Bits to Energy Lab

Smart Water Metering: Consumption Feedback at the Tap

Amphiro Study Report

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Dr. Thorsten Staake

Clemens Fischli

Dr. Thomas Stiefmeier

Prof. Dr. Gerhard Tröster

Prof. Dr. Elgar Fleisch

Contact: tstaake@ethz.ch

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE

University of St.Gallen

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About this study

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About the authors

Dr. Thorsten Staake: Director of the Bits to Energy Lab at ETH Zurich and the University of St. Gallen.

Clemens Fischli, B.A.: Head of the Amphiro field study at the Bits to Energy Lab at ETH Zurich and the University of St. Gallen.

Dr. Thomas Stiefmeier: Co-founder and Managing Director of Amphiro AG; Senior Researcher at the Electronics Laboratory at ETH Zurich.

Prof. Dr. Gerhard Tröster: Professor at the Electronics Laboratory at ETH Zurich.

Prof. Dr. Elgar Fleisch: Professor for Technology and Information Management at ETH Zurich and the University of St. Gallen.

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Executive Summary

Hot water usage accounts for 16% of household demand for energy, much more than lighting and cooking (5% each) and comparable to electricity usage for appliances (21%).[1] Since fossil fuels serve as the major energy source, about 5.7% to 6.9% of total CO_2 emissions result from water heating.[2] Consequently, water usage receives considerable attention from policy makers in their effort to cut greenhouse gas emissions and to preserve natural resources.[3]

An important way to conserve energy end reduce related emissions is to reduce individuals' (dispensable) consumption. A method for achieving sustainable consumption is to make energy demand visible to users, either by eco-labeling products or by providing consumption feedback for energy-intensive actions. This method would enable citizens to exercise their market power when purchasing goods and to adjust their behavior when using them.

The report at hand summarizes the findings of a field study on the effects of immediate consumption feedback on hot water usage. Miniaturized Smart Meters and wirelessly connected displays were made available to 200 participants between September 2010 and January 2011.[4] The participants were asked to install the devices between a faucet and a shower hose and to set up the waterproof displays inside their showers. Forty-nine percent of the participants used the devices, which then stored information on volume, temperature, energy, and time stamps for 3,164 shower sessions by 160 persons in 61 households.

Given feedback information, users reduced their average shower water consumption from 79 l to 61 l per day and household (-22.2%). At the same time, heat energy use declined by 0.6 kWh. Projected to one year, in addition to the savings attributed to already installed flow restrictors, an average household saved 6,400 l of drinking water and 210 kWh of energy. The effects were much greater than those typically seen in Smart Metering pilots for electricity. Presumably, the reasons for the effect size are the high levels of perceived and actual control over consumption in combination with real-time feedback directly at the point of use. The study results showed no decline in water savings between the first and second half of the treatment period, which suggests that feedback information remains effective over time.

Based on these findings, Smart Water Metering at the point of use can considerably contribute to reaching energy efficiency goals. In a scenario in which one out of four households in the DACH region[5] uses such a device, energy savings total 2,625 GWh per year, or 22% of the energy produced by all of the photovoltaic installations in Germany in 2010. With an anticipated sales price of 50 CHF per device and a period of use of three years, the avoidance costs per kWh total 0.079 CHF. When the savings of heat energy, water, and wastewater are accounted for, a device is amortized within nine months. Willingness to pay was reported at 47.30 CHF and indicated that the product is also interesting from a commercial perspective.

[1] Worldwide Trends in Energy Use and Efficiency - Key Insights from IEA Indicator Analysis. International Energy Agency, OECD/IEA, 2008, Paris, France.
[2] Jackson T., Papathanasopoulou E., Bradley P., and Druckman A.: RESOLVE Working Paper 01-07.
[3] European Commission: Action Plan for sustainable consumption, production and industry, MEMO/08/507, July 16th 2008
[4] The devices have been developed by Amphiro AG, Zurich. See www.amphiro.com for further information.
[5] DACH stands for Germany, Austria, and Switzerland.

1. Introduction

Water heating makes up a considerable part of the energy budget.

