Contrasting the effects of real-time feedback on resource consumption between single- and multi-person households

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Abstract

Residential energy consumption accounts for 25% of Europe's greenhouse gas emissions. Consumption feedback delivered via technology has been reported to produce from none to 20 percent energy savings. Yet it is still unclear how to best leverage the full potential of smart sensors and feedback information to achieve a high and persistent impact on user behavior and awareness. Showering is an ideal domain to investigate the effectiveness of different household constellations and different types of feedback information on resource: the effects of user actions are immediately visible, can easily be controlled by the user and are quantified easily. For that purpose, we developed a shower meter and display that measures and stores event-based time series data and provides users with in-situ real-time information about the current shower event. In a 2x3 randomized controlled trial with 697 Swiss households over two months, the impact of different feedback versions and household size on the dependent variables energy and water usage is analyzed. Measurement data are supplemented and evaluated with self-reported survey data before and after the field study. First results after the collection of the devices indicate a very promising savings potential for such feedback technology and important contributions to the broader literature on behavior change and social norms in general.

Introduction

Despite numerous national and international policies to cut emissions, world primary energy use has doubled over the past 30 years (IEA 2011), with 80% being provided by fossil fuels. In parallel, worldwide CO2 emissions have doubled, reaching new record levels of 31.6 billion tons in 2011 (IEA 2011). The residential buildings sector in Europe accounts for 25% of end-use emissions – comparable to the energy use of industry (26%) and transportation (29%) (European Environment Agency 2012).

The energy sector in Switzerland and worldwide is currently facing a challenging situation of major changes and uncertainty. In order to mitigate climate change, ambitious goals have been put forward and moved from pure visions into actual policy guidelines. One prominent example is the vision of the 2000-Watt-society with its pilot regions Basel, Zurich and Geneva (compared to current levels of 6000 W in Western Europe and 12,000W in the U.S.); another example are the 20-20-20 targets of the European Union, whose key objectives for 2020 aim at a 20% reduction in EU greenhouse gas emissions (from 1990 levels), a 20% share of renewable energy sources, and a 20% improvement in energy efficiency.

In order to reach these goals, both energy production and consumption will have to undergo a massive changes. This transformation is also accompanied by the political decision of Switzerland and

Germany to phase out nuclear power. While technological progress will certainly make important contributions to tackle these problems, relying on future technological breakthroughs is not an option according to Richard Lester's and David Hart's book "Unlocking Energy Innovation" (Lester and Hart, 2011). Instead, a timely decarburization of the energy production has to go hand in hand with much higher energy efficiency gains than at the current rate of improvement. Both the industry and private households will need to contribute to this transformation. This implies not only a large-scale adoption of more efficient technology, but also behavioral changes and increased awareness for the carbon footprint of our daily actions.

Many people in Europe are sensibilized for simple environmental actions such as switching off lights when leaving a room. While highly visible, the environmental impact of these actions is rather limited (lighting accounts for 5% of a household's end-use energy). By contrast, most people are not aware of the energy dimension and impact of water heating, although it accounts for 16% of residential end use energy, the 2nd largest share after space heating (U.S. DoE 2012). Showering accounts for the majority of residential hot water demand. Therefore, an immediate goal of our feedback device is to raise awareness for energy consumption in the shower and to bring attention to the high impact that users can have on their individual energy consumption in general. Besides that, we aim to gain valuable insights that can be applied in practice to many other feedback technologies and environmental campaigns. Beyond that, our empirical study strives to extend and supplement existing social science theory.

Related work

Households have been identified as a "huge reservoir of potential for reducing carbon emissions and mitigating climate change that can be tapped much more quickly and directly" than carbon emissions trading, fuel economy standards or changes on the energy supply side (Gardner and Stern, 2008). Apart from structural changes that increase the attractiveness of pro-environmental choices, e.g., by offering financial rewards (Steg and Vlek, 2009), academics and policy makers place high hopes on informational interventions that provide the basis for better-informed decisions or appeal to a socially desirable behavior of individuals. Social norms have been identified as one of the most powerful determinants of behavior change (Cialdini, 2001). Pilot programs and large-scale implementations that leveraged social norms e.g. in neighborhood comparisons have shown high economic returns and even negative net carbon abatement costs (Allcott & Mullainathan, 2010).

With the progress of information technology and the ongoing large-scale deployment of smart utility meters, even more possibilities open up to effectively bring energy consumption information to the attention of individuals in ways that effectively influence consumer decisions towards more sustainable behaviors. Despite numerous research reports which highlight in unison the potential of information systems to promote cleaner future (see, for example, Cisco (2008), McKinsey (Boccaletti et al. 2008), the Economist Intelligence Unit (EIU 2008), the Climate Group (2008), and the European Union (Barroso 2008)), the vectors to realize this potential are still fundamentally underexplored.

