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A Shower Meter to Save Water and Energy: the Influence of Two Feedback Sources, Goals, and the Role of Comfort on Conservation Behavior in a Lab and Field Experiment

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Content

1. Abstract

Persuasive Technologies in the form of interactive feedback systems have shown to be effective in reducing resource consumption. However it is unknown how the addition of a second feedback source influences resource saving behavior. In this research we studied the effectives of one and two sources of feedback on water and energy consumption in a shower task in a field experiment (Experiment 1). Results of the field experiment (Experiment 1) did not match our expectations that the presence of interactive water feedback, energy feedback or both in a shower leads to a reduction in water or energy consumption, as a result of people taking shorter showers, setting lower water flows or lower temperatures. One explanation for the lack of water and energy saving is the loss of thermal comfort experienced in the shower. To reduce the influence of thermal comfort the experiment was repeated in a lab setting in which participants completed a virtual shower task. Another possible explanation was the lack of a conservation goal. Therefore a goal manipulation was added in which participants were asked to shower as environmentally friendly as possible or as comfortable as possible. In line with our expectations results of Experiment 2 suggested that a second feedback increased feedback effectiveness by reducing virtual shower durations by 1 minute (21%). Not confirming our expectation however, this did not lead to lower energy or water consumption. Confirming our expectations results also suggested that having a conservation goal instead of a comfort goal increased feedback effectiveness resulting in 22% less water consumption and 25% less energy consumption. Evidence for an expected interaction effect between goal and feedback manipulation was not found. Overall, this research provided little evidence for a resource saving effect of one or two sources of feedback in a task were comfort is important. However, this study also suggested that when people have the goal to behave environmentally friendly ambient interactive feedback can positively affect conservation behavior.

Key words: Feedback systems, Ambient Persuasive Technology, Conservation Behavior, Energy & Water Consumption.

2. Introduction

Energy consumption forecasts (Deng, Cornelissen and Klaus, 2011) for 2050 show that to match future demands in a sustainable way, consumption should be almost halved compared to continuing with business-as-usual (Figure 1). The UN states that water use has grown at twice the rate of population and if present consumption patterns continue, two out of every three persons on earth will live in water-stressed conditions by the year 2025 (UN, 2003) .

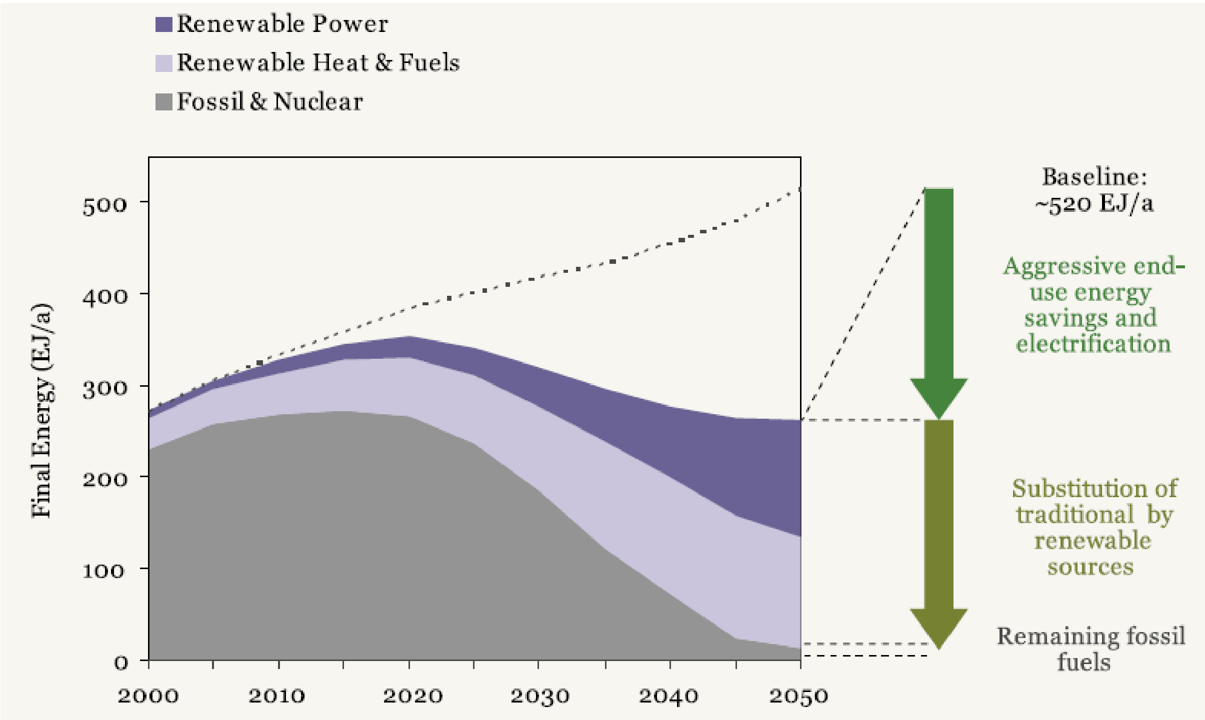


Figure 1. Projected global energy consumption between 2000 and 2050 (Deng, Cornelissen and Klaus, 2011)

The use of the best currently available technology could reduce present energy consumption by 30% (Bertoldi, Ricci, and de Almeida, 2000). While extrapolating this number to 2050 is a wild guess, it does give an indication that a 50% reduction target cannot only be met by a technical approach. It also needs a change in behavior by reducing the demand of individuals and groups of people.

However, curtailing water and energy usage in is a difficult task. The consumption of both water and energy is unlike most consumable goods. There is always warm water coming from the shower, heat coming from the radiator and electricity from the socket, which makes the supply seem unlimited. Billing happens only once a month and is not based on actual usage, but on an estimate based on the consumption of earlier years. Energy consumption and to a lesser extent water consumption are abstract, invisible, and untouchable (Fischer, 2008). It is, as Kempton and Layne (1994) put it, "considering groceries in a hypothetical store totally without price markings, billed via a monthly statement like 'US$527 for 2362 food units in April'.

Already in 1978 Seligman, Darley and Becker showed that monthly feedback on households' energy bills reduced their average energy consumption. In these early feedback studies time and place of the feedback were very distant from the actual energy consumption, which limited the effect of the feedback. Recent reviews (e.g., Darby (2000), and Fischer (2008), Abrahamse, Steg, Vlek & Rothengatter (2005)) of studies that give consumers feedback on their energy or water consumption show typical savings between 0 and 20% (Fischer, 2008) and 10-15% (Darby, 2000). It is in the interaction between humans and technology where decision on resource consumption are mostly made, and it there where feedback systems should interfere with the consumer. Not surprisingly, designs that performed best in the studies by Fischer (2008) and Darby (2000) provided frequent, interactive, task specific and tailored feedback. For example, McCalley and Midden (2002) demonstrated in several studies that such feedback systems could be effective in reducing energy consumption of laundry tasks. By adding an energy meter to the user interface of a washing machine they achieved 18% reduction of energy consumption.

All earlier research investigating the influence of feedback on resource consumption, investigated situations in which one feedback source was presented. However, in daily life we are constantly confronted with information from a multitude of sources that might influence our behavior. A simple act of buying a pack of milk in a grocery store might involve checking the price, the volume content, the expiration date, whether it is semi-skimmed or full cream, whether it is organic or not, etc. Additionally, there are factors influencing consumers unconsciously (Bargh,1994). For instance the placement of the pack on the shelve, the design of the pack, or that commercial on TV that you just watched. Also, in the future it seems likely that multiple household appliances will be equipped with resource consumption indicators and appliances might be equipped with meters that indicate resource consumption on more than one natural resource.

