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Inducing [sub]conscious energy behaviour through visually displayed energy information: A case study in university accommodation

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Keywords

Energy use, smart metering, energy feedback, occupant behaviour

Abstract

Direct feedback on energy use presented by in-home displays (IHDs) has been found to be useful in helping people learn about their energy use and make a reduction. However, it is not yet clear what is the best form in which to present energy information. Two six-week experiments were carried out in student residences at the University of Bath, UK, to investigate how visually displayed energy information presented in different ways could encourage reductions in energy use. Experiment 1 compared three energy display interface designs (one giving numerical information, one using analogue dials and one using emotional faces) all presenting the same information. This resulted in a 7.7% savings over baseline. Experiment 2 examined how well participants responded to ranking information in numerical format about their own consumption. This resulted in a 2.5% reduction from baseline. Although there was a trend towards the ambient faces display performing best, all the displays led to a reduction in energy use. A significant decrease in consumption was also seen in the groups that saw ranking information, whether compared to their baseline consumption or to the control groups. In conclusion, it would appear that the mere presence of a display device can reduce energy use, even when participants are not engaged with the display.

Keywords: energy use, smart metering, energy feedback, occupant behaviour

1. Introduction

A common problem encountered by households attempting to reduce their energy use is the invisibility of energy. A lack of feedback on consumption could hinder even those with a good understanding of the impact of behaviour on energy use from using energy more efficiently [2].

In the UK, energy meters are often hidden out of sight and are usually not easily accessible. The only feedback provided, typically, is through quarterly energy bills, where energy information is poorly presented and difficult to understand. This is further aggravated by infrequent meter reading, which means billed usage is often estimated, resulting in lack of knowledge, awareness, motivation and engagement for energy-use reduction. People who pay by regular automated payments (Direct Debit), which is encouraged by most energy providers, are particularly unlikely to receive any feedback on

their consumption as they pay automatically every month without having to open their bills. Pre-payment meter users have strong engagement but feedback is still limited [3, 4].

Another issue preventing users from taking control of their energy use is the mismatched understanding of how much energy each appliance in the house actually consumes. Previous research [5, 6, 24] has looked at householders' understanding of energy use compared with their estimates with actual usage. Results suggested that householders frequently underestimated their heating bills, while energy used for appliances, lighting and cooking was overestimated. The increasing number of electronic appliances with a standby/sleep mode also contributes to invisible energy use and wastage. Electronic devices put on standby/sleep mode continue to result in up to 12% of total domestic energy being wasted [7].

Feedback on energy use presented by in-home displays (IHDs) has been found to be useful in helping householders learn about their energy use and make energy-use reductions at home [1]. However, there are very few studies that investigate the presentation of energy information on real-time displays [26, 27], and it is not clear whether different display presentations of energy information benefit energy users equally. There is also a need to understand what motivates energy-efficient behaviour and how to maintain this over various periods of time.

The present work examines the impact of energy smart meter display designs in a live context through two quasi-experiments[1], one looking at the effect of different types of display design and one investigating self and peer comparisons. The experiments were conducted in a student residence at a UK university. Although people living in university accommodation might not in some respects be representative of typical householders, university accommodation provides a well-controlled environment to study the effects of short-term energy saving interventions on users' behaviour for a number of reasons:

1. The study venues are in buildings with similar physical and construction characteristics, services, room layout and size, and appliances. These properties cannot be modified by their inhabitants;
2. Participants may have similar demographic features in terms of age, education level and environmental attitude;
3. Student households may have similar size, lifestyle and composition.

On the other hand, there are ways in which university accommodation might show differences from residential settings. Students, unlike homeowners or tenants, are charged the same all-inclusive fees as their neighbours and do not receive bills or information on their energy consumption. This means they do not have a financial motivation to reduce consumption and might not be conscious about the energy demands or their behaviours [8]. Conversely, however, as many of the students are living away from home for the first time in their lives, this may be the best time to introduce the concept of energy awareness

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[1] A quasi-experiment allows the researcher to assign participants to conditions by using set criteria, but usually without control over the manipulated variables, e.g. male or female. Therefore quasi-experiments lack random allocation of participants to conditions or control, but are often the only method available when studying phenomena in real-world settings [23].

before their habits have been formed [9]. If students can be made aware of their energy consumption by providing them with direct feedback, and if they feel motivated to save energy through rewards or comparisons (whether self- or other-related), this work could potentially become a useful learning opportunity for them to develop energy conscious behaviour.

