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ORIGINAL ARTICLE

Reducing hot water consumption through real-time feedback and social comparison using persuasive technologies: evidence from a Swiss energy-efficient district

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Abstract The buildings sector is a substantial contributor to total energy consumption and, according to current forecasts, will remain so in the near future. Technical energy efficiency innovations can reduce energy demand; however, if not accompanied appropriately by building occupants' behaviour, discrepancies between planned and resulting energy consumption will persist, which is known as the building energy performance gap. To tackle this challenge, interventions such as feedback and social comparison are increasingly applied in combination with persuasive technologies. We report the results from a field experiment conducted in a Swiss energy-efficient district where two consecutive behavioural interventions involving persuasive technologies were tested: (1) real-time hot water consumption feedback while showering and (2) a weekly newsletter with social comparison feedback regarding overall hot water consumption, including hot water saving tips, in addition to real-time feedback. Based on the data from 33 households, we found that, compared with the baseline consumption, hot water consumption was 12.4% lower immediately after the real-time feedback intervention and 16.1% lower after the combined intervention. Hot water consumption increased again after the intervention phase, but it was still 9.7% lower than the baseline consumption 2 months after the combined intervention and 8.6% lower 4.5 months after the combined intervention. While the reductions after the real-time feedback and combined intervention were significant, the reductions 2 and 4.5 months after the combined intervention were not.

Keywords Hot water consumption · Real-time feedback · Social comparison · Persuasive technologies · Behaviour change

Introduction

The buildings sector, including construction, accounts for more than one-third of total energy consumption and nearly 40% of CO_2 emissions

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worldwide (United Nations Environment Programme 2020). Despite diverse scenarios for minimising energy consumption by 2050, there is a risk that energy consumption and the production of greenhouse gases in the buildings sector will continue to increase (Santamouris & Vasilakopoulou, 2021). In particular, buildings are expected to be the largest source of emissions by 2040, representing 11% of total emissions (Li et al., 2021). This has given rise to the increasing deployment of energy-efficient buildings with increasingly strict requirements regarding the energy efficiency performance of both buildings and appliances. For example, Switzerland has legally binding regulations (e.g. MuKEn 2014[1]) as well as certificates (e.g. Minergie-P[2]) for energy efficiency in new buildings and refurbishments, and these regulations are tightened every few years. However, these requirements often do not result in expected energy savings, and actual energy consumption can be substantially higher than predicted. This phenomenon, often referred to as the building energy performance gap, has been analysed by several studies, and occupant behaviour has been identified as one of its most important drivers (Far et al., 2022). In particular, occupant behaviour can induce large differences in energy consumption among households with identical equipment and appliances (Pereira & Ramos, 2019; WBCSD, 2009; Lindén et al., 2006; Branco et al., 2004).

Hot water plays an important role in residential energy consumption and is globally responsible for a substantial share of total energy consumption: 19% in the US (Pérez-Fargallo et al., 2022), 14.8% in the European Union (Eurostat, 2018) and 14.4% in Switzerland (Swiss Federal Office of Energy, 2019). Moreover, improvements in building technology, together with increasingly stringent building standards, especially for insulation, have led to an increasing share of water heating in the total energy consumption of residential buildings (Pomianowski et al., 2020).

To influence occupants' energy consumption behaviour, including hot water consumption, several energy conservation measures have been applied, as summarised, for example, by Abrahamse et al. (2005) and Andor and Fels (2018). One way to classify energy conservation measures is to differentiate between efficiency- and sufficiency-related measures. Efficiency-related measures involve technical improvements that aim to maintain current service levels at a lower energy consumption. They are structural and aim to change contextual factors, such as the availability and actual costs and benefits of behavioural alternatives (Steg & Vlek, 2009). Sufficiency-related measures, or curtailment measures, imply changing routines and lifestyles (Moser et al., 2015). Informational by nature, they address motivational factors, such as perceptions, motivations, knowledge, and norms (Steg & Vlek, 2009). Efficiency-related measures are generally considered to be more acceptable than sufficiency-related measures (Poortinga et al., 2004; Steg et al., 2006; Zawadzki et al., 2022). However, efficiency measures often involve so-called rebound effects (Moser et al., 2015), describing situations in which efficiency improvements do not result in a proportional decrease in energy consumption (Schmidt & Weigt, 2015). This has given rise to the suggestion that efficiency measures must be combined with sufficiency measures to achieve energy consumption reduction goals (Notter et al., 2013). While efficiency measures have long been the focus of policy approaches, expected energy consumption reductions have not been achieved (Zhang et al., 2018). Accordingly, there is a need to shed more light on sufficiency-related measures focusing on behaviour change.

Spurred by the progress in information and communication technologies and the digitalisation megatrend, informational strategies are increasingly being applied through so-called persuasive technologies. These were defined by Fogg et al. (2007) as applications of technology to change human attitudes and/or behaviour without applying coercion, manipulation, and deceit. As a framework to analyse the success factors of persuasive technologies, Fogg (2009) developed a behavioural model that identified motivation, ability, and trigger as the main drivers of human behaviour. According to this model, persuasive technologies, such as mobile applications, ambient displays, and persuasive games, act predominantly as a

[1] See https://www.endk.ch/de/energiepolitik-der-kantone/muken.

[2] See https://www.minergie.ch/de/ueber-minergie/baustandards/minergie-p/.

trigger and as motivation. Agnisarman et al. (2018) reviewed 38 papers published between 2000 and 2016 dealing with the evaluation of interventions with persuasive technologies and found that, in 16 of them, behaviour change was reported. While persuasive technologies have predominantly been applied to reduce electricity consumption, hot water consumption has been largely underrepresented.

However, many studies focus solely on the intervention effect on the targeted behaviour and neglect the possible intervention effect on the non-targeted behaviours (Maki et al., 2019), the so-called spillover effects, which can substantially alter the net effects of behavioural interventions. If there is a negative spillover, the environmental benefits of behavioural interventions may be overestimated. If a positive spillover is triggered, we may underestimate the environmental benefits of behavioural interventions. Studies to date have found mixed evidence of spillover effects, including positive and negative effects, and even no evidence of spillover effects (Carrico et al., 2018; Nash et al., 2017; Nilsson et al., 2017; Truelove et al., 2014). However, evidence on the spillover effect of behavioural interventions targeting behaviour related to hot water consumption is scarce.

Against this background, the goal of this study was to contribute to the emerging research agenda by highlighting the crucial role of occupant behaviour in residential energy consumption, specifically hot water consumption and sufficiency-related informational measures based on persuasive technologies. The specific measures analysed in this study were real-time feedback and social comparison. In addition, we investigated whether the real-time feedback intervention resulted in spillover effects on practices not directly targeted.

Theoretical background and literature review

One of the most prominent sufficiency-related informational interventions is feedback. According to Karlin et al. (2015), feedback refers to giving people information about their behaviour that can be used to reinforce and/or modify future actions. The earliest work on the behavioural effect of feedback focused on knowledge of results (e.g. Jones, 1910; Judd, 1905; Wright, 1906). These studies found a positive relationship between knowledge of results and performance. Later research in the field of behaviourism (e.g. Skinner, 1938; Thorndike, 1927) introduced the notion that a desired response to a behaviour serves as behavioural reinforcement while an undesired response serves as punishment. From that point of view, knowledge of desired results can be seen as behaviour reinforcement and knowledge of undesired results as punishment, thus serving to encourage or discourage behaviour. Bandura (1969) expanded this perspective and found that providing a goal and information about progress towards that goal could serve as a form of behaviour modification, much like providing a reward or a punishment. Similarly, goal-setting theory (Locke & Latham, 1990) views behavioural feedback as a form of self-regulation. According to this theory, behaviour is inherently goal-directed, and feedback about performance is needed to evaluate behaviour in relation to goals. Finally, Kluger and DeNisi (1996) introduced the feedback intervention theory based on a comprehensive review of previous theoretical and empirical research. They found that feedback is most effective when it successfully directs the individual's attention to the feedback–standard gap, which should be related to a pre-existing or feedback-provided goal that is relevant for the individual.