The current studies

Therefore, in the current research, we investigate the effectiveness of providing users with two streams of feedback at the same time. More specifically, we will provide users with feedback about energy consumption and about water consumption. The question is whether people are still able and willing to process and respond to multiple streams of feedback. On the one hand an additional feedback stream could give extra insight in resource consumption and therefore result in more persuasive power and less resource consumption. On the other hand another feedback source might not add much additional information when there is already a source of feedback present. The saving potential might have reached its limit with one feedback stream already. An additional feedback source could even confuse people or increase the complexity of the task. Cognitive load theory (Sweller, 1988) indicates that cognitive processing deteriorates when dealing with more complex tasks (Ayres & van Gog, 2009) and earlier research by Maan et al. (2011) suggested that under increased cognitive load, feedback can be less effective. Interestingly, the same research showed that when light is used to present feedback on energy consumption instead of digits in kWh participants used 24% less energy. In the current research, we argue that one way to overcome processing limit related problems when users need to process two feedback streams is Ambient Persuasive Technology. Ambient Persuasive Technology are generic technologies that are intentionally designed to change a person's attitude or behavior or both, that can be integrated unobtrusively into the environment and exert an influence on people without the need for their focal attention.

By designing the feedback in such a way that it takes a minimum of cognitive resources to process, multiple feedback streams might still be effective. According to Miller and Rich (2009) ambient displays are designed not to be invasive or annoying. Ishii and Ullmer (1997) suggested the use of ambient media such as sound, light, airflow, and water movement to act as background interfaces and work at the periphery of human perception. They also mentioned that even though ambient media are often processed in the background, they can move to the centre of attention. Wisnesky et al. (1998) supported this interpretation of ambient technology by describing ambient technology as being at the “periphery of our attention”, with a kind of “subconscious understanding” and possibly involving “all our senses”. Numerous forms of ambient technologies can be found in literature, however not much research is conducted regarding the application of ambient technology in feedback systems that involve resource efficiency. In addition to the study byMaan et al. (2011), Bonanni, Arroyo, Lee, & Selker (2005) developed the HeatSink that provides the user of a water tap with information about the temperature of the water. In addition, Arroyo, Bonanni &Selker (2005) described the WaterBot which gives feedback in the form of lighting the water stream together with auditory feedback on tap water use. Another application by Kappel and Grechenig (2009) is the Shower meter. This device measured the water consumption while a shower is taken and immediately gave feedback in the form of a blue LED strip.

To investigate the effectiveness of ambient feedback, we performed a study in which feedback was presented comparable to earlier research of Kappel and Grechenig (2009). A shower task was used because there are two resources involved, water and energy. The goal of the experiment was to research the effectiveness of one and two ambient feedback sources of a shower meter on water and energy consumption. We expected lower energy consumption when energy use feedback was given and lower water consumption when water use feedback was given. When the effect of one versus two feedback sources is compared, we expected two feedback sources to be effective in reducing both water and energy consumption, whereas only energy feedback was expected to reduce energy consumption, and only water feedback was expected to reduce water consumption.

3. Study 1: Field experiment

To investigate the effect of one versus two sources of ambient feedback a field study was conducted. The aim of this study was to see whether it is possible to reproduce results from single source feedback studies in a field experiment and to compare the effect of one versus two feedback sources on resource consumption. Feedback was given in the form of one or two vertical LED strips, comparable to earlier research conducted by Kappel and Grechenig (2009). A blue strip was used to visualize water use, and a red strip for energy use. The number of LEDs lit indicated resource consumption. This kind of feedback was chosen because, as argued above, this ambient feedback is expected to be more effective than for instance numerical feedback. Especially in case of a second feedback source when cognitive could be higher.

In general, when the baseline measure was compared to the treatment measure we expected to find an effect of water-use feedback and water & energy use feedback on water consumption and energy-use feedback and water & energy use feedback on energy consumption. To decrease water consumption in a shower one can decrease the water flow and/or shorten shower duration. We expected participants to do both and therefore expected to find an effect of water-use feedback and water & energy feedback on water flow and shower duration. To decrease energy consumption in a shower one can decrease the hot water flow which lowers the water temperature and/or shorten shower duration. Again we expected participants to do both and therefore expected to find an effect of energy-use feedback and water & energy use feedback on water temperature and shower duration. When water & energy use feedback was given, we thus expected to find a decrease in water and energy consumption caused by shortened shower duration, decreased water flow and lowered water temperature. The above mentioned expected effects add up to a main effect of the feedback treatment on shower duration (hypothesis 1: shorter shower duration when feedback was presented) and interaction effects between the feedback treatment and feedback type on water consumption (hypothesis 2: lower water consumption in the two conditions where water feedback was presented compared to only energy feedback), energy consumption (hypothesis 3: lower energy consumption in the two conditions where energy feedback was presented compared to only water feedback), water flow (hypothesis 4: lower water flow rates in the two conditions where water feedback was presented compared to only energy feedback) and water temperature ((hypothesis 5: lower water temperatures in the two conditions where energy feedback was presented compared to only water feedback).

In addition, an effect of water-use feedback on energy consumption and vice versa was also expected to be found. However it was unsure whether this would lead to an increase or decrease in consumption of the other resource. Two mechanisms with an opposite effect on resource consumption were considered to be important here: the rebound and spill-over effect.

Rebound effects, where efficiency gains are getting dissolved due to amplified consumption (Midden, Kaiser, & McCalley, 2007), are theoretically expected to derive from either an expansion or a substitution effect (Hertwich, 2005). In this context, expansion means that technological advancements stimulate demand (e.g. a more efficient car leads to bigger commuting distances). Subsitution means a reinvestment of freed assets in a different way (e.g. a more efficient car frees money of which a motorcycle is bought). Traditionally rebound effects are explained by the reinvestment of freed monetary or time assets into the same task (Midden et al. 2007). In this context, comfort could play an important role. For example, a decreased water flow in the shower can results in an increase of water temperature to retain the same level of comfort. In this case, water is substituted by warmth and thus a decrease in water-use leads to an increase in energy consumption. In similar fashion, to compensate for a loss of comfort caused by lowered water temperature one might increase water flow. Taking this rebound effect into account a negative effect on energy saving was expected when water-use feedback is presented and vice versa. When feedback is given on both water and energy use some energy and water saving is expected, however the savings are less compared to single feedback stream conditions due to rebound effects. In this case the rebound effect would have contributed to the interaction effect between feedback treatment and feedback type on all dependent variables except shower duration.

Spill-over effects might however lead to the opposite effect. That is, feedback given on water-use could lead to a reduction in energy consumption and feedback given on energy-use could lead to a reduction in water consumption. This can be seen as a spillover effect. Thøgersen and Ölander (2003) have demonstrated a slight positive spillover effect from one area of environmentally friendly behavior to others. The hypothesis that efficient behavior in one resource could spill over into efficient behavior in another resource is backed by several psychological theories (e.g. Self-Perception Theory, Balance Theory and Dissonance Theory) which claim that we have a need to avoid inconsistencies in our beliefs, attitudes, and behaviors (Bem, 1972 and Eagly & Chaiken, 1993). In this case, this would have lead to a main effect of feedback treatment on all dependent variables. No interaction effect between feedback treatment and feedback type would have been expected.

4. Method of the field experiment

4.2. Participants and design

Participants were all university students. Ages of the participants ranged from 19 to 26 years with a mean age of 23 years (*SD* = 2.1). In total eighteen participants (12 male, 4 female) participated in a 2 (treatment: baseline vs. treatment) x 3 (feedback: water, energy, water & energy) design. The feedback manipulation was designed as a between-subject factor, whereas the treatment manipulation was designed as a within-subject factor. Dependent variables measured per shower were water consumption in Liter, energy consumption in Joule, duration in seconds, water flow in liter per second, and water temperature in degree Celsius.