2. Experiment 1: display design types

2.1. Background

Previous research suggests that people are more likely to adopt energy-efficient behaviour if they can see their energy use and savings [10, 11]. Electronically displayed feedback provided by IHDs can help make energy use visible, by thus making the link between actions and their effects more immediate and salient to the householder. Such intervention could help raise awareness of energy consumption and possibly motivate energy savings.

While many studies [e.g. 1, 8, 12] have shown general support for a positive effect of IHDs on reducing energy consumption, there is a wide range of variations in the presentation of feedback and it is not yet clear as to how such visual feedback should be best presented. Now that the general utility of IHDs has been established, it is important to begin a process of optimising their design. The work presented in this paper builds on a previous laboratory experiment [13]. This earlier study examined different types of energy display design, assessing participants' subjective preferences as well as how easily people could detect changes on the various displays when they were looking for these changes. The present study built upon the last by looking at how these displays worked to influence energy behaviour in a residential setting, where people might or might not be actively looking for information on their energy use.

This last issue is important because numerical displays, which are used on most current IHDs, provide detailed and quantitative information but will likely require users to make a specific effort to study the information. As such, they might reasonably be expected only to work in real-world setting with people who are already engaged with issues of energy use. Analogue dial displays (speedometer dials were used in the experiment) illustrate the scale of consumption and might make it easier to compare and evaluate past, current and future states of energy use than numerical displays [14]. Ambient displays make use of colours, flashing lights, sounds or pictures to provide a general impression to the situation and do not require users' detailed attention [15]. Two-dimensional cartoon-like faces with emotions representing different energy use levels were introduced in the ambient design in the laboratory experiment [13] for their attention capturing property [16, 17].

Our working hypothesis was that the extent to which a display influenced behaviour would be a function of the extent to which it required active engagement from a user, with the ambient faces design likely to have the greatest influence and the numerical design the least.

2.2. Methods

2.2.1. Participants and baseline

The study evaluated electricity consumption[2] of a student residence[3] for first-year undergraduate students, which occupied the top five floors of a nine-floor campus building at the University of Bath, UK, in a six-week period between 16 February and 28 March 2012. Each floor had four kitchen groups consisting of between six and nine students per group. Each group had two separate sub-meters measuring electrical lighting and power in the kitchen, corridor, shared bathroom and study bedrooms, and so between these all the students' residential energy use was captured. A total of six kitchens, shared by seven students each, on floors 7, 8 and 9 were selected as experimental groups. Two of the remaining non-participating kitchens were used as controls[4].

Twelve days prior to the start of the experiment were used as the baseline period[5] in the analyses. Neither the control nor experimental groups were informed of when the baseline period was at any time during the experiment. These baseline data were used to show participants how their current energy consumption compared to their consumption before the study began. The idea of establishing baseline from historical data was rejected as there was no clear way to establish whether consumption by the groups under study would be comparable to student groups in previous years[6]. Prior to the study (but after the baseline period), students were told that a "winner takes it all" financial reward of £20 sterling would be given to each member of the group that showed the lowest electricity consumption by the end of the experiment.

2.2.2. Sensing and software architecture

The sensing and software architecture of the experiment is based on the existing network and smart-meter systems in the university campus buildings. Smart-meters installed in this residence are part of a commercial campus wide deployment. In this context, a "meter" represents any device that reads and transfers a building's total consumption, while a "sub-meter" represents a device that reads and transfers information of parts of a building. All meters and sub-meters are connected to a gateway device, which allows communication between the meter network and the campus network. The installed system collects data from the meters through gateway connections and stores them in Microsoft

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[2] This was considered appropriate since the study was designed to test differences in presentation for the same end use, rather than responses to different end uses. Further, on-campus electricity sub-metering is widespread with over 1,100 sub-meters on campus whereas meters for other end uses are at aggregate level (typically 4-5), limiting our ability to use them in these experiments.