On the empirical side, Karlin et al. (2015) conducted a meta-analysis of 42 studies on feedback about energy saving published between 1976 and 2010 and found that feedback was effective overall, although with significant variation between the studies. In addition, they found that several factors moderated the relation between feedback and energy savings, such as frequency, medium, comparison message, duration and combination with other interventions. Recently, interest has grown in the application of persuasive technologies to water use, as summarised by Koop et al. (2019). In a recent study conducted in an urban context in India (an affluent district of the city of Bengaluru), Vivek et al. (2021) tested a 5-week intervention based on weekly reports that included water consumption feedback, water saving goals, and tips. Based on a sample of 356 households, they found an immediate intervention effect of a 16% reduction in water consumption, which not only persisted but even increased to 23% after one year. Tom et al. (2011) tested two interventions: a detailed report on each individual household's water use based on weekly smart meter measurements, including water saving tips, and a visit from a trained water efficiency professional, followed by a written report including the findings and water saving recommendations. While 84% of the households reduced water consumption by an average of 39.05% following the smart meter intervention, 62% of the households reduced water consumption by an average of 20.48% following the visit of the water efficiency professional and the subsequent report. Hence, feedback through smart meters seemed to be more effective, at least in the shorter term. Davies et al. (2014) found a long-term water-saving effect of tailored feedback based on a trial with smart meters and in-home displays (IHDs). The trial included 1923 people living in 630 households and lasted 2 years. Over the duration of the trial, a water saving of 6.8% was observed. Even 3 years after the experiment had ended and the IHDs had been removed, savings were still 6.4%. Similarly, based on a sample of customers of a local energy provider, Tiefenbeck et al., (2016a, 2016b) found that real-time water and energy consumption feedback while showering led to a 22% reduction in energy consumption. Moreover, the reduction in energy use did not significantly decrease after one year, implying the long-term nature of the effect (Tiefenbeck, Tasic, et al. 2016). In another study, Tiefenbeck et al. (2019) found an energy consumption reduction of 11.4% due to real-time hot water consumption feedback under the shower, even when tested on a sample of hotel guests, who, in contrast to customers of a local energy provider, did not opt to participate in the study and were consequently less prone to self-selection bias. However, other studies suggest that water use reduction due to real-time feedback may disappear in the long term. Stewart et al. (2013) found that while showering volumes decreased by 27% immediately after the introduction of a display, they increased to their pre-intervention level after 4 months. Other studies also indicate that salient real-time information about water use in itself may not provide enough motivation to achieve long-term water savings (Boyle et al., 2013; Nguyen et al., 2018).

While previous research has provided robust evidence regarding the saving effect of real-time hot water consumption feedback in different contexts, some aspects still require further investigation. For example, there is little evidence of the possible spillover effect of a real-time feedback intervention in the showering context. Truelove et al. (2014) define spillover as 'an effect of an intervention on subsequent behaviours not targeted by the intervention'. Positive spillover effects occur when an increase in one pro-environmental behaviour is associated with an increase in another pro-environmental behaviour. Negative spillover effects occur when an increase in one pro-environmental behaviour is associated with a decrease in another pro-environmental behaviour. While positive spillover may result from a desire for consistency across behaviours or because an initial pro-environmental behaviour primes environmental concern, negative spillover is often attributed to moral licensing, such that an individual feels morally unaccountable after conducting an initial pro-social act and is less inclined to adopt further pro-social acts (Maki et al., 2019).

In a recent study based on a natural field experiment in 782 apartment buildings in Switzerland with 4775 households, Goetz et al. (2022) found a strong positive spillover from a hot water intervention on room heating, which persisted 1 year after the intervention. The tested intervention included hot water consumption feedback, social comparison, water conservation tips, a 5% energy-saving goal, and participation in a lottery dependent on achieving the goal. Similarly, Jessoe et al. (2021), in a randomised controlled trial including 7341 single-family homes in Los Angeles County, found a 1.3 to 2.2% reduction in electricity use due to an intervention incorporating social norms messaging in the context of residential water use. Moreover, in a meta-analysis based on 22 studies on pro-environmental behavioural spillover, Maki et al. (2019) found that a positive spillover was most likely when interventions targeted intrinsic motivation and when initial and subsequent pro-environmental behaviours were similar.

Unlike Goetz et al. (2022) and Jessoe et al. (2021), who made a somewhat large contextual jump from hot water to space heating and from hot water to electricity consumption, respectively, we built on the findings of Maki et al. (2019) regarding the higher likelihood of a positive spillover in the case of behavioural similarity and formulate the following research questions (RQs) and corresponding hypotheses:

RQ1: What is the effect of real-time hot water consumption feedback provided by persuasive technology on hot water consumption?

H1: Real-time hot water consumption feedback leads to a significant decrease in hot water consumption.
RQ2: How does the knowledge of the occupants change in response to real-time hot water consumption feedback?
H2: Real-time hot water consumption feedback during the act of showering leads to an increase in knowledge related to water and energy consumption related to showering.
RQ3: Is there a spillover effect of real-time hot water consumption feedback on hot water consumption practices beyond showering?
H3: There is a positive spillover effect of shower-related real-time hot water consumption feedback on hot water-related practices beyond showering.

Another widely adopted intervention strategy to change behaviour is the use of social comparisons when providing information and feedback (Abrahamse & Steg, 2013). Many behaviour change interventions involve social comparisons, which refer, according to Festinger (1954), to thinking about information about one or more other people in relation to oneself. Social comparisons activate social norms, which have been defined as 'rules and standards that are understood by members of a group, and that guide and/or constrain human behavior' (Cialdini & Trost, 1998). Cialdini et al. (1990) identified two types of social norms: descriptive and injunctive. While the former reflects beliefs regarding what is commonly done in a specific situation, the latter reflects beliefs regarding what ought to be done in a specific situation. Messages with descriptive norms thus provide information on what the relevant reference group is doing, whereas messages with injunctive norms provide information on what the relevant reference group approves of. According to Cialdini et al. (1990), descriptive and injunctive norms influence behaviour through different motivational mechanisms. While descriptive norms address the desire to make accurate and effective decisions, injunctive norms target the desire to gain or maintain social approval.

Empirical findings show mixed evidence regarding the effect of social comparison on water use, suggesting that messages with descriptive norms alone, such as average consumption, might not be sufficient to trigger consumption reduction, since they might demotivate below-average consumers and even cause a consumption increase in this subgroup (Bhanot, 2017; Landon et al., 2018; Otaki et al., 2017; Schultz et al., 2016). To prevent this and to maximise the net effect, Perren et al. (2016), Schultz et al. (2016), and Schultz et al. (2007) suggest combining descriptive social norms, such as average consumption, with injunctive social norms, such as emoticons. In an influential paper, Allcott (2011) evaluated the famous Home Energy Report Program of OPOWER, which involved social norms (descriptive and injunctive) and tailored energy-saving tips. In this large randomised natural field experiment with 600,000 US households, he found a significant 2% energy consumption reduction, which was equivalent to the effects of an 11%–20% short-term electricity price increase. Previous research has shown that reference group identification amplified the effects of descriptive norm perceptions (Rinker & Neighbors, 2014) and injunctive norm perceptions (Reed et al., 2007). For example, Lede et al. (2019) found that an in-group norms message was more effective in encouraging college students to take shorter showers than a combined descriptive and injunctive norm message that did not highlight the students' university in-group. It has also been shown that descriptive norm messages were more effective when applied as so-called provincial norms, meaning that they are embedded in a social context similar to that in which the person is currently situated (Goldstein et al., 2008).

Against this theoretical and empirical background, we combined descriptive and injunctive social norms within our social comparison intervention and used neighbours as a reference group (in-group norms and provincial norms) to maximise identification with the group and formulated the following research questions and corresponding hypotheses:

RQ4: Does social comparison have an additional effect on hot water consumption when added to real-time hot water consumption feedback?
H4: Social comparison leads to a significant decrease in hot water consumption on top of the decrease caused by real-time hot water consumption feedback.
RQ5: How do social norms regarding hot water consumption change in response to the social comparison intervention?