Hot water usage accounts for 16% of the total demand for energy in private households, which is much more than the energy demand attributable to lighting and cooking (5% each) and comparable to the energy usage of appliances (21%).[6] About 5.7% to 6.9% of total CO_2 emissions – including industry, transportation, and agriculture – result from individuals' water usage (see Figure 1).[7,8]

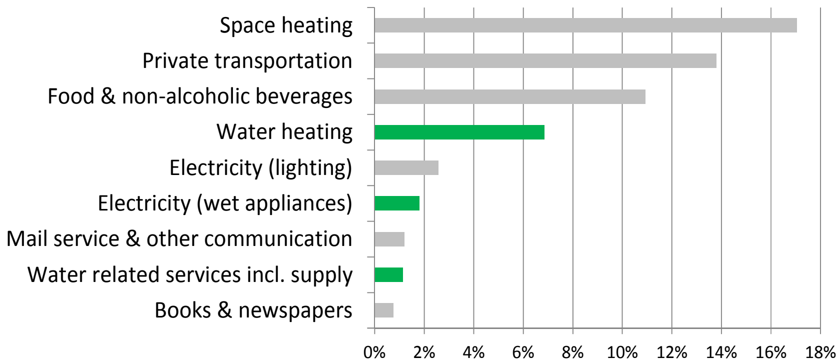

Figure 1. CO_2 emissions by usage account[8]

Achieving efficiency targets requires the involvement of consumers in energy conservation.

In addition to the tremendous efforts of scientific and commercial research that led to the development of more energy-efficient devices and cleaner ways of producing energy, an important method of protecting the environment is the individual reduction of (dispensable) consumption behavior (Gardner & Stern, 2002; McKenzie-Mohr, Nemiroff, Beers, & Desmarais, 1995; Steg & Vlek, 2009). Given the importance of consumer behavior to sustainable development, it is not surprising that techniques to motivate and support individuals to act in an environmentally sustainable way have received considerable attention from researchers, companies, and policy makers.[9]

Direct consumption feedback can promote the efficient usage of resources.

In this context, high hopes are being placed on Smart Meters that offer prompt feedback information about energy consumption. This technology enables people to see how much energy they use during or shortly after their actions. The common hypothesis is that providing a higher degree of transparency with respect to personal energy consumption closes a feedback loop, which enables and motivates individuals to act responsibly. Following this line of argument, numerous studies have shown the impact

6 Numbers for IEA19 countries including Germany, France, UK, USA, and Switzerland, among others, for 2005. Source: Worldwide Trends in Energy Use and Efficiency - Key Insights from IEA Indicator Analysis. International Energy Agency, OECD/IEA, 2008, Paris, France.

7 Water heating accounts for on average 2000 kWh of a single-family household (Jürg Nipkow, Stefan Gasser, Eric Bush: Der typische Haushalt-Stromverbrauch, Bulletin SEV/VSE 19, 2007).

8 Jackson T., Papathanasopoulou E., Bradley P., and Druckman A. RESOLVE Working Paper 01-07.

9 See OECD (2008) for a summary on household behavior and the environment.

of consumption feedback with respect to electricity and gas (see Darby for a review).[10]

Despite the high share of a household's energy budget taken up by water heating, thus far no comprehensive assessment of the effects of Smart Water Metering has been reported for Europe. The study at hand aims to shed light on the effects of consumption feedback on water usage. For a specific but relevant application – immediate feedback on water usage in the shower – the work reports the magnitude of saving effects, the stability of these effects over time, and other key data including user acceptance and willingness to pay for a shower monitor.

2. Related Work

The only comparable study has been conducted in Australia. However, the results do not necessarily reflect the situation in Europe.