[3] This particular student residence, unlike most of other campus residences at the University of Bath, had Wi-Fi coverage and separate meters for each kitchen, which meet the requirements for the wireless data technology to be used to monitor individual kitchen groups.

[4] Not all the historical consumption data of the non-participating groups in Experiments 1 and 2 were retrievable. Therefore the number of control groups in both experiments was different.

[5] Baseline period is the time period during which no energy saving interventions are installed and the consumption data from which are representative of the average level, so that the data can be compared with those from the experimental period (when interventions are installed) in order to determine the effectiveness of these interventions. The lengths of the baseline periods were different in Experiments 1 and 2 to account for the timing of the teaching terms during which the experiments were conducted.

[6] Further work on whether it is possible to establish baseline using long-term historical data is currently underway using signal processing techniques.

Access database files. These files are saved on a networked computer on. While the system can poll the meters and sub-meters at sub-minutely level, owing to the particular design of the system and the large number of meters on campus, readings are currently half-hourly.

At the front-end of the system architecture, ten-inch android tablets, running a custom-written application, were used to present meter readings in each kitchen. The tablets require continuous power supply and were fitted in the kitchens in a custom-modified polyester cabinet with a tilted viewing panel and a lockable door, which was mounted approximately 1.8 m above floor level (Figure 1 – Figure 2).

The tablets and the Electronic Data Store (EDS) were on different data networks. Therefore, an integrated system architecture design was necessary to procure the tablets' frequent communication with the database (Figure 3).

As shown in Figure 3, the link between the tablets and EDS was established through the use of a local Extensible Messaging and Presence Protocol (XMPP) server and a data feed application. XMPP is a messaging protocol used in online "chat" environments such as "Google Talk". In our implementation, each tablet used this service to "chat" with other tablets and the experiment monitor application. Presently, the XMPP server uses the public jabber.org server for communications. While this meant that the data being posted was notionally "public", no publicly identifiable / human-readable data were posted. This setup could easily be replaced with a custom installation on a local machine in future for more rigorous data security. The "Data Feed" application acquired half-hourly data from the EDS using Structured Query Language (SQL) queries, which were then transmitted to the tablets. Similarly, visual presentation application "Sensor Visualiser" on the Android tablets also had an XMPP client to receive the meter data to display. Finally, a "heartbeat" monitor application was written to monitor the experiment remotely. Using the same XMPP protocol, this application could detect any malfunction or latency in data updates so that fixes could be issued or the tablets could be reset.

Although the building separately sub-metered lights and small-appliance power for each kitchen, these data were combined to present an overall consumption figure for each kitchen group to reduce complexity for the participants.

2.2.3. Experimental design

Three display designs were used to represent energy information: numerical design, analogue dials design, ambient faces design (Figure 4 – Figure 6). Each design was displayed to the students for two weeks before changing to the next one. Table 1 shows the rotation schedule. All six possible orders of the three display designs were tested (hence six experimental groups).

The consumption ranges were determined from the baseline period. Three types of ranges were computed:

A. Half-hourly: A maximum and minimum range limit for each half hour of the day was calculated cumulatively from midnight. For example, if the limits for 09:00:00 to 09:29:59 are 10-22 kWh (i.e. energy consumed since 00:00:00), the range is

divided by 3 to give:

"low" range: <10 to 14 kWh

"average" range: 14 to 17.9 kWh

"high" range: 18 to >22 kWh.

Figure 10 shows the normal probability plot of the data used to construct the ranges with the above thresholds highlighted using green dotted lines. The plot shows that the data are approximately normal, though likely to have long tails. This is unlikely to affect their use to determine ranges for the displays since we are primarily interested in deviations from the average range.

B. Daily: Daily average weekday and daily average weekend.

C. Weekly: A daily average range for the entire week from a weighted average of the weekday and weekend averages in (B) above.