Fig. 1 Residential district under consideration; left: 3D visualisation; right: map with the excluded building crossed out

H5: The social comparison intervention activates social norms regarding hot water consumption.

Materials and methods

Site description and participants

The residential district used as the research site consists of 8 buildings and was built in 2016 with the aim of sustainable construction and operation. Its building technology systems are based on the motto ‘simple and efficient’. The energy for heating and domestic hot water is generated in a decentralised way in each house using a geothermal heat pump. The domestic hot water supply is designed conventionally with one hot water tank per house. Distribution in the house is via central shafts accessible from the stairwell. Apart from a nursery, the buildings are residential. The district comprises 69 households with approximately 230 inhabitants. Of the eight buildings, one is equipped with a different building technology and was therefore not included in this study due to the lack of comparability (Fig. 1, right, crossed out). An initial survey conducted in Autumn 2017 found that the residents were, on average, 44 years old, that 50% had an academic background, and that 82% were employed. Originally, 39 of the 69 households agreed to participate in the research project, of which this study is a part. Recruitment took place by signing a data protection agreement between the real estate owner and the occupants. In the data protection agreement, the occupants were informed that their energy consumption would be measured and that the corresponding data would be transmitted to the two involved universities of applied sciences, which would analyse these data in an anonymised form for the purposes of a research project. In addition, a separate agreement was signed allowing the real estate owner to forward the e-mail addresses to the project teams of the two involved universities of applied sciences for recruitment purposes for the surveys. After some sample attrition before and during the study (1 household moved before the study began, 1 household refused to install the necessary equipment, 2 households were assessed as inappropriate for the purposes of the study, as described above, and 2 households decided to withdraw from participation during the study), the final sample consisted of 33 households.

The socio-demographics of the participants, according to the survey conducted in November 2017 at the very beginning of the project, are presented in Table 1. The sample does not differ substantially from the Swiss average regarding age and gender, while the education level is much higher, and the household size is much larger in Hüttengraben compared to the Swiss average.

Table 1 Socio-demographics of the sample

	Hüttengraben	Switzerland
Age (M, SD), $N=39$	44.40 (13.02)	41.99[a]
Female (%), $N=39$	48.60	50.42[b]
Education (% tertiary), $N=36$	50.00	30.30[c]
Household size (M, SD, $N=27$)	2.93 (1.00)	2.25[d]

[a] Swiss Federal Statistical Office (2016a). [b] Swiss Federal Statistical Office (2018). [c] Swiss Federal Statistical Office (2017). [d] Swiss Federal Statistical Office (2016b)

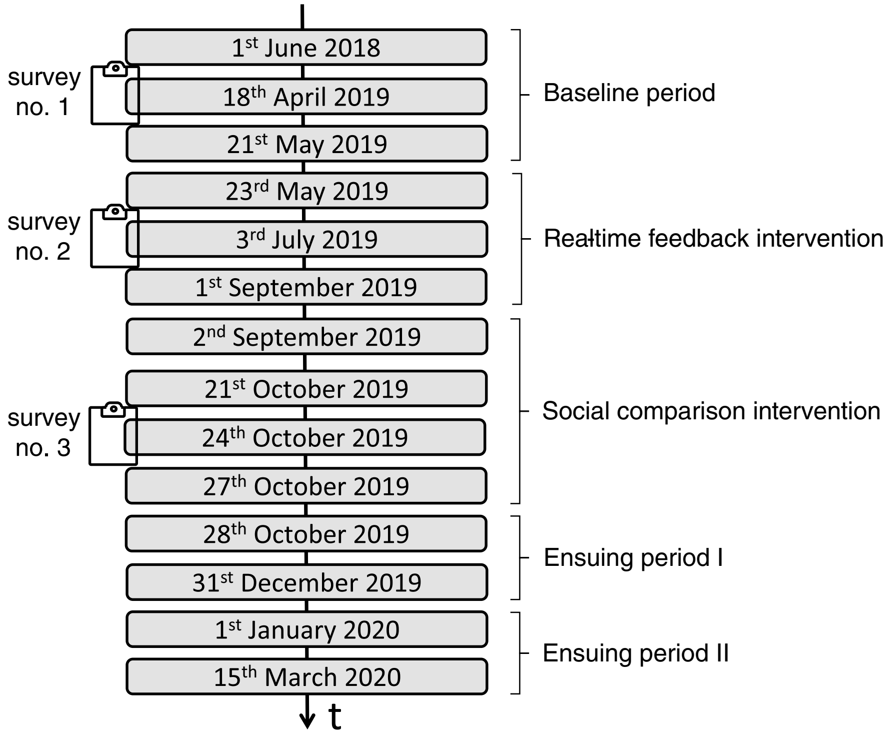

Fig. 2 Different steps of the study design in chronological order

Procedure

Our field trial was divided into the following five periods:

- Baseline period, 1 June 2018–21 May 2019
- Real-time feedback period, 23 May 2019–1 September 2019
- Social comparison period, 2 September 2019–27 October 2019
- Ensuing period I, 28 October 2019–31 December 2019
- Ensuing period II, 1 January 2020–15 March 2020

For 6 households, this real-time feedback period began on 6 June 2019 and 12 June 2019, respectively, since the installation of the necessary equipment was delayed. The two ensuing periods were introduced to study the intervention effects over time. The experiment ended with the start of the COVID-19 lockdown in Switzerland on 16 March 2020, which considerably changed the frame conditions of the research setting (i.e. home offices and closed shops, sports facilities, recreational and cultural facilities and restaurants).

In addition to analysing domestic hot water consumption data, three surveys were conducted partly using the same questions due to the pretest–posttest design. The baseline survey was conducted shortly before the start of the real-time feedback intervention. The second survey was conducted 6 weeks after the real-time feedback intervention. The third survey was launched shortly after the combined intervention (real-time feedback, social comparison, and hot water saving tips). Figure 2 shows the different research design milestones on the timeline.

Interventions

Real-time feedback

After the baseline period, the participating households were equipped with a device called 'Amphiro', which displays hot water consumption in real time while showering. Amphiro is a display that can be installed between the showerhead and the shower hose without any specialist technical know-how. The displayed information includes the real-time water and energy consumption, the water temperature, and the consumption efficiency class (A to G) assigned to a consumer depending on their consumption. The consumption range associated with each class is defined by Amphiro experts based on their experience. In addition, an animation of a polar bear on an ice floe melting as water and energy consumption increase is shown as a reminder of the long-term effects of CO_2 emissions generated by energy consumption. For the sake of completeness, it should be mentioned that in addition to the display, there is also the Amphiro app, which communicates with the display via a Bluetooth connection and offers the following services: (1) information on the showerhead's flow rate, including its efficiency class; (2) energy consumption under the shower expressed as usage times of different common examples of consumer electronics; (3) a game where points are collected depending on whether certain goals were achieved when taking a shower; (4) comparison with the consumption of the Amphiro user community; (5) consumption associated with previous showers; and (6) a 'Did you know?' section containing further illustrations of how hot water consumption under the shower translates into different everyday energy-consuming practices. As only one participant reported using the app regularly in the survey, we assumed that the hypothesised effect from Amphiro came from the display and not the app.

Social comparison newsletter

Fourteen weeks after the installation of 'Amphiro', the social comparison newsletter was launched. Weekly e-mail newsletters were sent to the participants every Monday for 8 weeks. The newsletter included the following: (1) information on household per capita hot water consumption; (2) comparative information on the average per capita hot water consumption of all the households and the average per capita consumption of the 20% of households saving the most hot water; (3) normative evaluation of the comparative statistics with a smiling face if a household's per capita hot water consumption was below average, a smirking face if a household's per capita hot water consumption was (approximately) average and a neutral face if a household's per capita hot water consumption was above average; (4) the household's own hot water consumption expressed as the energy consumption of some common everyday practices, such as the distance travelled in an electric vehicle or the number of hours of lighting with an LED bulb; (5) evolution of the per capita hot water consumption since the first social comparison newsletter (for one's own household, the average household and the 20% of households saving the most hot water); and (6) a new hot water saving tip each week. Online resource 1 includes an example of a newsletter for (1) a household belonging to the 20% of household's saving the most hot water, (2) a household with below-average consumption, (3) a household with (close to) average consumption, and (4) a household with above-average consumption.

