results in a voluntary setting the same simulation should be run with other shower data sets from other regions and cultures. To go beyond self-initiation and to quantify the potential of flow restrictors in a regulatory setting, ideally, a large randomized controlled field experiment should be conducted in which the flow rate is varied exogenously.

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