Consumption data were updated every 30 minutes on all displays along with the range information for that half-hour. Bluish-green (RGB (0, 158, 115)) and vermillion (RGB (213, 94, 0)), which can be distinguished by people with deficient colour vision [18], were used to represent low and high consumption levels respectively, with black used for average consumption level for each of the three displays[7]. For the ambient faces design, happy face, neutral face and sad face were used to represent low, medium and high ranges, respectively, combined with appropriate range colour for consistency. This effectively overloaded the information content for this display (i.e. information on consumption levels was being conveyed through two mechanisms simultaneously: colour and emotion).

The design consisted of five display components:

1. The component "Today So Far" showed the cumulative energy consumption in kWh from 00:00:00 for that day at the time of data update. The range information was obtained from (A) above.

2. The component "Yesterday" showed the total cumulative consumption value of the preceding day between 00:00:00 and 23:59:59, and the value stayed the same throughout the current day. The range information was obtained from (B) above.

3. The component "This Week Average" showed the daily average consumption in the current week computed for all completed days (i.e. the display was blank for Monday, with Friday showing the average over Monday to Thursday). The range information was obtained from (C) above.

4. The component "Last Week Average" showed the average daily consumption in the previous week and the value stayed the same for all of the current week. The range information was obtained from (C) above.

5. The component "Group Ranking" showed the given group's rank compared to the other five groups at the time the data were updated. The values ranged between 1 and 6, the smaller the value the higher level the rank. This component was updated

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[7] A previous laboratory experiment did not reveal significant difference in task performance between colour and black-on-white images and could therefore be considered to have set an upper bound of the effectiveness of the use of colour [13]. The present experiment does not intend to establish the validity of the results reported in [13] and therefore more work would be required to confirm if they continue to be true in a "live" context.

half hourly and was calculated based on the total energy consumed from the start of the experiment.

2.3. Results and discussion

Table 2 and Figure 7 show daily energy consumption, compared to the mean baseline consumption of 18.27 kWh per day, for the users of the three display designs. Ninety-five per cent confidence intervals are included on the plot, so that any error bar ranges that do not cross zero show a change in mean daily consumption that is statistically significantly different from zero change. This works because, in line with the Central Limit Theorem, replicates assessing a true population effect size will produce a sampling distribution normally distributed around that true effect size; it is therefore justified, on the assumption that the population standard deviation can be estimated from the sample standard deviation, to apply confidence intervals derived from a normal distribution to a point estimate to assess the plausibility of that point estimate including or not including a given value – in this case a change of zero [25].

A mean daily average reduction of 1.3 kWh (approximately 7.7% below baseline) was achieved. Given that the 95% confidence intervals of all three designs excluded zero change, the changes were each significant at the .05 level. The confidence interval for the control group's change *did* include zero, indicating that their change from baseline is not reliably different from zero. The effect sizes also supported the idea that all three designs showed non-trivial changes in energy use, but the ambient faces design appeared to be the best-performing display type, and it was significantly different to control as shown by the non-overlapping intervals in Figure 7.

Although the ambient faces design seemed to work the best among the three display designs, it was not a big enough difference to achieve statistical significance – there is currently the possibility, in the absence of further data, that the three designs presenting the same information might communicate equally well to participants.

In the previous task-based laboratory experiment [13], the numerical display was found to perform better than the other displays when the task was specifically to spot changes in the information being displayed. In the present experiment, where participants were not focused solely on the task of distinguishing changes in the displays but rather were asked to carry out their other daily tasks as usual, the numerical display had no advantage. This demonstrates that low-level usability studies, which focus on the perceptibility or interpretation of displays rather than the influence of those displays on energy consumption behaviour, are likely not a good guide to whether a smart meter will influence energy use in real settings. In a similar vein, in both the previous laboratory study and in the present experiments, users reported a subjective preference for the numerical designs – given the choice, they said they would rather see numbers than other displays. But despite this, there is no increased reduction in energy use amongst people seeing this display – indeed, the ambient faces display appears to have the advantage. This suggests that simply asking people what they prefer in a display is not a good guide to smart meter design if the primary goal is to reduce energy use.