To control for the different types of showers a baseline period measure without feedback and a treatment period wherein feedback was present was taken. First one week baseline measures were taken for water consumption, energy consumption, shower duration, water flow and water temperature. After the baseline measures participating residents were assigned to one of three conditions, as shown in Table 1.

Condition 1. Only water feedback. In this condition after the baseline measure participants only received feedback on their water consumption. Water consumption was visualized as a vertical blue lighted LED bar

Condition 2. Only energy feedback. In this condition after the baseline measure participants only received feedback on their energy consumption. Energy consumption was visualized as a vertical red lighted LED bar.

Condition 3. Water and energy feedback. In this condition after the baseline measure participants received feedback on both water consumption and energy consumption. Water consumption was visualized as a vertical blue lighted LED bar and energy consumption as a red bar.

Table 1. Field study design with a one week before measure and a two week treatment measurement period in three accommodations.

	Accomodation 2: 6 participants	Accomodation 3: 6 participants	Accomodation 4: 6 participants
Week 1	Before measure	Before measure	Before measure
Weekend 1			
Week 2	Treatment Condition 1: Water-use feedback	Treatment Condition 2: Energy-use feedback	Treatment Condition 3: Water & energy user feedback
Weekend 2			
Week 3			
Weekend 3			

4.3. Materials

The shower meters as shown in figure 2, were developed using the open source Arduino platform. The shower meters consisted of a processing unit equipped with a real-time clock and SD-card data storing functionality. Other key components were a water flow meter (AMess) and a digital thermometer. The flow meter and digital thermometer were installed between the faucet and a flexible tube. For each half liter of water flowing through the flow meter one tick was sent to the processing unit. The processing unit then read the digital thermometer. This information was converted into LEDs lighting up according to a pre-set factor. When the time difference between two ticks was larger than one minute, the shower meter was automatically reset allowing the next user to start showering. At every tick of the water meter a time stamp was created by means of the build in real-time clock. Shower durations were derived from the elapsed time between the first tick after a reset and the last tick before a reset. The processing unit was placed in a small plastic box outside the shower cabin to prevent it from becoming wet. On one end, two wires were connected to the flow meter and thermometer and on the other end a cable was connected to the LED bar. The cable had enough length to permit the LED bar to be inside the shower cabin in line of sight of the user. The amount of water and/or energy needed to light one LED can be set according to the range needed. Two small scale pilot studies and a study with a similar device (Kappel & Grechenig, 2009) showed that a five liter per LED range was a setting that resembled the range of average shower turns; i.e. lighting up some LEDs in short showers and not maxing out in longer showers.

Figure 2. Shower meters installed in the shower. From left to right: water feedback, water & energy feedback, energy feedback.

4.4. Procedure

The three conditions were tested at the same time to minimize the influence of weather variations and other time dependent variables. The conditions were tested between subject in three comparable student households equipped with a Shower meter. These households were selected on the criteria that they had at least six occupants sharing one shower. Per household one person was asked to volunteer as a contact person. Emails with instructions were sent to all participants. In this email participants were asked to either reply the email, or inform the contact person about their willingness to participate. Furthermore, the goal of the experiment (gaining insight in shower behaviour), the use of the shower meters ("It can help you save water and energy by motivating you to shower shorter, colder or with a softer water jet."), their reward (fifteen Euros), their tasks ("shower as you would normally do for three weeks", "write your name on a list before or after you showered", "fill out a questionnaire after the three weeks are over"), and further proceedings were mentioned in the email. All members from all households responded positive to the invitation.

One day before the baseline period the measuring devices without the LED bars were installed and the shower lists with instructions were applied to the shower doors. The instructions were similar to the e-mail which the participants had received earlier with the addition that participants were requested to fill out their name, date and time on the shower list. In this way logged showers could afterwards be matched with the shower lists entries.

At the end of the treatment period the shower lists and measuring devices were removed. Hereafter a questionnaire was distributed by email which was returned by fourteen out of eighteen participants. The questions aimed at collecting demographic information. Additionally, participants were asked to indicate to what degree the feedback changed their showering behavior. After returning the questionnaire participants were rewarded fifteen Euro, debriefed and thanked for their participation.

5. Results of the field experiment

The energy consumption, water consumption, shower duration, water temperature and water flow were all separately analyzed using a 3 (feedback type: water feedback (house 1) vs. energy feedback (house 2) vs. water and energy feedback (house 3)) x 2 (treatment: baseline measure vs. feedback) MIXED MODEL analysis, controlling for different showers per participant.

Results of this analysis provided no evidence to support our first hypothesis, (H1: a main effect of feedback treatment on shower duration), $F < 1$. That is, participants who received water feedback (M = 430, SD = 207) did not shower shorter compared to the baseline measure (M = 420, SD = 213). Results also provided no evidence for an interaction effect between feedback type and treatment on water consumption (H2), energy consumption (H3) and water flow (H4), all $F < 1$. As can be seen in table 2**,** for hypothesis 2 this means that the difference in water consumption between treatment measures of water feedback (*M* = 64.61 *SD* = 37.17) and water & energy feedback (*M* = 44.71, *SD* = 25.42) and the baseline measures (water *M* = 63.89, *SD* = 33.07; water & energy *M* = 47.00, *SD* = 19.53) is not larger compared to energy feedback (treatment *M* = 33.62, *SD* = 25.42; baseline *M* = 33.43, *SD* = 21.55). For hypothesis 3 this means that the difference in energy consumption between treatment measures of energy feedback and water & energy feedback and there baseline measures is not larger compared to water feedback and for hypothesis 4 that the difference in water flow between treatment measures of water feedback and water & energy feedback and there baseline measures is not larger compared to energy feedback (see table 2 for means and standard deviations).