Although a thorough body of literature deals with consumer behavior and the effects of consumption feedback in general,[11] related work on Smart Water Metering is sparse. Compared to the number of feedback studies focusing on electricity and gas, very few studies exist on the effects of consumption information on water usage. To our knowledge, the first comprehensive report was authored by a group of researchers and engineers affiliated with the Australian company Invetech. The team investigated the effects of a shower monitor that they installed and operated in 44 households in the Melbourne region.[12] During the study, the devices measured baseline consumption within the first month (measurement without display) and thereafter automatically switched into feedback mode to display current water consumption. In feedback mode, the devices also provided an acoustic alarm signal when a user-adjustable volume was exceeded. Four additional devices with deactivated displays measured consumption over the entire six months to control for seasonal fluctuations. In their study, the authors report an average savings of 15% in feedback mode compared to the baseline.

The study by Willis et al.[12] offers valuable insights into the effects of real-time feedback on water usage. It is, however, difficult to apply the findings to countries where water is abundant. The effects seen in Australia might be stronger than in Europe due to a more pronounced problem awareness, or they might be weaker because a considerable proportion of the saving potential has already been exploited. Another drawback of the study is the intrusiveness of the equipment installation because it possibly strengthened the participants' feelings of being in an experimental situation and fostered socially desired behavior.

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[10] Darby S. The effectiveness of feedback on energy consumption. Environmental Change Institute, University of Oxford; 2006.

[11] For a detailed summary on energy behaviour of private households, see "Household Behavior and the Environment, Reviewing the Evidence", published by the OECD (2008).

[12] Willis R.M., Stewart M.R.A, Panuwatwanich K., Jones S., and Kyriakides A.: Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. Resources, Conservation and Recycling, Volume 54, Issue 12, October 2010, Pages 1117-1127.

Taking a different approach, IBM conducted a pilot project with conventional Smart Water Meters.[13] The meters were connected to 303 households' main water supplies in the city of Dubuque, Iowa, USA. In this project, 151 households were granted access to an online portal that provided information on water usage, which was based on hourly aggregated data, together with information on trends and a personal ranking. An additional 152 households served as the control group and received no feedback information. The feedback group saved 6.6% more than the control group over a period of nine weeks. Comparable feedback studies for electricity, in which feedback information is made available over an online portal rather than at the point of use, typically lead to savings of 3% to 4% if longer treatment periods are investigated (see, for example, Schleich et al.).[14] Although the study is valuable in the context of automated billing, it does not capture the effects of real-time feedback at the point of use.

3. Study Design

Our sample includes 200 households.

This research is based on a field study of 200 households in Switzerland that was conducted between September 2010 and January 2011. To recruit the sample, researchers of the Bits to Energy Lab placed 200 Smart Water Meters in the internal mail boxes of employees of the Swiss Federal Office of Energy (BFE) and the Swiss Federal Electricity Commission (ElCom). Participation was voluntary and the Bits to Energy Lab pledged to make participation, individual user behavior, and questionnaire data anonymous.

Before using the Smart Water Meters, participants had to fill out a first questionnaire. The participants were asked to return the devices immediately if they were unwilling to participate in the study. In addition to demographics, we collected data on environmental attitudes and technology affinity. A second questionnaire distributed after the feedback experiment contained constructs to capture the participants' experiences concerning the shower monitors.

The measurement device aggregated consumption data in order to provide easy to interpret information.

The measurement equipment was manufactured by Amphiro AG, Zurich, Switzerland, and consists of two parts: a self-powered measurement device (a cylinder about the size of a wine cork) and a bright, waterproof, battery-operated five-digit, seven-segment display module that communicates with the measurement module via infrared (see Figure 2). The display automatically turned active whenever water was being extracted, so no user action was required during the experiment. After long periods of inactivity, the display automatically reset and started to

[13] IBM Research - Watson, Smart Water Pilot Study Report, 06/10/2011 Milind Naphade, David Lyons, Chris A. Kohlmann, Cindy Steinhauser (Naphade et al. 2011).

[14] Schleich, J., Klobasa, M., Brunner, M. Gölz, S., Götz, K., and Sunderer, G. Smart Metering in Germany and Austria – Results of Providing Feedback Information in a Field Trial. Working Paper Sustainability and Innovation No. S 6/2011, Fraunhofer Institute for Systems and Innovation Research (ISI).

count from its initial value. The automatic rest function ensured that the shower monitor provided feedback for individual shower sessions. Moreover, to simplify interpretation of the data, the device automatically aggregated consecutive extractions to one shower if they followed each other within a short period in time in order (e.g.: extraction from 0.00l to 34.05l; pause to wash hair; sampling from 34.05l to 68.28l; restart from 0.00l after three minutes of inactivity).