Consumption feedback delivered via technology has been reported to produce from none to 20 percent energy savings (Faruqui et al. 2010; Ehrhardt-Martinez et al. 2010), yet with very heterogeneous results. Houde et al. (2011) attribute the heterogeneity in outcomes to three main factors: a) different research designs (size, participant selection procedures, duration, and evaluation methods), b) features of the feedback technology (timeliness, data display, interactivity, sociability, and controllability) and c) differences in the participating population (self-selection bias). Technology features that were identified as relevant by meta-studies (Darby, 2006; Fischer, 2008; Ehrhardt-Martinez et al. 2010) include frequency, duration, timeliness, content, breakdown, medium and way of presentation, and comparisons. Stern (2011) points out that the relevance of psychological and psychosocial variables is behavior specific and higher for behaviors that are not strongly constrained. This implies a particularly large potential for behavioral interventions on highly discretionary behaviors such as showering.

A considerable share of the IT artifacts presented in academic literature still has not overcome prototype status. This is particularly true for systems aiming to influence resource consumption in the shower, many of which focus on establishing a proof of concept/operation and interface design. Arroyo et al. (2005) introduced “Waterbot”, a system to inform and transform water consumption behavior at the sink. Kuznetsov and Paulos (2010) developed “UpStream”, a pervasive display for showers and sinks; Kappel and Grechenig (2009) an ambient shower display named “show-me”. Laschke et al. (2011) designed “Shower Calendar”, another pervasive concept study to motivate shower water savings. Our study seeks to overcome the limitations of previous research by moving away from the prototype stage to the deployment of a product on a larger scale, while providing insights that can be generalized to a much wider domain of social sciences and residential energy consumption.

The current field study

Our study is carried out in collaboration with the local utility company ewz and with researchers from the University of Lausanne and funded by the Swiss federal office of Energy (BFE). Our study draws on the literature on social norms in social psychology, sustainable behavior in information systems research, and the utility derived from the adoption of personal and social norms in behavioral economics. We thus respond to Allcott’s and Mullainathan’s (2010) call for a “*concerted effort by researchers, policy makers and businesses to do the ‘engineering’ work of translating behavioral science insights into scaled interventions, moving continuously from the laboratory to the field of practice*”.

We developed a shower meter that measures and stores time series data on actual behavior and provides numeric and symbolic normative in-situ feedback to the users. Our goal was to conduct an empirical study on the effects of disclosing information on individuals’ resource consumption to himself and other household members on subsequent resource usage. The devices were deployed in 697 households in the Zurich metropolitan area over two months. Households were recruited from a larger pool of 6,000 households. All of them received the device as a gift for having completed a smart metering study with the local utility company ewz. In order to opt into our study, willing participants were asked to fill out our survey. They had to declare their willingness to temporarily ship the device back after two months for data read-out. Among those who did comply with this request, 324 single- and 372 two-person households were selected. Household size was restricted due to the limited number of shower events that the device can store. We used a 3 (type of feedback) x 2 (single-vs. 2-person-household) research design with random assignment of households to one of the three feedback conditions, each of which is subdivided into one-person households and multi-person households (Figure 1).