Data

Hot water consumption data

Hot water consumption was measured in terms of volume (m^3). To assess hot water consumption, a data acquisition system developed by ENASTRA was used. The system collected 117 data points at 1-min intervals. Via several gateways and intermediate storage, all measured data were merged into a cloud server, retrieved from there, and stored in the university's own monitoring database. This resulted in 168,480 timestamp value pairs per day.

Data pre-processing and calculation of the baseline

The original measurements of hot water consumption (1-min intervals) were aggregated to a daily consumption value per household. Days with fewer than 2 l of hot water consumption per person and household were assumed to indicate absence and were removed from the data analysis.

The impact of ambient air temperature on hot water consumption (e.g. through its effect on the drinking water temperature at tap) was incorporated by assigning specific ambient air temperature windows of 5 °C (e.g. 0–5 °C, 5–10 °C, 10–15 °C, etc.) each day during the baseline period. For each temperature window, day of the week and household, the average baseline hot water consumption was calculated (e.g. the mean of all Mondays between 5 and 10 °C for household A). Hence, every household had its own baseline consumption for every day of the week and every ambient temperature range. This was applied to control for seasonality and possible day-of-the-week differences. The number of days used to calculate each average baseline consumption had to be greater than or equal to 3 and was never larger than 14 (mean: 7.5 days).

The average baseline consumption per household, temperature window and day of the week was compared with daily consumption in the 'Amphiro', 'newsletter', 'ensuing I' and 'ensuing II' periods. The difference between the measured daily consumption from the 'Amphiro', 'newsletter', 'ensuing I' and 'ensuing II' periods and the respective average baselines were used to show the change in consumption.

Surveys

Surveys were conducted using the Unipark online tool. The survey invitations were e-mailed., followed by a reminder 1 week after the first invitation. In contrast to the analysis of the hot water consumption data described above, the unit of analysis in the surveys was the individual occupant rather than the household. This meant that the invitation to participate in the survey was sent to every person in the households that agreed to participate in the study rather than to only one household representative. To incentivise participation, a 50 CHF (roughly 50 USD) voucher for several pre-selected shops was offered to every person who participated in all three surveys. While the baseline survey had a response rate of 49% (32/67), the second and third surveys had response rates of 51% (34/67) and 46% (31/67), respectively.

The baseline survey included questions on self-reported behaviour related to showering and hot water consumption, as well as on equipment used in water-related infrastructure, such as low-flow taps, showerheads, bathtubs, etc. (see Table 9 in the Appendix). In addition, questions on the psycho-social behavioural determinants of showering and hot water consumption were asked (see Table 10 in the Appendix), such as knowledge of one's own hot water consumption and the link between hot water and energy consumption, as well as social norms regarding saving hot water. The second and third surveys consisted of two parts. The first part included the same questions asked in the baseline survey to allow a comparison of the responses between the surveys and to collect standard socio-demographic information from the persons who did not participate in the previous or the baseline surveys. The second part of the second and third surveys consisted of questions specifically addressing general assessment and assessment of the individual elements of the two interventions, as well as questions on household-related circumstances that might have influenced hot water consumption, in addition to Amphiro and the newsletter (see Tables 11 and 12 in the Appendix). The participants were asked, for example, about any absences, guests staying overnight, or household members added since the baseline survey.

Statistical analysis

To compare the hot water consumption data from the different study periods, paired-sample t-tests were applied. Regarding the self-reported practices related to hot water consumption, paired-sample t-tests were applied to the Likert scale and continuous variables, and McNemar's tests were applied to the categorical variables. While there is a debate as to whether parametric or non-parametric tests should be applied to Likert scale variables, we referred to Mircioiu and Atkinson (2017), who argue that non-parametric and parametric tests yield for $n > 15$ almost the same significant and non-significant results, even if the distribution is not normal, and decided to apply parametric paired-sample t-tests. The paired-sample t-test is an appropriate variant of the t-test, since we compared repeated measurements for one and the same case from different periods. In most cases, t-tests directly related to testing the central hypotheses of this paper; consequently, one-sided p-values were considered to measure the significance level. In a very few specific cases where there was no underlying hypothesis, a two-sided p-value was considered.

Results

In the 'Measured hot water consumption' section, we start by comparing the measured hot water consumption from different study periods in answer to research questions 1 and 4. In the 'Self-reported practices related to hot water consumption' section, we compare, based on the survey data, the practices related to hot water consumption between the real-time feedback period and the baseline and between the social comparison period and the real-time feedback period to shed additional light on research questions 1 and 4 and answer research question 3 dealing with possible spillover effects. Finally, in the 'Knowledge about

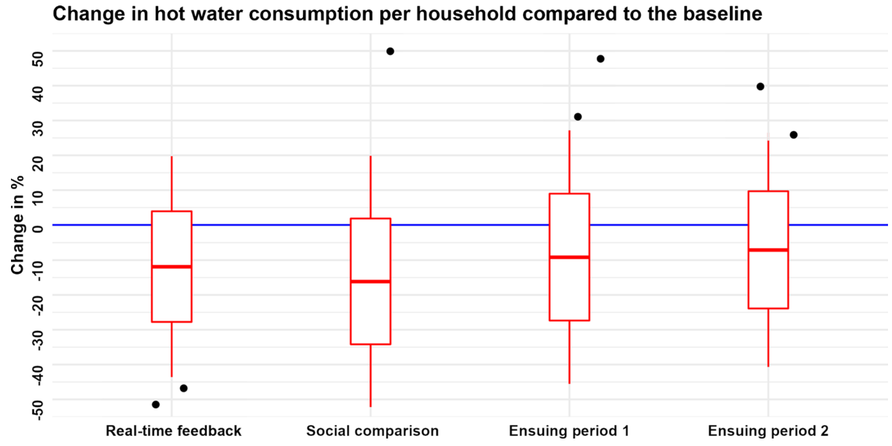

Fig. 3 Percentage change in hot water consumption per household compared with the baseline (blue line). *Note*: The red lines in the middle of the box plots indicate the mean hot water consumption reduction (in %) in the respective period. The half of the box is one standard deviation. The length of the whisker is one standard deviation

Table 2 T-test results regarding the percentage change in hot water consumption in different study periods compared to the baseline

	ΔM	SD	t	df	*p*	Cohen's d
T0–T1	−12.36	14.42	−4.923	32	0.000[a]	−0.857
T0–T2	−16.14	17.37	−5.336	32	0.000[b]	−0.929
T0–T3	−9.67	18.34	−3.029	32	0.175[b]	−0.527
T0–T4	−8.57	15.93	−3.092	32	0.140[b]	−0.538
T1–T2	−3.78	14.76	1.471	32	1.000[a]	0.256
T2–T3	−6.47	14.50	−2.562	32	0.525[b]	−0.446
T3-T4	−1.09	9.11	−0.690	32	1.000[b]	−0.120

[a]1-sided., [b]2-sided. *T0* baseline; *T1* real-time feedback intervention; *T2* social comparison intervention; *T3* ensuing period I; *T4* ensuing period II. *p* values are Bonferroni-corrected

hot water consumption and neighbourhood-related social norms' section, we compare, based on the survey data, the knowledge of hot water consumption between the real-time feedback period and the baseline to answer research question 2 and the neighbourhood-related social norms between the social comparison period and the real-time feedback period to answer research question 5.