Figure 2. Installation of the Smart Water Meter (Amphiro AG)

Installation was performed by the study participants.

The Smart Water Meters were built to be set up with Switzerland's dominant shower design (a hand shower with a flexible hose connected to a mixer tap) and allowed for easy installation between the shower faucet and the shower hose. The four-step installation was described thusly: "remove the hose from the faucet – attach the Smart meter (a black cylinder) to the faucet – attach the hose to the Smart meter – place the waterproof monitor within sight." A step-by-step manual illustrated the installation process. The system did not require any configuration or pairing of the measurement and display module. To provide help during installation, the research team set up a hotline in case the participants had questions, but there were no requests for telephone support.

We used a within-subject design to determine the effects of feedback information.

During the first nine shower sessions, the devices did not provide feedback on water consumption but instead only showed the number of showers until the display started to show information on water usage. This phase served to measure baseline consumption and was explained as a calibration and charging period of the batteryless, microgenerator-driven measurement module.

4. Response Rates and User Acceptance

Out of 200 devices, 95 were returned unused.

To conduct the study, 200 devices were handed out to staff at BFE and ElCom. Ninety-one devices were installed and used; 95 were returned unused. Fourteen devices were not returned until after completion of the study.

In total, the equipment recorded 3,614 measurements in 61 households with 160 individuals.

Of the 91 devices installed, 61 devices obtained usable records with more than 24 measurements, and 44 of those obtained very good records with more than 40 measurements. On average, the devices stored 52 measurements nine baseline mode plus 43 in feedback mode). In total, 3,164 shower sessions were recorded in 61 households with about 160 individual users.

Of the 91 installed devices, 30 devices obtained no usable data. Reasons for this were either an insufficient number of measurements recorded (i.e., too few showers taken), obvious manipulation of the experiment (e.g., the shower was operated nine times on the first day to avoid the baseline measurement and immediately set the device to feedback mode), or hardware failure.

Participants installed 49% of the devices.

The participation rate totaled 49% (91 devices used, 95 devices not used) (see Figure 3). Reasons for not using the devices include concerns about data privacy, lack of interest, unwillingness to consider consumption while showering, difficulties during installation (e.g., the shower hose could not be screwed off), and incompatible screw threads at some bathroom installations (selected showers use 3/8” instead of 1/2” windings).

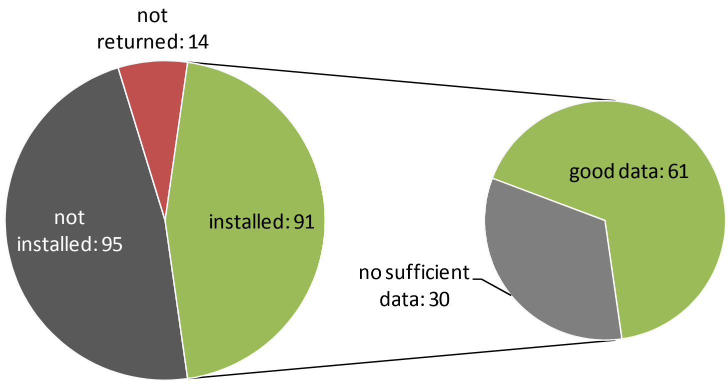

Figure 3. Participation and share of usable records

The participants completed 93 initial questionnaires and an additional 100 questionnaires after returning the devices. Forty households returned both questionnaires and produced useable measurements. Overall, the number of operated devices and completed questionnaires was within the expected range and had been taken into account when deciding upon the number of distributed devices.

5. Effect on Water Consumption

The reported effects were measured using 61 devices, which recorded 3,164 shower sessions in 61 households with about 160 individual users. Changes in water usage are given either as absolute or relative changes between the baseline measurement (no feedback information) and feedback mode (the display shows the volume per shower session).