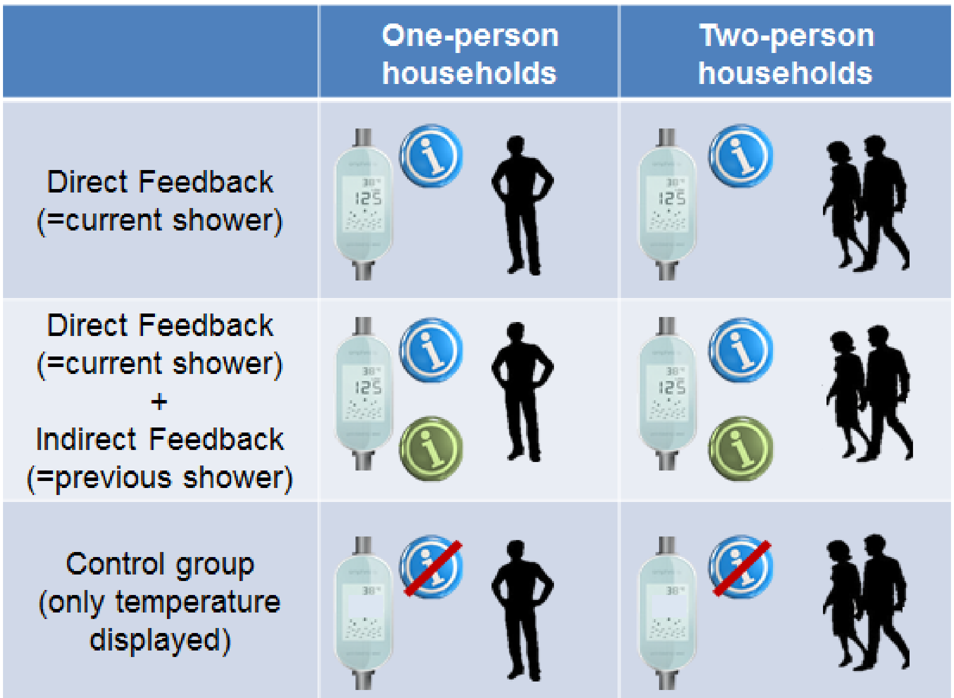

Figure 1: 3 (feedback condition) x2 (household size) research design

The three device versions only differed in display content. All devices were originally equipped with the same software and then reconfigured into one of the three special feedback condition modes for the study. Whereas control group devices only displayed temperature throughout the study, the "previous shower invisible" condition households received real-time feedback on their current shower event. Households in the "previous shower visible" condition could additionally see the water volume consumed in the previous shower event (figure 2). Distinguishing between single- and 2-person households in all three feedback conditions allows us rule out several alternative explanations and to break down the anticipated effects into components that are self-internalized by the individual alone and effects that we can attribute to social dynamics between household members.

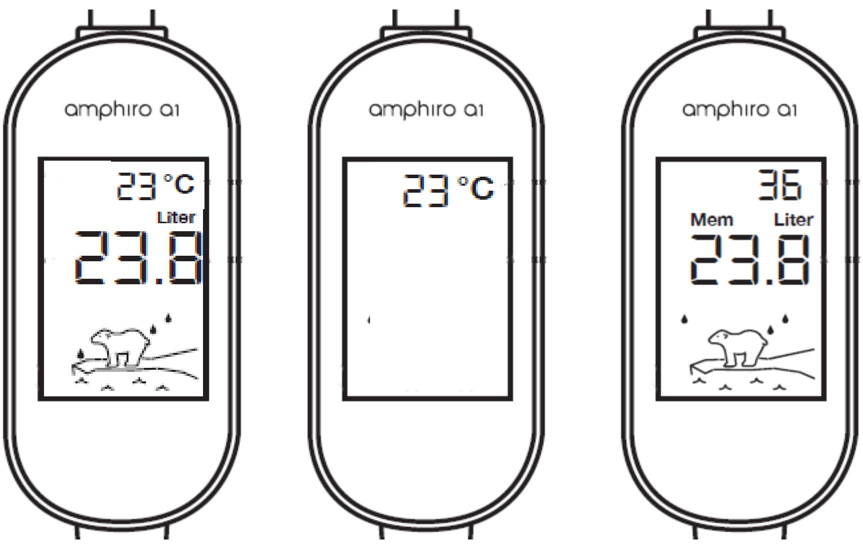

Figure 2: Examples of the information shown on the three display version. From left to right: a) "previous shower invisible" condition, b) control group, c) "previous shower visible" condition

Each participating household received a shower feedback device in the first week of December 2012. Devices were shipped with a user manual that was adapted to the specific s of the three feedback conditions. For instance, the control group was informed that we were testing different display elements in this study and that they would be able to see additional information on the display after completion of the study, allowing them to test two different display versions.

The installation, requiring no tools or skills, was carried out by the users. The device is mounted between the hose and the handheld showerhead, a location that facilitates and elicits periodic user glances during the shower process. A built-in turbine harvests energy from the water flow, allowing the device to continuously measure water temperatures and flow rates during each shower event. Based on these data, the device calculates the accumulated water and energy consumption and shower time since the start of the shower and stores the final values of up to 200 individual shower events. Showers with short interruptions (e.g., for lathering up) are stored as one coherent event; only interruptions of more than three minutes result in the data being logged as two separate shower events. In contrast to previously deployed systems, which all rely on batteries, this power harvesting concept allows for a much longer deployment of the sensors by eliminating the most prevalent risk for operation failure. This enables tracking user behavior and feedback response over extended periods of time.

As baseline measurement, all devices only displayed the temperature for the first ten shower events. The user manual of the “previous shower invisible” and “previous shower visible” conditions explained this with “adjustment time upon installation”, without specifying the exact number of showers to complete this phase. Once completed, the device automatically switched to its normal operation mode.

After two months, all participants were asked to temporarily return the device for data read-out. For that purpose, devices are triggered to enter a special read-out mode that allows the research team to read out the datasets from the display using a camera and a dedicated software program written for that purpose. Once the dataset from the device is matched with the corresponding survey data, the device is reprogrammed and shipped back to the participant.