Measured hot water consumption

The percentage change in hot water consumption in individual households relative to the baseline is shown in Fig. 3 for each trial period. The blue line (0) indicates no change, positive values indicate increased consumption, and negative values indicate decreased consumption. The four study periods are listed in chronological order on the horizontal axis. During the real-time feedback period, the mean hot water consumption was 12.4% (SD = 14.2) lower than at the baseline. Subsequently, the decrease in the mean hot water consumption reached 16.1% (SD = 17.1) during the social comparison period and then declined to 9.7% (SD = 18.1) in the ensuing period 1 and to 8.6% (SD = 15.7) in the ensuing period 2. The corresponding per-household consumption data on which these percental changes are based are reported in Table 13 in the Appendix.

As shown in Table 2, the decrease in hot water consumption in the real-time feedback period compared to the baseline was significant. This confirms the H1 hypothesis that real-time hot water consumption feedback leads to a significant decrease in hot water consumption. The decrease in hot water consumption was also significant in the social comparison period compared to the baseline. However, the decrease in hot water consumption was not significant in ensuing periods I and II compared to the baseline.

Table 2 also shows that the decrease in the social comparison period was not significantly higher than

Table 3 T-test results regarding the comparison of practices related to hot water consumption between the baseline and the real-time feedback intervention period (metric variables)

	M_{T0} (SD)	M_{T1} (SD)	t	df	*p* (1-sided)	Cohen's d
Showering frequency (no. of showers)	5.83 (1.88)	5.87 (2.24)	−0.153	22	1.000	−0.032
Showering duration (min. per shower)	6.28 (3.14)	6.40 (3.89)	−0.203	24	1.000	−0.041
Showering temperature (scale 1–5)	3.88 (0.73)	3.48 (0.57)	2.619	24	0.280	0.524
Showering water quantity (scale 1–5)	2.68 (0.90)	2.76 (0.66)	−0.527	24	1.000	−0.105
Bathing frequency (no. of baths)	2.00 (1.73)	2.33 (1.80)	−1.160	14	1.000	−0.300
Filling the washing machine (scale 1–5)	4.45 (0.80)	4.45 (0.80)	0.000	21	1.000	0.000
Washing clothes at low temperature (scale 1–5)	4.50 (0.67)	4.59 (0.59)	−0.810	21	1.000	−0.173
Wearing clothes > 1 day before washing (scale 1–5)	3.52 (1.38)	4.13 (1.18)	−1.908	22	1.000	−0.398
Turning water off when brushing teeth (scale 1–5)	3.88 (1.54)	4.46 (1.29)	−1.941	23	1.000	−0.396

T0 baseline; *T1* real-time feedback intervention. *p* values are Bonferroni-corrected

Table 4 McNemar's test results regarding the comparison of practices related to hot water consumption between the baseline and the real-time feedback intervention period (categorical variables)

	Yes (T0)	Yes (T1)	N	*p* (1-sided)
Turning water off when soaping	8	14	25	0.560
Low-flow showerhead	2	4	7	1.000
Water flow restrictor on the tap	1	2	6	1.000

T0 baseline, *T1* real-time feedback intervention. *p* values are Bonferroni-corrected

the decrease in the real-time feedback period. This rejects hypothesis H4 that social comparison leads to a significant decrease in hot water consumption on top of the decrease caused by real-time hot water consumption feedback. In addition, the decrease in ensuing period 1 was not significantly lower than the decrease in the social comparison period, and the decrease in ensuing period 2 was not significantly lower than the decrease in ensuing period 1. The results also suggest large differences between households, as demonstrated by the large standard deviation values.

Self-reported practices related to hot water consumption

To better understand the mechanisms underlying the hot water consumption figures presented in Table 2, we compared, based on the survey data, which is by nature self-reported and thus subjective, the real-time feedback period to the baseline (Table 3 and Table 4) and the social comparison period to the real-time feedback period (Table 5 and 6) regarding practices related to hot water consumption.

Table 5 T-test results regarding the comparison of practices related to hot water consumption between the real-time feedback intervention and the social comparison intervention period (metric variables)

	M_{T1} (SD)	M_{T2} (SD)	t	df	p (1-sided)	Cohen's *d*
Showering frequency (no. of showers)	5.32 (2.00)	5.26 (2.08)	2.52	18	1.000	0.058
Showering duration (min. per shower)	5.70 (3.86)	5.61 (2.92)	1.56	22	1.000	0.032
Showering temperature (scale 1–5)	3.48 (0.59)	3.70 (0.70)	−1.553	22	1.000	−0.324
Showering water quantity (scale 1–5)	2.70 (0.64)	2.70 (0.82)	0.000	22	1.000	0.000
Bathing frequency (no. of baths)	2.46 (1.90)	2.23 (1.88)	0.610	12	1.000	0.169
Filling the washing machine (scale 1–5)	4.26 (0.87)	4.37 (0.68)	−0.567	18	1.000	−0.130
Washing clothes at low temperature (scale 1–5)	4.58 (0.61)	4.32 (0.95)	1.229	18	1.000	0.282
Wearing clothes > 1 day before washing (scale 1–5)	4.20 (1.06)	4.05 (1.28)	0.679	19	1.000	0.152
Turning water off when brushing teeth (scale 1–5)	4.41 (1.33)	4.36 (1.05)	0.176	21	1.000	0.037

T1 real-time feedback intervention; *T2* social comparison intervention. *p* values are Bonferroni-corrected

Table 6 McNemar's test results regarding the comparison of practices related to hot water consumption between the real-time feedback intervention and the social comparison intervention period (categorical variables)

	Yes (T1)	Yes (T2)	*N*	*p* (1-sided)
Turning water off when soaping	15	14	23	1.000
Low-flow showerhead	4	4	5	1.000
Water flow restrictor on the tap	1	1	5	1.000

T1 real-time feedback intervention; *T2* social comparison intervention. *p* values are Bonferroni-corrected

The results in Table 3 and 4 show that there were no significant differences regarding shower-related practices in the real-time intervention period compared to the baseline. The largest effect was observable in the showering temperature, which decreased from 3.88 to 3.48 on a 1–5 Likert scale. The magnitude of Cohen's d (0.524) can be interpreted as a medium effect size (Cohen, 1977). A notable change, although not significant, occurred with the item 'turning water off when soaping'. The number of persons reporting this practice increased from 8 in the baseline to 14 in the real-time intervention period, as shown in Table 4.

Returning to Table 3, none of the items related to hot water consumption practices beyond showering changed significantly in the real-time feedback intervention period compared to the baseline. In addition, there was no significant increase in the number of installed water flow restrictors on the tap, as shown in Table 4. This rejects hypothesis H3 that there is a positive spillover effect of shower-related real-time hot water consumption feedback on hot water-related practices beyond showering. The strongest effect was associated with the items 'wearing clothes more than one day before washing' and 'turning water off when brushing teeth', which both increased in the real-time intervention period. However, the effect size was small, according to Cohen (1977).

A similar picture resulted when showering and broader hot water consumption practices were compared between the real-time feedback and the social comparison periods. Tables 5 and 6 show that none of the differences were statistically significant. The strongest effect (Cohen's $d = -0.324$) was associated again with showering temperature, which, after its initial decrease in the real-time feedback period from 3.88 to 3.48, increased in the social comparison period to 3.70. The magnitude of Cohen's d can be interpreted as a small effect size (Cohen, 1977).

As shown in Table 6, the changes in the categorical variables related to showering and hot water consumption practices between the social comparison and the real-time feedback periods are, apart from one person, fewer reporting 'turning water off when soaping', practically non-existent.

Knowledge about hot water consumption and neighbourhood-related social norms

As shown in Table 7, while self-reported knowledge of one's own shower-related energy consumption and shower water temperature increased slightly after the real-time feedback intervention compared with the baseline, this increase was not significant, according to McNemar's test. This rejects hypothesis H2 that real-time hot water consumption feedback while showering leads to an increase in knowledge related to water and energy consumption related to showering. What is also observable in Table 7 is that the knowledge level of the shower water temperature reported in the baseline survey was already quite high. The item 'knowledge of the interplay between water and energy consumption' (not reported in Table 7) was also intended to measure the effect of the real-time feedback intervention on knowledge. However, since all the participants knew about the interplay between water and energy consumption, according to the baseline survey, an improvement in knowledge could not be expected.