Choosing this within-subject design allows for evaluating the effects of feedback information regardless either of varying water pressure in individual households or of the pressure drop that is caused from our measurement device.

Water consumption declined by 22.2% when feedback was present.

With feedback information, users reduced their average shower water consumption per day and household from 79 l to 61 l (-22.2%). At the same time, heat energy use declined by 0.6 kWh. Projected to one year, in addition to savings attributed to already installed flow restrictors, an average household saved 6,400 l of drinking water and 210 kWh of energy.

Savings primarily result from reduced shower time per session.

The sharp drop in daily shower volume is attributable to the shortening of individual shower processes. Although the participants reduced the duration of individual showers, we found no effects with regard to shower frequency. Moreover, we found no changes in shower temperature, though this might result from a poor resolution of 1 degree of our devices. Most households' flow rates remained relatively stable. The data, however, show a sharp and persistent drop of the flow rate within the feedback period in three households. This might indicate replacement of a conventional shower head by a low-flow model.

The saving effects varied considerably between different households. Sixty-two percent of the households reduced their water and energy consumption per shower by at least 10%, and 28% achieved saving rates of more than 30%. However, 20% of the households did not save a significant amount of water and energy, and 18% consumed more when feedback information was present (see Figure 4).

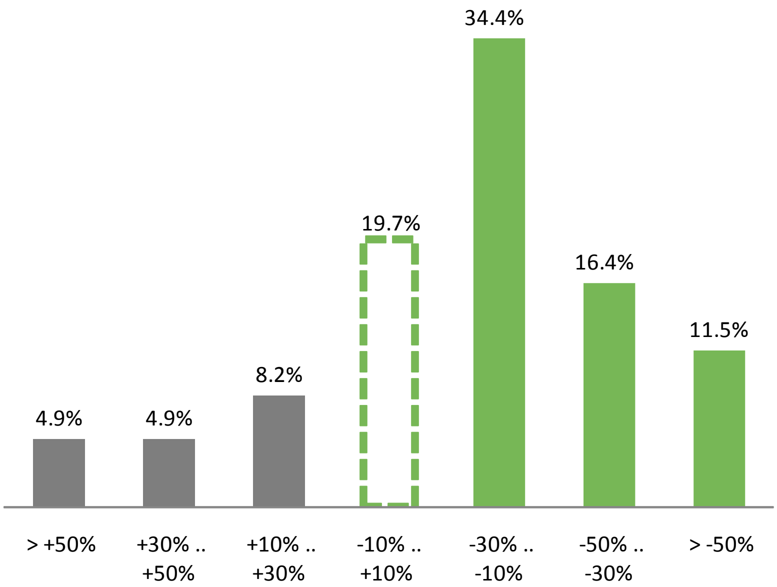

Figure 4. Distribution of the changes in daily water and energy usage per household *(N_blind=548, N_treat=2616)*

For the further analysis, we report savings effects in percent of the baseline measurement. Please note that the average savings expressed relatively to the individual baseline do not necessarily equal the overall saving in water or energy consumption. Absolute savings in water and energy consumption (the relevant measure from an environmental perspective) in the study are 22.2%, while the average savings per household over baseline are 12.9%. The latter number is smaller as it is influenced heavily by users with low average consumption who increase their water demand slightly with respect to the absolute value but strongly when expressed as a share of baseline consumption. See the following scenario to exemplify the effect.

Scenario:

Participant A increases his consumption from 20 l/day to 30 l/day (+50%).
Participant B reduces his consumption from 100 l/day to 70 l/day (-30%).

While average household consumption increases by 10% when initiating consumer feedback, the consumption of participants overall reduces by 17% (from 120 l to 100 l).

The saving effects clearly exceeded those achieved by Smart Metering for electricity.

A more detailed analysis revealed the dependence of saving effects on baseline consumption. Although virtually all users with high baseline consumption decreased their demand, consumers who used very little water per shower were prone to increase water usage when provided with feedback information. This "constructive and destructive" effect of descriptive feedback is well-known and discussed in Schulze et al., who showed that feedback can even lead to an overuse of resources among already efficient consumers.[15] When looking at average savings per household over baseline after dividing households into above- and below-median consumers, the effects of baseline consumption on saving effects become apparent (see Figure 5). Above-median users saved significantly more (20.2%) than did below-median users. Below-median users saved an average of 4.9%.