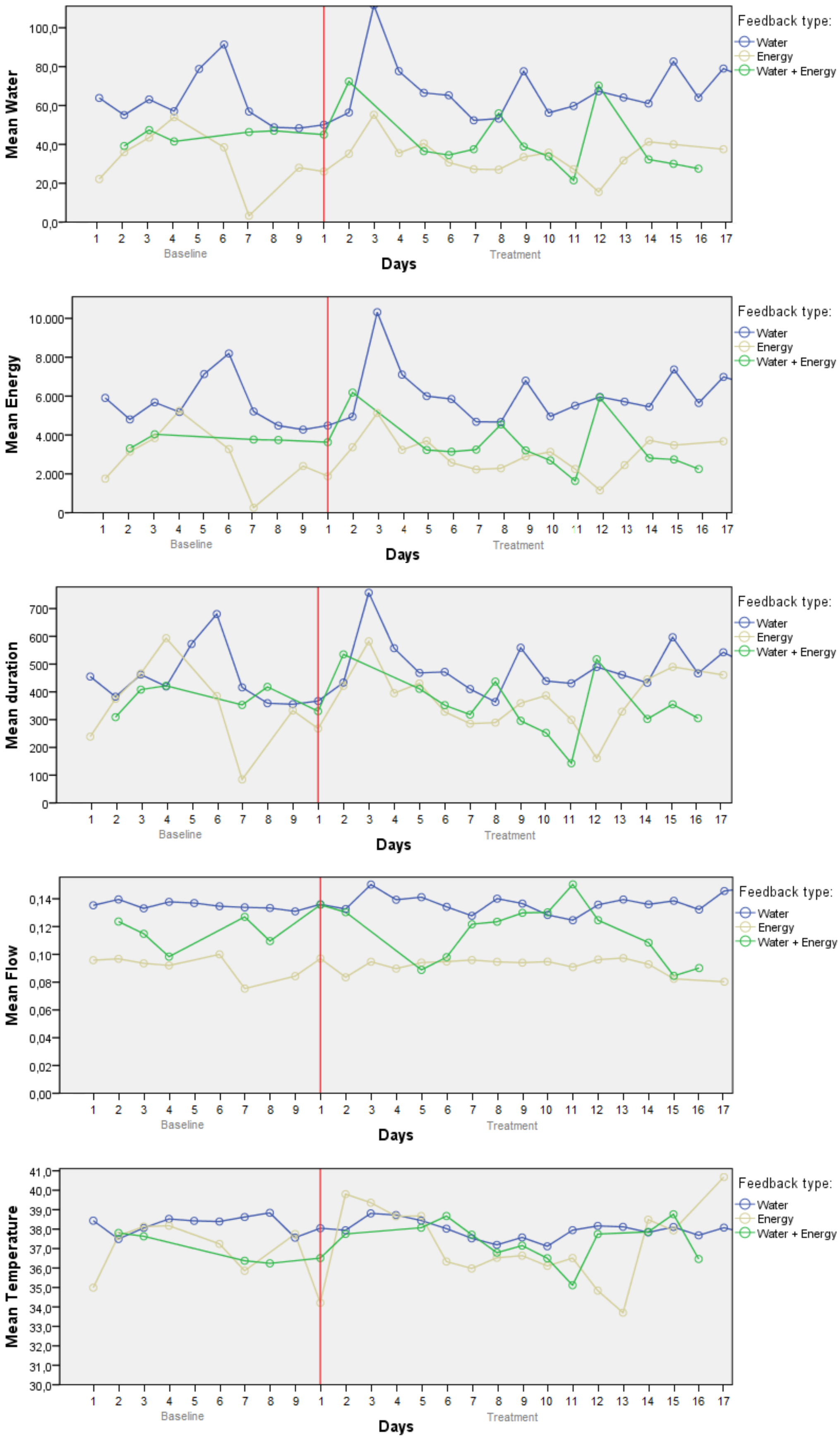
Furthermore, results also indicated an unexpected main effect of treatment on water temperature, $F(1, 207.885) = 6.134$, $p < .05$, indicating a higher water temperature when feedback was given (*M*=37.74, *SD*=.43) compared to the baseline period (*M*=37.33, *SD*=.44). Furthermore, an unexpected interaction effect between feedback type and treatment on water temperature was found, $F(1, 207.629) = 7.348$, $p < .05$. The interaction effect showed that when only energy feedback is given participants set a higher water temperature when feedback is given (*M*=37.76, *SD*=.79) compared to the baseline period (*M*=36.66, *SD*=.81). When only water use feedback or both water use and energy use feedback is given, this difference does not occur. These results contradicted hypothesis 5, since a decrease in temperature was expected instead of an increase

What can also be seen in table 2 is that water consumption, energy consumption and water flow vary greatly over the different feedback type condition, also in the baseline measurements. This finding is statistically backed by a main effect of feedback type on water consumption $F(2, 19.197) = 3{,}868$, $p < .05$, energy consumption $F(2, 19.155) = 3{,}858$, $p < .05$ and water flow $F(2, 16.440) = 7.757$, $p < .05$.

Table 2. Mean water consumption, energy consumption, shower duration, water flow and water temperature by feedback type and treatment.

	Feedback type:	1. Water feedback			2. Energy feedback			3. Water & energy feedback		
		Mean	*SD*	*N*[2]	*Mean*	*SD*	*N*[2]	*Mean*	*SD*	*N*[2]
Baseline	Water [L]	63.89	33.07	46	33.43	21.55	15	47.00	19.53	16
	Energy [J]	5777	3089	46	2955	2180	15	3845	1498	16
	Duration [s]	466	224	46	363	231	15	392	95	16
	Flow [L/s]	.1353	.0163	46	.0924	.0224	15	.1184	.0320	16
	Temp[1] [°C]	38.4	1.10	46	37.1	2.38	15	36.8	1.22	16
Treatment	Water [L]	64.61	37.14	79	33.62	12.32	38	44.71	25.42	28
	Energy [J]	5782	3479	79	2951	1291	38	3765	2038	28
	Duration [s]	465	250	79	371	137	38	360	151	28
	Flow [L/s]	.1363	.0173	79	.0915	.0084	38	.1212	.0263	28
	Temp[1] [°C]	38.0	1.06	79	37.4	2.93	38	37.5	1.73	28

[1] Corrected temperatures, due to a programming error original datapoints were 3 degrees too low
[2] Number of shower turns



a.

b.

c,

d.

e.

Figure 3. Graphs of the effect of feedback type and treatment on water consumption (a), energy consumption (b), shower duration (c), water flow (d), and water temperature (e).

Figures 3a till 3e show graphs of the effect of the feedback treatment on the five dependent variables over time. Visual inspection of the graphs show no clear diminishes of water consumption, energy consumption, shower duration, water flow or water temperature over time. It does show that the shape of water consumption, energy consumption and shower duration graphs is almost identical. In these three graphs peaks are visible some days after installment of the LED bars. For the next four to five days, consumption scores decline again after which they settle around an average score comparable to the baseline measure.

Pearson correlation coefficients were calculated between water flow and temperature. This analysis provided evidence for a weak positive correlation between water flow and temperature when water feedback was given ($r = .36$, $p < .01$), a weak negative correlation for the energy feedback condition ($r = -.32$, $p < .05$) and a moderate negative correlation when water & energy feedback was given ($r = -.60$, $p < .01$).

6. Discussion and conclusions of the field experiment

The results of the previous study did not confirm our expectations: feedback on the consumption of energy, water or both did not result in any savings at all. We think this can be explained by the nature of the task that was used in this research. In earlier research (e.g., McCally & Midden, 2002; Maan et al. 2011) laundry tasks or space heating tasks were used or feedback was given on total household energy consumption (Abrahamse et al. 2005) —that is, participants felt no bodily, perceptual consequences of their energy-saving actions. However, in the current task, any resource savings directly affected thermal comfort. As Munir, Takada, Matsushita and Kubo (2010) showed, showering can be seen as an energy balance between incoming energy through conduction of warm water to the skin and outgoing energy from water evaporation, and conduction and radiation from the skin to the surrounding. Many studies mentioned comfort as a cause or as main cause to not save natural resources (Becker et al., 1981; Morell, 1981; Van Raay & Verhallen, 1981, Heijs & Stringer, 1988). More specifically, research on thermal comfort in humans under showers shows a comfort compensating effect to retain thermal comfort. For instance, research from Ohnaka, Tochihara and Watanabe (1994) showed a negative correlation between water flow and water temperature. When participants were asked to use less water, they increased the temperature of the water to compensate the decrease in thermal comfort. Similarly, Rohles and Konz (1982) reported that participants who showered with restricted-flow heads increased their water temperature with 2.1 degrees Celsius as compared to participants who showered with standard flow heads. They suggested that a reduction in flow rate was accompanied by an increase in water temperature to compensate for thermal discomfort. This negative correlation between water flow and temperature was also found in this research for the energy feedback condition and water & energy feedback condition. This could indicate a comfort compensating effect in which a trade-off is made between either higher water flows or higher water temperatures. These findings suggest that the influence of feedback resource consumption in shower is limited because of comfort issues.

7. Study 2: Lab experiment

In the real world, comfort will always be an issue in a shower task. To overcome this comfort issue we designed a second experiment in which participants had to complete shower tasks on a computer. This experiment was not performed in the field, but in the lab where participants performed a virtual shower task in which they received no bodily comfort feedback which would allow us to research the effect of a second feedback source more specifically. We had similar hypotheses as for the first study. That is, we expected lower energy consumption when energy use feedback is given and lower water consumption when water use feedback is given. When the effect of a second feedback source is compared to a single feedback source only, we expected the consumption of the second resource to decrease when the second feedback source is added.