Table 7 McNemar's test results regarding the comparison of knowledge-related items between the baseline and the real-time feedback intervention period

	Yes (T0)	Yes (T1)	*N*	*p* (1-sided)
Knowledge of shower-related energy consumption	10	15	25	1.000
Knowledge of the shower water temperature	20	24	25	1.000

T0 baseline; *T1* real-time feedback intervention. *p* values are Bonferroni-corrected

The results presented in Table 8 show a negligible change in neighbour-related descriptive social norms and absolutely no change in neighbour-related injunctive social norms after the social comparison intervention compared to the situation immediately after the real-time feedback intervention. This rejects hypothesis H5 that the social comparison intervention activates social norms regarding hot water consumption.

Discussion

Discussion of the main results

Our RQs 1 and 4, as stated in Sect. 2, concerned the effects resulting from real-time feedback (RQ 1) and the social comparison intervention (RQ 4). Hot water consumption decreased by 12.4% after the real-time feedback intervention and by 16.1% after the intervention, combining real-time feedback with social comparison compared with the baseline. Both decreases were significant compared to the baseline. However, the additional 3.7% increase associated with the combined intervention was not significant. The decline associated with real-time feedback is in line with research conducted

Table 8 T-test results regarding the comparison of neighbour-related social norms between the baseline and the social comparison intervention periods

	M_{T1} (SD)	M_{T2} (SD)	*t*	df	*p* (1-sided)	Cohen's d
Neighbour-related descriptive social norms (scale 1–5)	2.70 (0.93)	2.74 (0.75)	−0.238	22	1.000	−0.050
Neighbour-related injunctive social norms (scale 1–5)	2.43 (1.04)	2.43 (0.99)	0.000	22	1.000	0.000

T1 real-time feedback intervention; *T2* social comparison intervention. *p* values are Bonferroni-corrected by Tiefenbeck et al., (2014, 2019); Tiefenbeck et al., (2016a, 2016b); and Tiefenbeck, Tasic, et al. (2016), who found that the real-time feedback provided by Amphiro significantly reduced hot water consumption in households. It is also in line with Davies et al. (2014), who found water savings of 6.8% over the duration of a trial that involved tailored feedback provided through a smart meter and IHDs, and Stewart et al. (2013), who found that showering volumes decreased immediately after the introduction of a display providing real-time feedback by 27%. The additional hot water consumption reduction of 3.7% due to the social comparison intervention on top of the real-time feedback intervention is of a similar order of magnitude to the electricity consumption reduction found by Allcott (2011), who reported a 2% electricity consumption reduction due to so-called home energy report letters with a strong focus on social comparison messages. While the 2% reduction reported by Allcott (2011) was significant due to an extremely large sample size (almost 600,000 households), our small sample size (33 households) prevented us from finding a significant reduction, even if it was slightly higher than that of Allcott (2011). Our result regarding the non-significant additional hot water consumption reduction of 3.7% associated with social comparison is substantially less supportive of social comparisons than the results of Schultz et al. (2016), who found that the group that received an intervention with aligned descriptive and injunctive norms in addition to water saving tips was associated with 16% less residential water consumption than the control group. This might, however, be attributable to the different settings of the two studies. The sequential testing of interventions in our study, as opposed to the randomised control trial conducted by Schultz et al. (2016), might have limited the potential for additional reductions from the social comparison intervention since a large portion of the hot water saving potential might have already arisen due to the real-time feedback intervention.

Interestingly, while we found a significant decrease in hot water consumption both after the real-time feedback alone and after the combined intervention (both compared to the baseline), we found no significant changes in self-reported behaviour related to hot water consumption. While some practices, such as taking colder showers and turning the water off when soaping, showed tendencies to increase, these were not significant. Hence, the findings related to the self-reports could be, to a certain extent, seen as inconsistent with the findings related to the observed hot water consumption. This is in line with previous studies, e.g. Corral-Verdugo (1997) and Fuj et al. (1985), that reported a low correlation between observed and self-reported behaviour, demonstrating the importance of research measuring actual behaviour in a real-life setting. Another problem with self-reports is that the reference point might change over time. For example, we could initially perceive water as cold; however, after taking showers regularly at approximately the same water temperature over weeks or months, we might get used to colder showers and, in the end, perceive the water as rather warm.

Non-significant self-reported practices related to hot water consumption provided an answer to research question 3, which deals with possible spillover effects. We found no spillover effects from showering on other behaviours related to hot water consumption in response to the real-time feedback intervention. While we found vague evidence for a decreased likelihood of washing clothes after only one day of usage and turning off the water when brushing teeth (small effect size in both cases), this evidence was not significant. This result contrasts with the results of Goetz et al. (2022), who found a significant positive spillover from a hot water intervention on room heating (5.6% reduction), as well as Jessoe et al. (2021) and Carlsson et al. (2021), who found up to 2.2% and 9% reductions in electricity use, respectively, due to an intervention incorporating social norms messaging in the context of residential water use. In contrast to Goetz et al. (2022), Jessoe et al. (2021), and Carlsson et al. (2021), we addressed the question regarding the possible spillover effect based on self-reported rather than observed behaviour, which might explain the differences in results, considering the generally low correlation between self-reported and observed data discussed above.

RQ 2 dealt with the effect of real-time feedback on knowledge. The results show that while the knowledge on shower-related energy consumption and shower water temperature increased slightly after the intervention, this increase was not significant in both cases. This is in line with claims that feedback can work effectively without reflective decision-making (Hansen & Jespersen, 2013) and without increasing knowledge about one's own consumption (Tiefenbeck et al., 2014). Similarly, Mitchell et al. (2013) found that despite achieving a 5% reduction in water consumption, there was no increase in households' ability to provide accurate estimates of their average daily water use due to home water reports.

Finally, RQ 5 dealt with the effect of social comparison on social norms. We found no significant increase in neighbour-related descriptive social norms and no increase at all in neighbour-related injunctive social norms due to the social comparison intervention. These results are in line with Lede et al. (2019), who found in their trial with an in-group norms intervention that water conservation in-group norms were only marginally, however not significantly, higher in the treatment group relative to the control group. While no significant increase in neighbour-related descriptive social norms could be due to the lack of general perception that the neighbours use hot water consciously, no increase in neighbour-related injunctive social norms might be attributable to not perceiving the neighbours but, for example, the landlord as the sender of the injunctive social norm message included in the newsletter.

Limitations

Our study has several methodological limitations that should be kept in mind when interpreting the results. Out of 69 households living in the district, the study results were based on observations from up to 33 households. Since participation was voluntary, the participating households might be particularly pro-environmental and, hence, prone to so-called self-selection bias (Davis et al., 2013); therefore, the effects of the interventions might be overestimated (Frederiks et al., 2016). Conversely, it may also be possible that these households had already taken measures to save energy, and thus, further savings were more difficult to achieve for them compared with the general population (Tiefenbeck et al., 2016a, 2016b). The results of the survey conducted in November 2017 (N=41) confirmed our assumptions regarding self-selection bias. In the survey, the participants, on average, chose the ‘agree’ or ‘rather agree’ options for the following statements: ‘Climate change is a serious problem that we as a society should actively address’ (M=4.56, SD=0.95, 1–5 scale), ‘Our society is currently overusing the environment’ (M=4.27, SD=0.78, 1–5 scale) and ‘Saving energy is important to me in my everyday life’ (M=3.77, SD=0.95, 1–5 scale). These responses suggest an above-average level of environmental awareness. In addition, the participants reported, on average, that they almost always filled the washing machine to the maximum (M=4.92, SD=1.06, 1–6 scale) and often took short showers (M=4.23, SD=1.18, 1–6 scale), which suggests an above-average baseline level of energy-saving practices related to hot water consumption.