For further insights into the distribution of the amount of water used, Figure 6 shows the share of users allocated to six volume bins for both baseline and feedback measurements.

[15] Schultz, P. W., Nolan J. M. , Cialdini R. B., Goldstein N. J., and Griskevicius V. 2007. The Constructive, Destructive, and Reconstructive Power of Social Norms," Psychological Science (18:5), pp. 429-434.

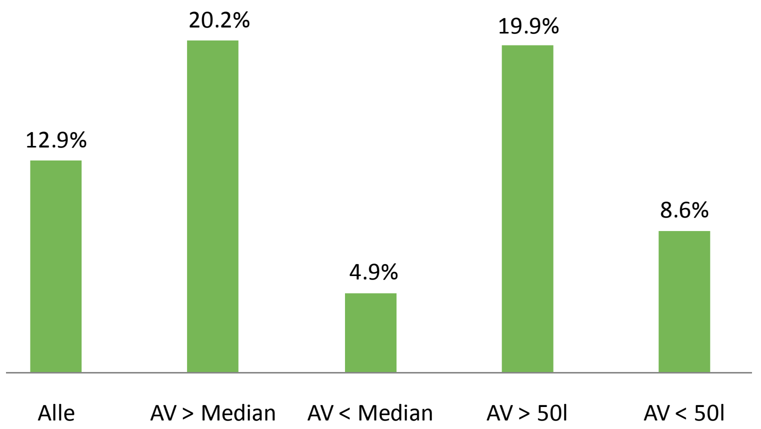

Figure 5. Saving effects by baseline consumption (AV)
(N_alle=3164, N_>M=1685, N_<M=1479, N_>50l=1094, N_<50l=2070)

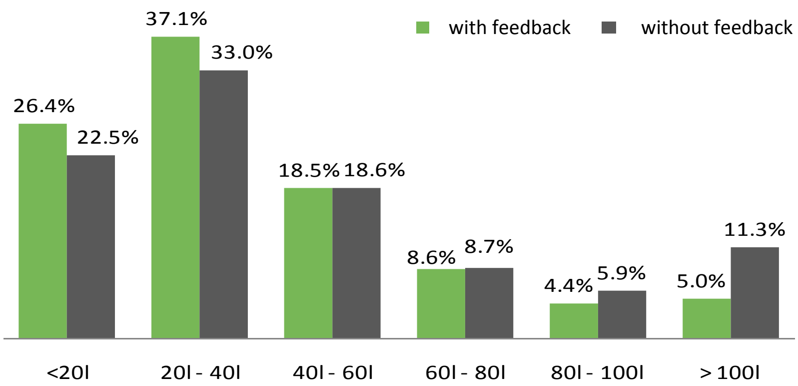

Figure 6. Number of shower processes according to volume sampling
(N_blind=548, N_treat=2616)

The saving effects remained stable over time.

The practical importance of the findings depends heavily on the long-term stability of the saving effects. To measure the stability of the effects across the duration of the study, we split the feedback period into two phases of equal length (1,208 and 1,207 measurements). Although the first half of the feedback period showed savings of 24%, we can report savings of 20% during the second half (see Figure 7). Thus, the effect of feedback on water consumption did not wear off considerably over the course of the study.

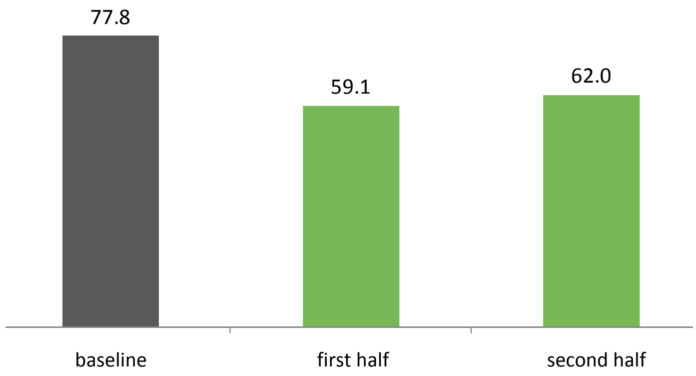

Figure 7. Average water consumption per day for first and second half of the treatment in comparison to baseline *(in liter; N_blind=31 N_H1=1208, N_H2=1207)*

6. Willingness to Pay and Perceived Usefulness

Users indicated a willingness to pay up to 47 CHF.