However, thermal comfort might not have been the only explanation for the lack of expected results. As acknowledged by Locke (1991) feedback without a goal “represents information and unevaluated feedback is effectively neutral”. This means that if a goal to save energy or water does not exist, feedback should have no or little effect. This might also explain the lack of energy and water savings in the first experiment. This is confirmed by feedback studies in which participant who had a designated energy reduction goals used less energy than participants who did not have a goal

(McCalley & Midden, 2002). Therefore, In addition to the feedback type manipulation we assigned half of the participants a conservation goal.

But in most social situations we operate with several goals, some of which may be included in structured systems of goals (Bandura, 1991; Austin & Vancouver, 1996). Goals may conflict with each other, or be mutually supportive. They can be ordered in terms of priority, and some goals may be subsidiary to others. Although the role of goal-setting on feedback effectiveness has been studied (McCalley& Midden, 2002, Becker, 1978), no study is known to us that studies the influence of opposite goals on feedback effectiveness. Since in daily life we function with various goals in mind, it is important to know how goals influence the effectiveness of feedback devices on resource consumption. Therefore, the other half of the participants were assigned a comfort goal. Thereby this group of participants resembled the real life situation more closely compared to not assigning them any goal, because in real life people will strive for a comfortable showering experience in most cases.

We expected participants who were assigned a conservation goal to behave more environmentally friendly as participants who were assigned a comfort goal by consuming less water and energy for their virtual shower turns. In addition, we expected the second feedback source to be more effective for people with a conservation goal compared to a comfort goal. However, since the second feedback source comes on top of the first feedback source the potential resource saving is limited. We expected that participants would not further give up comfort for the second feedback source and therefore expected participants to only shorten their shower turns. In other words, we expected an interaction effect between the goal and feedback manipulation on shower duration.

8. Method of the lab experiment

8.1. Participants and design

Eighty-one participants (50 male, 31 female) participated in a 2 (goal: conservation/ vs. comfort) x 2 (feedback: water consumption feedback vs. water and energy consumption feedback) between subject design. Participants were randomly assigned to one of the four conditions. Sixty-six participants were university students and thirteen indicated to be employed and two indicated to be housewifes/men. Ages of the participants ranged from 19 to 61 year old with a mean age of 26.3 years (SD = 4.2).

8.2. Materials and procedure

On arrival participants were welcomed and requested to take a seat in front of the computer. Next, the experiment leader started the virtual shower task program and left the room. In the experiment a virtual shower task was used to gather data about the participant's water and energy consumption behavior (see Figure 3). A typical thermostat shower tap was modeled and programmed to obtain water and energy consumption data. Water consumption was calculated taking into account the water flows and durations of different shower actions. Energy consumption was calculated based on participants' settings of water temperature and water consumption for the different shower activities. As input for this model participants had to set the desired water flows, water temperatures and durations for a selection of fourteen shower actions (e.g. applying shampoo, rinse-out hair, brushing teeth, enjoy the water). Participants were informed that for water flow eight options could be chosen ranging from "off" to "a painfully strong jet". Likewise, participants were informed that for the water temperature also eight options could be chosen ranging from "cold" to "painfully hot". Duration could be set per shower action with steps of half a minute.

In the conservation goal condition participants were instructed that water and energy conservation is very important. In the comfort goal condition, the importance of a comfortable shower experience was deemed more important. The following text was presented to accomplish this goal manipulation: "In this research we are curious about your most environmentally friendly shower settings in different circumstances. Try to shower as you would normally do but try to consume as less water and energy as possible. You can make your shower turn environmentally friendly by limiting the duration of the shower turn, limiting the force of the water jet, and limiting the water temperature. Try not to give up too much comfort but keep in mind that in this case environmentally friendliness is more important than comfort". Another text with the same structure but stressing comfort was used in the comfort goal condition. Mentioning comfort in the conservation goal condition was done to make sure participants would not set extremely low temperatures when pursuing their main goal.

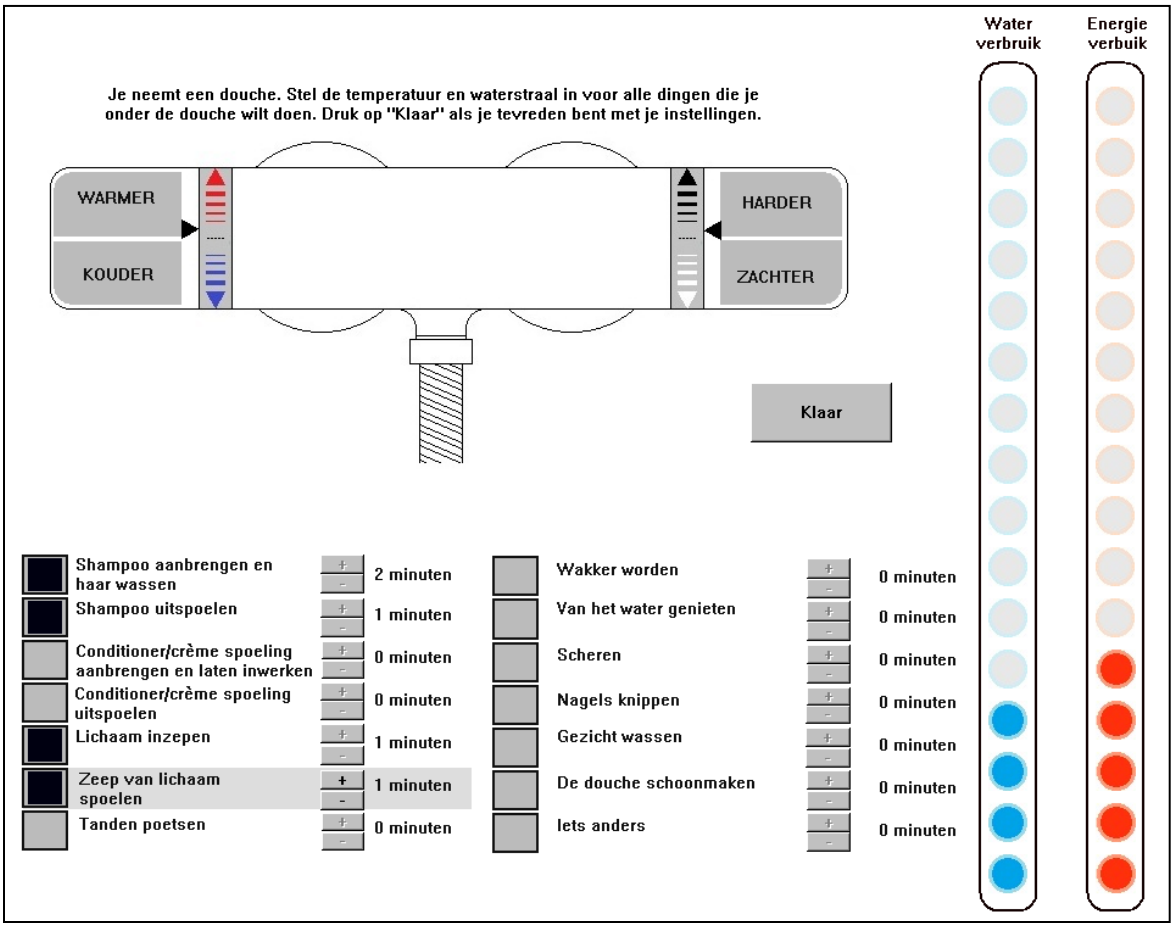


Figure 3. The interface of the virtual shower experiment with from top to bottom the scenario, the virtual tap with left the water temperature adjustment and right the water flow adjustment, the fourteen shower actions with left the selection option and right the duration adjustment. On the right side the water consumption and energy consumption feedback as presented to the participants.

After these instructions, participants were asked to complete a practice trial. The ten test trials that followed were similar to the practice trials. In each trial, a participant had to set the shower for a specific scenario. Examples of these scenarios are: “You just did sports intensively,” “You are getting up to go to your work/university”, or “It is a relaxed Sunday morning”; varying time of day and reasons to have a shower.