Another limitation is that, due to the small sample size, the evaluations of the intervention effects were conducted using a one-group pretest–posttest design rather than a methodologically superior randomised control trial (Campbell, 1969; Haynes et al., 2012; Vine et al., 2014). Therefore, the chosen research design relativises to a certain extent the causal character of the relationship between the interventions and the savings achieved. A larger sample size would allow us to assign participants to a control group and a separate group for each intervention, including the combined intervention. In this way, we would be able to analyse more precisely the separate effect of the individual interventions as well as other interesting research questions, such as whether the intervention effects are additive, whether the social comparison intervention helped to maintain the effect of the real-time feedback intervention or whether it compensated for the decrease in the real-time feedback effect over time.

Regarding the calculation of the intervention effect, there is also a potential confounding effect of the drinking water temperature since the seasonally dependent drinking water temperature can influence the proportion of drinking and hot water used independently from a possible behavioural adjustment. Without measuring the drinking water temperature at tap we are not able to separate the effect of the drinking water temperature on the hot water consumption from the intervention effect. We try to address this confounding effect by comparing only the consumption on days belonging to the same outdoor temperature range addressing that way at least the issue of seasonality. However, drinking water temperature is a complex issue depending on many other factors in addition to seasonality, as shown by (Agudelo-Vera et al., 2020).

Finally, the monitoring period in our paper (4.5 months) was too short to shed more light on the important question regarding the persistency of the intervention effects, on which there is mixed evidence so far, as summarised by Tiefenbeck, Tasic, et al.(2016). The decision to limit the time frame for data analysis to 4.5 months after the second intervention was made due to the concern about bias caused by the outbreak of the coronavirus pandemic, which was not the focus of this study.

Conclusion

Real-time hot water consumption feedback while showering can induce significant savings in hot water consumption. This finding also held when real-time feedback was combined with social comparison. However, the additional benefit of the social comparison was not significant. While some hot water savings were still there 4.5 months after the interventions, these savings were not significant. Based on the consumption data, our findings thus suggest that persuasive technologies, especially those involving real-time hot water consumption feedback, could be, at least in the short term, effective measures for reducing the building energy performance gap, as they influence occupants' behaviour. However, these results should be cautiously interpreted, particularly with regard to the causality of the intervention effect, since the experimental design did not include a control group. Moreover, the households that participated in this study were likely prone to a self-selection bias towards being more pro-environmental than the average household. This could imply both greater motivation and less potential for additional pro-environmental shifts in behaviour, resulting in either over- or underestimating the savings depending on the net effect of the two aforementioned tendencies.

In contrast to the consumption data, the survey data showed no significant effect on practices related to hot water consumption. Several reasons could be responsible for this, including the small sample and the large number of statistical tests, as well as the general difficulty in measuring self-reported behaviour. While there is some vague evidence based on the survey data of a positive spillover effect from the real-time feedback intervention (which focused on showering) on activities beyond showering involving hot water consumption, these spillover effects were not significant. Interestingly, even if knowledge slightly improved following the real-time feedback, the knowledge increase was not significant, suggesting that the reduction in consumption due to the real-time feedback intervention might be primarily attributable to the change in non-reflective decision-making. On the other hand, no significant activation of neighbour-related social norms due to the social comparison intervention highlights the importance of identifying a reference group, which is not only relevant for the target group but is also likely to be perceived by the target group as conducting the target behaviour much more in the sense of the intervention than the target group. In addition, it highlights the importance of directing much attention to making the link between the message content and the reference group as an emitter of the message as explicit as possible.

Future studies should aim for a larger sample where consideration of a control group and, thus, stronger conclusions regarding the causality of the intervention effect would be possible. A larger sample would also allow the inclusion of a separate group for each type of intervention and thus test the relative effectiveness of different intervention strategies, e.g. the relative effectiveness of real-time hot water consumption feedback and a newsletter providing comparative statistics and hot water saving tips. Furthermore, it would be interesting to shed light on long-term behaviour change and explore how savings could be maintained over time. Another interesting avenue for further research could be to investigate whether the intervention studies in this paper have a positive spillover effect on other domestic activities involving energy consumption, such as electricity or space heating consumption behaviour. In addition, future research could also strive to compare the effects of real-time hot water consumption feedback in different contexts, for example, by comparing the household context studied here with less private contexts, such as a public swimming pool or workplaces. Finally, it would be interesting to analyse to what extent intervention-induced decreases in hot water consumption arise due to the substitution of hot water with drinking water and to what extent due to the overall decrease in water consumption. In addition, further research could test related interventions in technical settings where drinking water temperature is measured to control for the potential confounding effect of drinking water temperature more accurately.

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Declarations

Conflict of interest The authors declare no competing interests.

Appendix

Survey content

Table 9 Items related to showering and hot water consumption

Variable	Item	Scale
Showering frequency	Please make an estimation of how many showers you take per week on average	Number of showers
Showering time	Please make an estimation of how long do you typically take a shower	Minutes per shower
Showering temperature	Please indicate the warmth of the shower you take	1: cold 2: rather cold 3: lukewarm 4: rather warm 5: warm
Showering water quantity	Compared to the people from my surroundings, the water quantity that I consume per shower is…	1: much lower 2: lower 3: ca. the same 4: higher 5: much higher
Bathing frequency	Please make an estimation how many times per month you take a bath on average	Number of baths
Filling the washing machine	Washing machine possibly full	1: never 2: rarely 3: occasionally 4: often 5: always 6: does not apply to me
Washing clothes at low temperature	Washing clothes at low temperature	1: never 2: rarely 3: occasionally 4: often 5: always 6: does not apply to me
Wearing clothes > 1 day before washing	Not washing the clothes after only one day of usage	1: never 2: rarely 3: occasionally 4: often 5: always 6: does not apply to me
Turning water off when brushing teeth	Not letting the water run while brushing the teeth	1: never 2: rarely 3: occasionally 4: often 5: always 6: does not apply to me
Turning water off when soaping	Do you turn off the water when you soap under the shower?	yes/no
Low-flow showerhead	Do you have a low-flow showerhead?	yes/no/don't know
Water flow restrictor on the tap	Do you have one or more water flow restrictors on your taps?	yes/know/don't know

Table 10 Psycho-social behavioural determinants

Variable	Item	Scale
Knowledge of how to save hot water	I know how to save hot water in my household	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Knowledge of the interplay between water and energy consumption	When showering, not only water but also energy is consumed	yes/no/don't know
Knowledge of shower-related energy consumption	I know how much energy I consume when I take a shower	yes/no/don't know
Knowledge of the shower water temperature	I can make a good guess regarding the water temperature when I take a shower	yes/no/don't know
General descriptive social norms	People important to me save hot water	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
General injunctive social norms	People important to me expect me to save hot water	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Importance of neighbours-related social norms	It's important for me to make a good impression on my neighbours	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Neighbours-related descriptive social norms	I have an impression that my neighbours save hot water	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Neighbours-related injunctive social norms	I have an impression that my neighbours expect me to save hot water	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Attitude to hot water conservation	I wouldn't relinquish comfort in order to save hot water	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Attitude to energy conservation	I wouldn't relinquish comfort in order to save energy	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Personal efficacy	The reduction of hot water consumption by every single person contributes to environmental protection	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies
Collective efficacy	The reduction of hot water consumption in households is an effective measure for mitigating environmental problems	1: does not apply at all 2: does rather not apply 3: neutral 4: rather applies 5: fully applies