The analysis of questionnaires distributed before the trial showed that a Smart Shower Monitor is regarded as an expedient device (see Figure 8). Despite the Shower Monitor's prototypical design, experiences with the device were rated as positive in responses collected after the trial. The interest in Smart Water Metering is confirmed by users' sound willingness to pay on average 47.27 CHF per shower monitor.

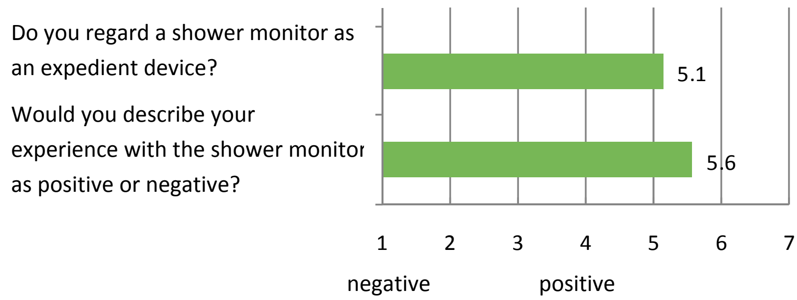

Figure 8. Acceptance of Smart Water Metering

Limitations of the study.

The following limitations of the study should be emphasized. Study participants come into contact with energy matters through their work at BFE more than average citizens do. The proportion of university graduates also is above average. This limitation must be put into perspective because many opinions on the topic of Smart Metering exist within the Federal Office of Energy, and the study took into account entire households (overall, more than two-thirds of users do not work at BFE or ElCom). Furthermore, a future study should investigate the persistence of the effects of feedback over a longer period of time than was investigated here. Thus far, however, the presented work can be considered the most extensive and best published analysis based on real behavior data in the area of consumption feedback and water usage.

7. Evaluation and Recommendations for Action

The findings presented in this study highlight that the presence of the consumption display leads to a sustainable adaption of behavior. Feedback information resulted in a reduction of average shower water consumption from 79 l to 61 l (-22.2%) per day and household. Consequently, heat energy use declined by 0.6 kWh. Projected to one year, in addition to savings attributable to already installed flow restrictors, an average household saved 6,400 l of drinking water and 210 kWh of energy.

The effects were much greater than those typically seen in Smart Metering pilots for electricity, which typically range from 3% to 4%. A possible explanation for the effect size is the high level of perceived and actual control over consumption and the immediacy of the feedback directly at the point of use. Moreover, the context is clear ("taking a shower"), and it is probably easier for users to memorize what is a good performance as compared to, e.g., the assessment of a household's electricity consumption and the interpretation of Smart Metering data on a household level.

Another positive finding relates to the persistence of the effects of feedback over time. The study suggests that the consumption display leads to a sustainable adaption of behavior. However, a longer study period should be applied to probe the validity of the finding.

With an anticipated sales price of 50 CHF per device and a period of use of three years, the avoidance costs per kWh amount to 0.079 CHF. When savings of heat energy, water, and wastewater are accounted for, a device is amortized over nine months, which makes consumption feedback at the tap a very cost-efficient option to conserve energy.

In addition to the abovementioned findings, the study revealed that only one-half of the participants were willing to use the shower monitor. Moreover, the effects varied considerably between households with above- and below-average shower consumption. When similar devices are deployed on a larger scale, the cost-benefit ratio can be increased considerably by selecting the right target group for the devices. This could happen by packaging the devices with other energy efficiency services (e.g., a green electricity tariff) or by selling them to customers who already are aware of their high consumption.