After the ten test trials participants were asked to fill out the GEB questionnaire (Kaiser, 1998), some manipulation checks and demographic questions. They were then debriefed, paid €5,-, and thanked for their participation. The duration of the experiment was approximately 25 minutes.

Dependent variables were water consumption in Liter, energy consumption in Joule, shower duration in minutes, water flow in Liter per minute and water temperature in degree Celsius. Total water consumption was calculated from the water flows and durations set per shower action. Similarly, total energy consumption was calculated based on the water temperatures, water flows and durations per shower action.

9. Results of the lab experiment

Dependent variable scores, water consumption, energy use, shower duration, water flow and water temperature were submitted to a 2 (goal: high conservation/low comfort vs. low conservation/high comfort) x 2 (feedback: water consumption feedback vs. water and energy consumption feedback) x 5 (measure: shower duration, water consumption, energy consumption, water flow, and water temperature), x 10 (scenario's) mixed MANOVA with goal and feedback as between subject factors and measure and scenario as within subject factors. In addition, the participants GEB score was included as a covariate.

Mauchly's test of sphericity indicated that the assumption of sphericity has been violated for the main effects of scenario ($X^2(44) = 156.24$, $p < .001$) and measure ($X^2(9) = 2589.59$, $p<.001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity.

There was a main effect of the within subject factor Scenario on all dependent variables: Energy, $F(5.91, 419.66) = 28.00$, $p < .001$; water, $F(6.23, 442.30) = 18.63$, $p < .001$; duration, $F(6.37, 452.03) = 23.16$, $p < .001$; temperature, $F(6.05, 429.31) = 67.88$, $p < .001$; flow, $F(6.66, 494.07) = 2.68$, $p < .01$. This analysis suggested that the used scenarios were not identical and participants took virtual showers with different settings as would also be the case in real life. Appendix I shows the average dependent variable values with standard errors per scenario.

First of all, results provided evidence for our first hypothesis; participants with a conservation goal scored lower on dependent energy conservation measures than people with a comfort goal. That is, results indicated a main effect of the goal manipulation on energy use and water use. Contrast analysis revealed that participants with a conservation goal used on average 1741 Joule or 25 percent less energy ($M = 5256$, $SD = 462$, $F(1, 72) = 6.59$, $p < .05$) and 13.2 liter or 22 percent less water ($M = 47.8$, $SD = 3{,}8$, $F(1, 71) = 4.91$, $p < .05$) as participants with a comfort goal (energy $M = 6998$, $SD = 487$; water $M = 61.1$, $SD = 4{,}0$). A marginally significant effect was found on shower duration ($F(1, 72) = 3.11$, $p < .1$, 50 seconds shorter, $M = 5.57$, $SD = .32$ vs. $M = 6.40$, $SD = .34$) and water temperature, ($F(1, 72) = 3.15$, $p < .1$, 1.0° Celsius colder, $M = 39.57$, $SD = .40$ vs. $M = 40.61$, $SD = .42$). There was no effect of the goal manipulation on water flow. The above results are qualified by a significant interaction effect between goal and measure ($F(1, 71) = 6.59$, $p < .05$). This confirms a different effect on the dependent variables for participants with a conservation goal compared to participants with a comfort goal.

As expected there was no main effect of the second feedback source compared to one feedback source on any dependent variable. Nor was there an interaction effect between the goal and feedback manipulation on any of the dependent variables (all F's < 1). However, in partial support of the hypothesized interaction effect, an effect of the feedback manipulation was found on shower duration in participants with a conservation goal. This was statistically tested by taking only the participants with a conservation goal into consideration and analyzing this data with an ANOVA with the feedback manipulation as independent variable. When having a conservation goal, planned contrast revealed that additional energy feedback on top of water feedback significantly reduced mean shower duration ($M = 5.21$, $SD = 1{,}46$, $t(37.1) = -1.98$, $p < .05$ (1-tailed)) compared to only water feedback ($M = 6{,}21$, $SD = 1{,}74$). This effect is visualized in Figure 4 which shows the standardized Z-scores for all dependent variables. The figure gives an indication of the effect sizes of the dependent variables relative to each other. As reported before and as figure 4 showed, energy and water consumption did not decrease when water & energy feedback is compared to only water feedback in the conservation goal condition. A decrease in shower duration would lead to a decrease in energy and water consumption except when water flow or temperature is raised. However this effect does not reach statistical significance (*p* = .12 and *p* = *.16*).

Only a marginally significant effect of the GEB covariate was found on energy use ($F(1, 72) = 2.82$, $p < .1$). No effect was found on water use, shower duration, water temperature and water flow.

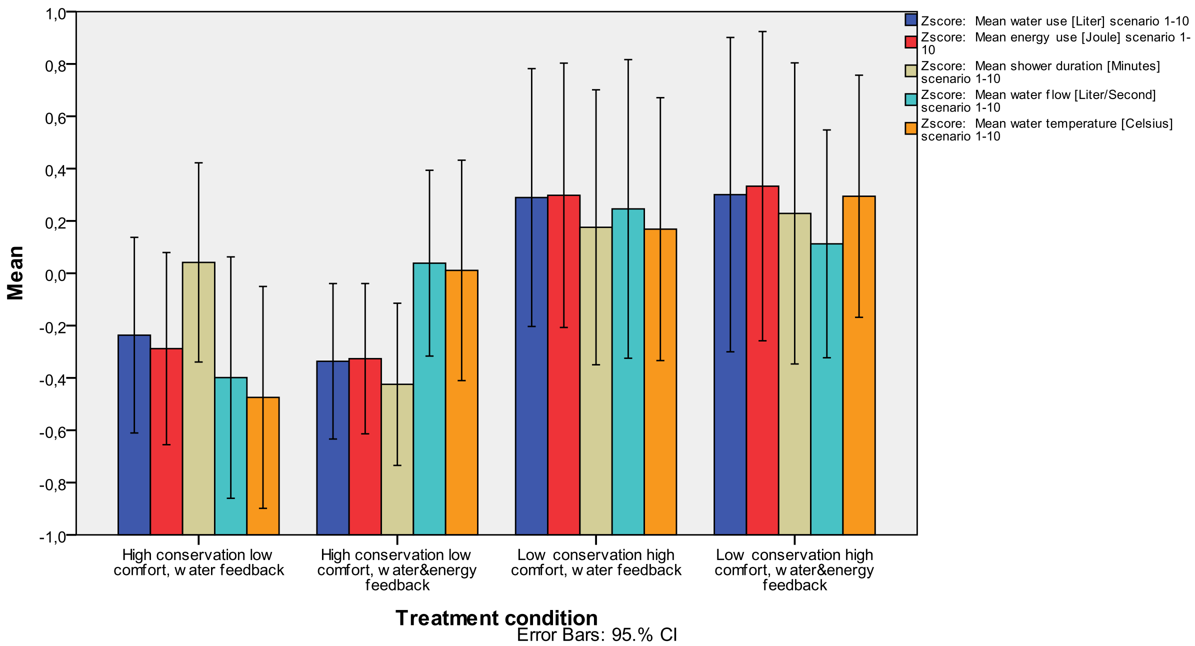


Figure 4. Standardized scores for mean water consumption, mean energy consumption, mean shower duration, mean water flow and mean water temperature for the different conditions.

Manipulation checks were analyzed with a one-way ANOVA for both the comfort and conservation goal. As can be seen in table 1, both the comfort goal and conservation goal significantly differ across the goal manipulation as expected, $F(1, 79) = 34.0$, $p < .05$ and $F(1, 79) = 26.4$, $p < .05$. However, with value “4” as midpoint of the scale, it is remarkable that both goals score at the “agree” side of the comfort manipulation check, whereas the conservation manipulation check does spread from the “agree” to “disagree” side of the scale corresponding to the goal manipulation. From this can be concluded that the goal manipulation was only partially successful with participants having two goals (a conservation *and* a comfort goal) in the conservation goal conditions and one goal (a comfort goal) in the comfort goal condition.