Table 11 Follow-up questions to real-time feedback

Variable	Item	Scale
Change in the household size	Has the number of people in your household changed (e.g. by moving in or out) since the Amphiro shower display was installed (on 22 May)?	**yes**—> Please briefly describe how the number of people in your household has changed since the installation of the Amphiro shower display (on 22 May) and for what period (from when to when) **no**
Guests staying overnight	Since the installation of the Amphiro shower display (on 22 May), have you had guests staying overnight (e.g. one-week visit, frequent overnight guests)?	**yes**—> Please briefly describe when guests stayed with you since the installation of the Amphiro shower display (on 22 May), for how long (from when to when) and how many were there in each case **no**
Absent for several days	Have you been absent for several days at a stretch (e.g. on a holiday or a business trip) after installing the Amphiro shower display in your shower?	**yes** 1: less than a week 2: 1–2 weeks 3: 2–3 weeks 4: 3–4 weeks 5: more than 4 weeks 6: Generally present less than 50% of the days (e.g. second home) **no**
Self-set consumption limits	Since installing the Amphiro shower display, have you set yourself certain upper limits (e.g. maximum number of litres) or lower limits (e.g. personal minimum energy efficiency class) regarding consumption per showering session that you try not to exceed or fall below respectively?	1: Water consumption of maximum ___ litres 2: Energy consumption of maximum ___ kWh 3: Personal energy efficiency class from A + to G – (A + : very low consumption to G – : very high consumption 4: Temperature of maximum ___°C 5: Ice floe should be ___ (still whole; no more than broken off; still present) 6: I do not set any particular upper or lower limits 1–5—> Do you stop showering as soon as you have gone above/below the upper/lower limit you have set? (yes/sometimes/no)
Satisfaction with Amphiro	Overall, I was satisfied with the Amphiro shower display	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree

Table 11 (continued)

Variable	Item	Scale
Paying no attention to Amphiro	In the last two weeks, I have hardly paid any attention to the display	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Amphiro helpful in saving water	The display helped me save water	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Amphiro helpful in saving energy	The display has helped me save energy	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Amphiro annoying	The device annoyed me	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Polar bear motivating to save energy	The polar bear motivated me to save energy	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Comprehensibility of Amphiro information	The Amphiro shower display shows different information. How understandable was the following displayed information to you? ● Temperature (°C) ● Water consumption (l) ● Energy consumption (kWh) ● Energy efficiency class (A + − > G −) ● Polar bear animation	1: not at all 2: somewhat 3: to a medium degree 4: quite 5: very much

Table 11 (continued)

Variable	Item	Scale
Interest in Amphiro information	Not all the information on the Amphiro shower display is of equal interest to different users. How much attention did you pay to the following information on the display? • Temperature (°C) • Water consumption (l) • Energy consumption (kWh) • Energy efficiency class (A+ − > G−) • Polar bear animation	1: not at all 2: somewhat 3: to a medium degree 4: quite 5: very much
Interaction with other household members regarding Amphiro	How often have you communicated with other household members about the consumption values shown on the Amphiro shower display?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Interaction with neighbours regarding Amphiro	How often have you exchanged information with neighbours about the consumption values shown on the Amphiro shower display?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Discussions with other household members about water/energy consumption	How often have you discussed the general water/energy consumption in your household with the other household members?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Discussions with neighbours about water/energy consumption	How often have you discussed the general water/energy consumption in your household with your neighbours?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day

Table 12 Follow-up questions to social comparison

Variable	Item	Scale
Change in the household size	Has the number of people in your household changed (e.g. by moving in or out) since you received our hot water consumption newsletter (2 September 2019)?	**yes**—> Please briefly describe how the number of people in your household has changed and for what period (from when to when) **no**
Guests staying overnight	Have you had guests staying overnight (e.g. week-long visit, frequent overnight guests) since you received our hot water consumption newsletter (2 September 2019)?	**yes**—> Please briefly describe when guests stayed with you, for how long (from when to when) and how many were there in each case **no**
Absent for several days	Since receiving our hot water consumption newsletter (2n September 2019), have you been absent for several days at a stretch (e.g. on a holiday or business trip)?	**yes** 1: less than a week 2: 1–2 weeks 3: 2–3 weeks 4: 3–4 weeks 5: more than 4 weeks 6: Generally present less than 50% of the days (e.g. second home) **no** **no indication**
Number of newsletters read	How many of the newsletters have you read?	1: none 2: 1 3: 2–3 4: 4–5 5: 6–7 6: all
Satisfaction with the newsletters	Overall, I was satisfied with the newsletters	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Paying no attention to the newsletters	In the last two weeks, I have hardly paid any attention to the newsletters	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree

Table 12 (continued)

Variable	Item	Scale
Newsletters helpful in saving water	The newsletters helped me save water	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Newsletters helpful in saving energy	The newsletters has helped me save energy	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Newsletters annoying	The newsletters annoyed me	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
The newsletters motivating to save energy	The newsletters motivated me to save energy	1: do not agree at all 2: rather do not agree 3: neutral 4: rather agree 5: fully agree
Diagrams vs. text	The newsletter contained different information and forms of presentation. Which form of presentation was more helpful for you?	1: diagrams 2: text 3: both to the same degree
Comprehensibility of the information in the newsletters	How understandable was the following information for you? • Comparison of your hot water consumption with the average weekly hot water consumption of households in Hüttengraben • Comparison of your hot water consumption with the average weekly hot water consumption of the most economical 20% of households in Hüttengraben • Change in your hot water consumption over individual weeks • Change in the average hot water consumption of households in Hüttengraben over individual weeks • Water saving tips	1: not at all 2: somewhat 3: to a medium degree 4: quite 5: very much

Table 12 (continued)

Variable	Item	Scale
Interest in the information in the newsletters	How interesting was the following information in the newsletter for you? • Comparison of your hot water consumption with the average weekly hot water consumption of households in Hüttengraben • Comparison of your hot water consumption with the average weekly hot water consumption of the most economical 20% of households in Hüttengraben • Change in your hot water consumption over individual weeks • Change in the average hot water consumption of households in Hüttengraben over individual weeks • Water saving tips • The graphics in the newsletter are more interesting than the text information	
Interaction with other household members regarding the newsletters	How often have you communicated with other household members about the newsletter contents?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Interaction with neighbours regarding the newsletters	How often have you exchanged information with neighbours about the newsletter contents?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Discussions with other household members about water/energy consumption	How often have you discussed the general water/energy consumption in your household with other household members?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day
Discussions with neighbours about water/energy consumption	How often have you discussed the general water/energy consumption in your household with your neighbours?	1: less than 1 × per month 2: 1 × per month 3: several times per month 4: several times per week 5: (almost) every day

Table 13 Average daily hot water consumption in 4 study periods compared to the baseline (in l/day)

Household	Baseline	Real-time feedback	Social comparison	Ensuing period 1	Ensuing period 2
1	76.1	46.8	47.8	83.5	76.9
2	19.6	14.8	16.4	15.8	15.2
3	139.7	110.9	101.7	126.1	111.8
4	126.5	80.2	120.7	134.2	131.7
5	78.6	58.2	60.1	69.3	74.0
6	207.9	151.9	155.9	168.6	183.2
7	171.1	116.3	104.0	126.6	132.1
8	144.7	127.0	178.4	163.0	147.1
9	103.1	81.5	79.2	96.4	102.6
10	113.4	91.3	95.5	103.3	120.0
11	82.8	69.5	61.8	72.0	63.7
12	136.7	129.6	156.4	179.4	154.4
13	202.7	182.9	183.2	226.8	233.6
14	129.7	114.2	127.6	151.5	137.7
15	53.3	46.0	42.3	58.0	54.9
16	184.7	128.0	130.5	148.6	170.5
17	100.0	81.3	91.3	137.2	145.8
18	247.7	193.7	284.5	287.1	278.6
19	151.5	126.1	134.4	127.0	120.9
20	185.9	139.3	122.3	129.4	127.5
21	136.9	99.7	102.8	129.8	134.4
22	105.9	79.5	68.4	67.5	77.7
23	68.4	57.5	49.3	59.0	66.3
24	302.9	263.3	261.6	354.6	294.0
25	159.6	127.6	117.8	132.9	157.2
26	99.0	90.0	94.1	110.6	108.0
27	178.2	152.8	156.2	179.9	197.7
28	136.2	109.5	119.8	118.0	140.8
29	282.1	217.5	238.2	246.3	281.2
30	189.0	209.7	139.2	153.0	158.0
31	100.8	82.8	66.5	80.9	86.6
32	71.6	65.3	58.3	60.9	62.7
33	220.6	122.1	123.8	136.3	139.1

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