First results

The two-month deployment phase of the devices in the households has ended on February 9th, 2013. We are currently in the process of collecting and reading out the study devices. A second survey was administered at the end of the study. One week after the end of the study, over 350 devices had been shipped back to our office and over 500 surveys had been completed. Based on survey results and correspondence with participants during the study, an estimated 93% of devices was fully functional throughout the study. 80% of survey participants state that they (rather) certainly plan to use the device again after the read-out; only 10% indicate that they do (rather) not plan to reinstall it.

Expected challenges, research objectives and impact

Once all devices have been returned, read out and matched with the corresponding survey data, the datasets will be filtered for outliers and potential measurement errors. Besides a number of simple sanity checks, additional outlier analyses will be performed on the dataset. Based on a combination of water volume, temperature, and survey data, water extraction events that are not caused by showering will need to be identified and excluded with good accuracy. Similarly, incidences where the subsequent showers of two persons was mistakenly counted as a single shower event need to be discarded from the dataset with good reliability. Altogether, we expect to obtain approximately 550-600 complete datasets.

In terms of impact on household resource consumption, we will investigate how real-time consumption feedback on resource usage in the shower can increase awareness and foster saving effects. A prior pilot study carried out by the Bits to Energy Lab shows a very promising potential for such real-time consumption feedback devices: with an earlier generation of the device, the role of a virtual water budget and the persistence of savings was investigated. Overall, participants in that study decreased their water consumption by 22% on average and the savings were sustained over time. This corresponds to accumulated savings of 6,400 l of water and 210 kWh of heat energy per year and household.

The objective of the current study is to test the effectiveness of real-time feedback depending on feedback information provided, household dynamics, and other contextual factors. The study will contribute to social science literature on social norms and comparisons, feedback and the visibility of behavior. We will quantify saving effects and evaluate the feasibility and cost-effectiveness of a large-scale adoption. One of the main research trajectories focuses on how and to what extent the presence of another household member affects the impact of feedback. In this context, several hypotheses will be tested, including the following four:

H1: Compared to single households, the presence of (an)other household member(s) increases the effect of the feedback display, as social pressure within the household increases the motivation to reduce one's shower consumption.

H2: Savings are even more pronounced in 2-person households when the water consumption of the previous shower event is visible to others in the subsequent shower event.

H3: Compared to single households, the presence of (an)other household member(s), as it leads to a trend in the middle between household members: savings of one household member are (partly) compensated by the increased consumption of the household member who started at a lower consumption level.

H4: Compared to single households, the presence of (an)other household member(s) leads to more persistent saving effects, as discussions and comparison in the household help to maintain a higher level of interest and engagement with the device.

Overall, we expect valuable insights on the role of social dynamics within households and other contextual factors and how they can be leveraged in an optimal way – also in other energy efficiency campaigns – to increase the impact and cost-effectiveness of such programs. The aspired results advance the theoretical knowledge on the mechanisms behind social norms and are of high practical relevance for the design of information systems that motivate a sustainable resource usage amongst individuals.

Discussion

In contrast to the majority of related work, this study features real household data over a longer timespan (2 months) and a large sample size of initially 697 households. An average of 80 data points per household is expected, each containing information on several parameters. By focusing on a single behavior (showering), we also hope to reduce measurement noise compared to studies that investigate the entire water/energy/electricity consumption of households.

Although many efforts were made to carry out this study in a clean research design, empirical studies with real household data are always subject to external factors that are difficult to control for. We hope to capture the most of these with survey data, so that we can control for them. Besides, these issues will partially be mitigated by randomization, a relatively large sample size, and rather large number of data points per participant.

One aspect that is certainly to be considered is external validity. Caution is warranted in particular with findings on the adoption rate and usage of the device. Self-selection effects and a certain bias towards a higher level of awareness and interest towards the device and similar technologies that among the general public must be kept in mind. Nevertheless, the experimental setup as a randomized controlled trial allows us to draw meaningful conclusion from differences between the experimental groups. Besides, one should keep in mind that the participants received the device whether or not they were interested in it or not, unless they specifically opted out. This implies that the results will also include households that have less interest in the technology than an actual buyer would. In that sense, results on adoption and impact might actually be conservative compared to actual buyers of the device.

Conclusion

This work-in-progress paper outlines a 2-month field study with 697 households in Switzerland that investigates the effect of household dynamics and social norms on resource consumption. For that purpose, real-time feedback right at the place of consumption is provided to users, in this case in the shower. A 2x3 randomized controlled trial allows to derive insights on the effect of individual elements and contextual factors from comparisons both between and within the groups. Time series data from individual shower events are supplemented with survey results. We expect valuable insights from this empirical study that can be transferred to other areas of resource consumption and behavior change. Given the technological progress and deployment rate of smart meters for instance, these insights can help to foster both adoption and effectiveness of feedback technologies on a large scale. These technologies can empower individuals and households to play a much more informed and active role in the energy transition progress and to shape a sustainable future for our society.

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