Table 2. Manipulation checks for the conservation and comfort goal given on a 7-point Likert scale, a lower value corresponds to a higher agreement.

	Conservation goal	**Comfort goal**
“My goal was to set the shower as comfortable as possible” *	2.9	1.7
“My goal was to set the shower as environmentally friendly as possible” *	3.4	4.9

* $p < .05$

10. Overall discussion and conclusions

In this research we studied the effectiveness of one and two sources of feedback on water and energy consumption in a shower task in a field experiment (Experiment 1). The research was repeated in a lab environment with the addition of a goal manipulation to explore the role of comfort in feedback effectiveness (Experiment 2). Results of the field experiment did not provide evidence that the presence of interactive water feedback, energy feedback or both in a shower leads to a reduction in water or energy consumption, as a result of people taking shorter showers, setting lower water flows or lower temperatures. Results did suggest a rise in water temperature when feedback was presented. Although this effect seems counterintuitive, it is in line with earlier research by Ohnaka et al (1994) and Rohles and Konz (1982) who found that when participants showered with lower water flow they increased the water temperature. This negative correlation between water flow and temperature was also found in this research for the energy feedback condition and water & energy feedback condition. This suggests that participants in these conditions made a trade-off between a hot shower with a weaker water jet or a cooler shower with a strong water jet. This is probably due to a limited hot water supply with the result that water temperature is regulated by regulating the cold water flow. When hot water supply is limited participants either reached their desired comfort level by a hot, weak water jet or a cooler, strong water jet. This energy balancing mechanism fits the energy balance thermal comfort theory of Munir, Takada, Matsushita and Kubo (2010). Interestingly, in the water feedback condition a positive correlation between water temperature and water flow was found. This could be explained be the higher mean flow rate found in this accommodation compared to the other to accommodations (47% between accommodation 1 and 3). Probably, no trade-off had to be made because enough hot water was available. These differences in flow rate could also result in different shower experiences which in turn could influence the effectiveness of feedback. Especially when the shower has a low water flow, the shower might not be experienced as comfortable. This in turn can limit the willingness to give up even more comfort to save resources. Future research should therefore use very similar accommodations in order to minimize flow differences over accommodations. Also in both the lab and field study an additional “no feedback” condition could be added to better compare consumption scores of one and two feedback sources against a condition in which participants receive no feedback at all.

One explanation for the lack of water and energy saving is the loss of thermal comfort experienced in the shower. To reduce the influence of thermal comfort the experiment was repeated in a lab setting in which participants completed a virtual shower task on a computer in which bodily discomfort was not present. Another possible explanation was the lack of a conservation goal. Therefore a goal manipulation was added in which participants were either given a conservation goal or a comfort goal.

In line with our expectation the lab experiment (Experiment 2) suggested that participants who had a conservation goal used 22% less water and 25% less energy in a virtual shower task than participants who had a comfort goal. Thereby, the current research suggests that feedback can have stronger persuasive effects when participants have a conservation goal than a comfort goal**.** This fits earlier research by McCalley & Midden (2002) who conclude that conservation is dependent on having a goal to save energy as a primary goal of the user.

We also expected participants to take shorter showers with a comfort goal when presented with water & energy feedback compared to only water feedback. In line with our expectations, planned contrast analysis suggested that a second feedback increased feedback effectiveness by reducing virtual shower durations by one minute (21%). Not confirming our expectation however, analysis did not show an expected interaction effect between goal and feedback type manipulation, nor did the reduction in shower duration lead to lower energy or water consumption. This is however in line with another study (WRc, 2007) which found an inverse relationship between duration and flow rate. This study suggested shorter duration were compensated by higher flow rates resulting in similar resource consumption. Although figure 4 suggests such a compensating effect, neither an increase of water flow nor an increase in water temperature reached statistical significance. This could be caused by the large error bars as depicted in figure 4**.** Future studies on this subject could use more participants for more statistical power or use more equal scenarios to reduce variance. This comfort compensating effect also needs further research. A link with research on rebound effects (e.g. Hertwich, 2005) can also be made. In this context, energy and water saving behaviors such as reducing shower duration might rebound because resource consumption is increased by showering with a higher water flow or temperature.

Another explanation for the lack of an interaction effect was found after inspecting the manipulation checks that were included in a questionnaire. Participants with a conservation goal still indicated to have a fairly high comfort goal although they were assigned a conservation goal. From this can be concluded that the goal manipulation was only partially successful with participants having two goals (a conservation *and* a comfort goal) in the conservation goal conditions and one goal (a comfort goal) in the comfort goal condition. Future research could continue the investigation of whether conflicting goals influence resource consumption.

The combined results from the two experiments do not make a strong case for the effectives of a second feedback source in reducing water and energy consumption in a shower task. However, the lab experiment does indicate an effect of a second feedback source on shower duration. In the field experiment, were participant’s comfort was really affected by resource saving behavior, no reduction was found and the presence of feedback even caused an increase in water temperature. In the lab experiment results showed that feedback can be more effective when people have a conservation goal instead of having a comfort goal. The results of the lab experiment can explain the lack of feedback effectives in the field experiment because in this experiment participants were not assigned a conservation goal. This was deliberately not done because we wanted to research the effect of feedback on resource consumption and not that of goals. Since comfort in the field experiment plays a bigger role than in the lab experiment (where participants could not feel the effect of their shower settings) it is likely that the initial goal of the participants in the field study is comparable or even stronger than the comfort goal condition in the lab study. Future research could try to assign a conservation goal in a field experiment to research if feedback is effective in that case.

To make the feedback more effective in reducing resource consumption other measures can be taken. Feedback could be more social (McCalley & Midden, 2002), it could include a competition or game element, it might use a different type of lighting for instance with color variation, or it might need to be more tailored to the differences in shower behavior between participants.

It can be concluded that in the shower people are not easily persuaded to consume less water and energy. One feedback source did not result in resource saving in the field nor did two feedback sources neither in the field nor in the lab. This study suggested that comfort plays a crucial role and that feedback in the form of LED lightning might not be enough to persuade people to behave more environmentally friendly and to give up comfort. However, this study also suggests that when people have the goal to behave environmentally friendly ambient interactive feedback can positively affect conservation behavior.

11. Acknowledgments

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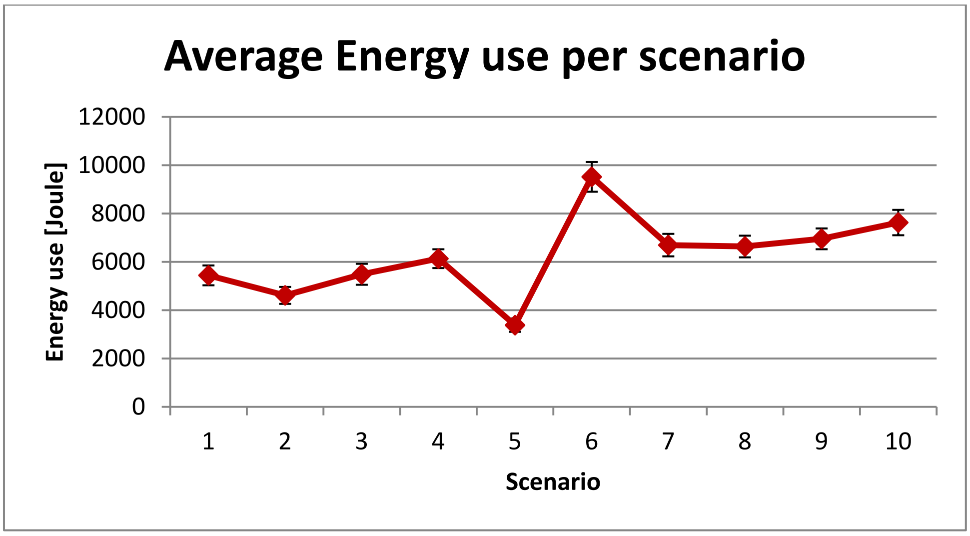
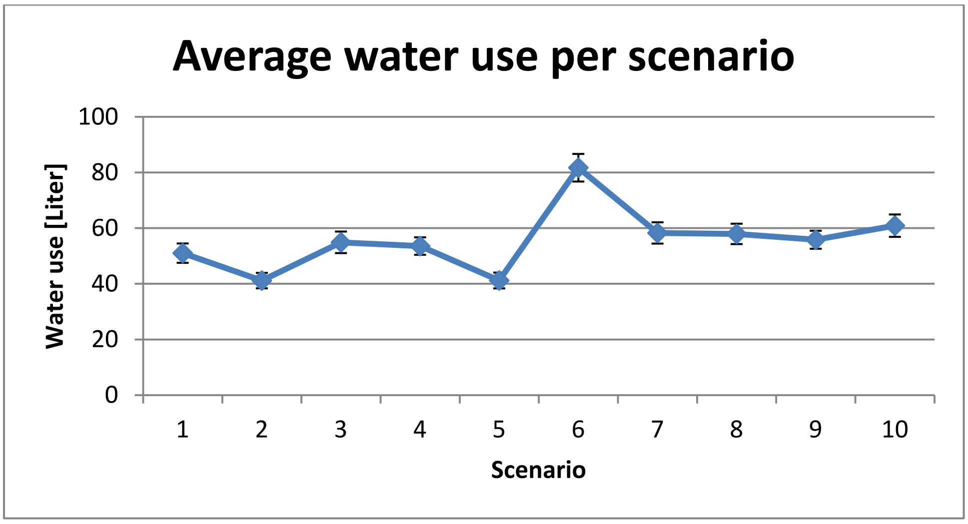
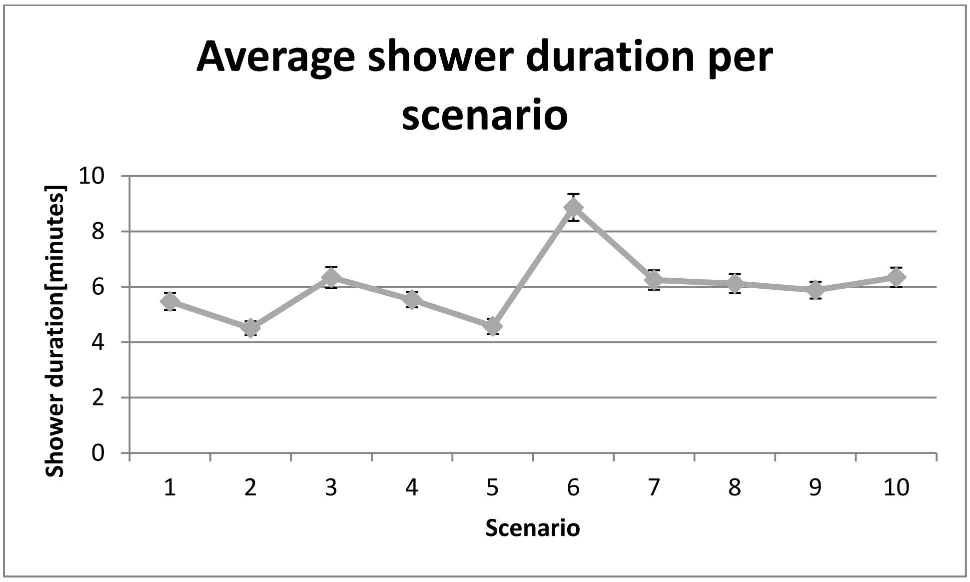
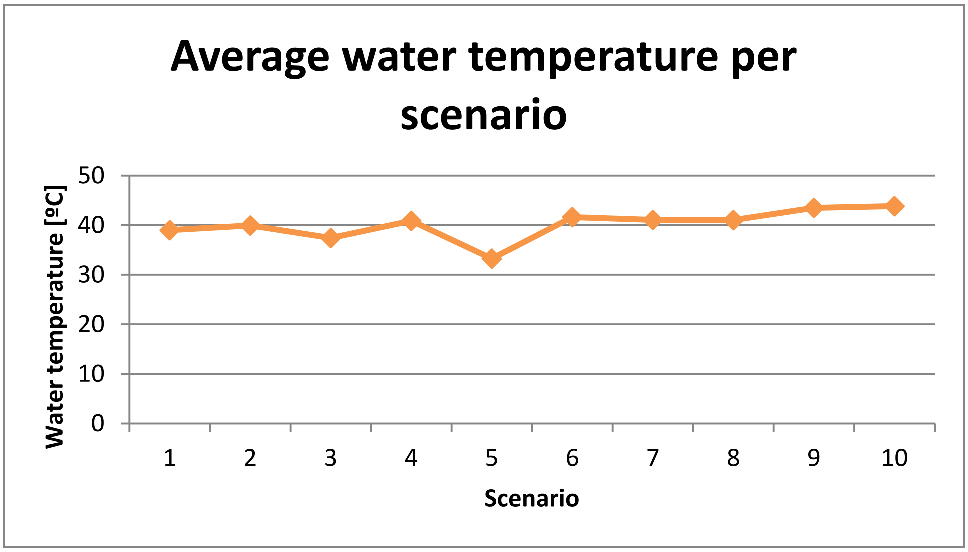
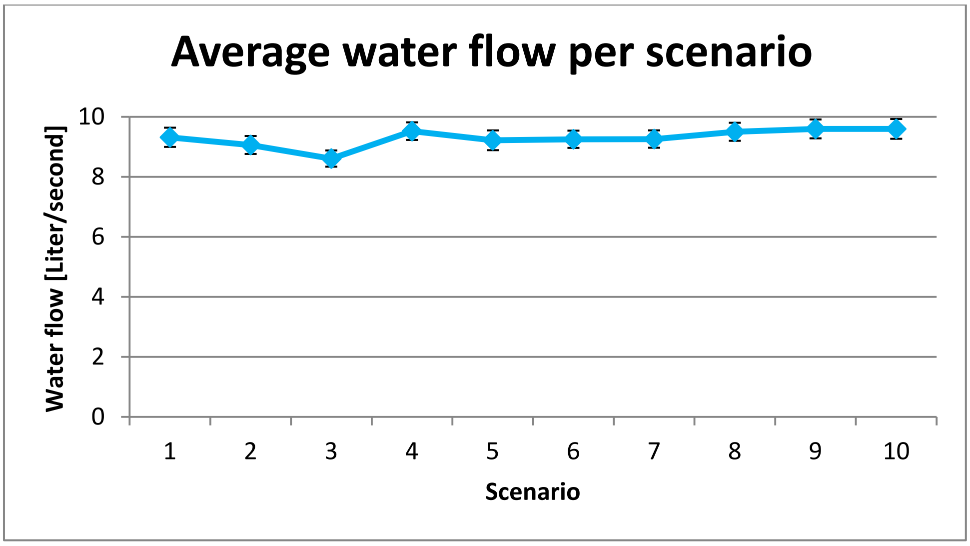
13. Appendix 1: mean dependent variable scores per scenario of the lab study






Average shower duration per scenario
10
8
6
4
2
0
Shower duration[minutes]
1 2 3 4 5 6 7 8 9 10
Scenario


Average water temperature per scenario
50
40
30
20
10
0
Water temperature [ºC]
1 2 3 4 5 6 7 8 9 10
Scenario


Average water flow per scenario
10
8
6
4
2
0
Water flow [Liter/second]
1 2 3 4 5 6 7 8 9 10
Scenario