3. Experiment 2: self-relative ranking

3.1. Background

Information provision is commonly used to increase knowledge and awareness, with the aim of changing behaviour. It has been suggested that information that allows comparisons to take place will be particularly effective in facilitating behavioural change [19]. Such comparisons can be self-relative (a person's current behaviour is compared to their past behaviour) or other-relative (a person's behaviour is compared to other people's behaviour at the same time). According to social comparison theory, comparison with others reduces uncertainty and helps establish personal behaviour, suggesting that other-relative comparisons should provide an effective mechanism for providing energy savings [20, 21]. This was consistent with findings in a follow-up survey to Experiment 1 that, out of the five display components shown (see Section 3.2.3), participants paid most attention to the ranking component. However, early trials in the UK suggested that scepticism over the accuracy of readings hindered the use of other-relative comparisons and that self-relative comparisons were much better received [4]. To revisit this issue, Experiment 2 sought to test self-relative comparisons (though remaining in the context of other-relative comparisons, see Section 4.2.2).

This was supplemented by testing a reward scheme that complemented self-relative comparisons. Rewards are known to motivate behavioural change and can usually be offered after a behaviour and can take various forms. Monetary rewards are in the forms of either direct payments to save energy, or financial savings accrued from reducing energy use. Emotional rewards, such as enhanced self-esteem, could prompt people to carry out actions for the good of society or act in more environmentally responsible ways [19], even in the absence of financial incentives [21]. Although rewards can certainly help to initiate a behaviour, there is little research on whether such rewards motivate longer-term energy reductions. Our primary goal in this experiment was to make the savings obtained via self-relative comparison more salient by converting them into appropriate monetary rewards.

3.2. Methods

3.2.1. Participants and baseline

The study again evaluated electricity consumption of the same six groups of students as in Experiment 1. It was carried out four weeks after Experiment 1 ended using the same sensor framework described in Experiment 1, but using a modified display containing new metrics. The rooms were fully occupied by the same students in both experiments. This experiment looked at whether introducing a simplified source of information could provide additional energy savings over and above those already achieved in Experiment 1.

Nine days prior to the start of the experiment (after Experiment 1 ended and during which the displays were switched off) were used as the baseline period in the analyses, and 11 of the non-participating kitchens were used as controls. The experimental period ran from 25 April to 2 June 2012. Once again, neither the control nor experimental groups were informed of when the baseline period was at any time prior to or during the experiment.

Students were appraised of the terms of the reward prior to the start of the experiment (but after the baseline period), as described in 4.2.2 below.

3.2.2. Experimental design

To test the effectiveness of self-relative comparisons, Experiment 2 used just the ranking component from Experiment 1 (since it was preferred to the other metrics) with a supporting component to express the ranking information more clearly. The display was updated once a day and the two display components were produced as follows (Figure 8):

1. The ranking component now calculated rank based on improvement against one's own baseline. For example, if Group A saved 4% and Group B 3% compared to their baseline, Group A would rank higher even if its absolute consumption in kWh were higher.

2. It was also clear from Experiment 1 that although the ranking component was preferred, this component by itself does not convey a lot of information because it is an ordinal scale. For example, for 3 participating groups A, B & C with reductions of 4%, 3% and 8% the rank order would be C, A, B. On seeing this, group A might reasonably, but mistakenly, assume that they are half way between C and B. To convey the degree of separation between groups an artificial 'distance factor' was created. Further, to make the savings more salient, the distance factor was converted to a reward. Energy savings expressed in monetary units (based on a pre-determined artificial monetary rate of £0.35 for every unit of energy saved). These "earnings" were based on daily cumulative savings until the end of the experiment and were split among group members. Unlike Experiment 1, therefore, every member of every group stood to gain a reward provided they had cumulatively saved energy from their own baseline over the experiment period.

3.3. Results and discussion

An overall daily reduction of 0.4 kWh (2.5% savings) was achieved with the ranking display compared to baseline average of 16.43 kWh. Figure 9 shows that there was an overall decreased consumption trend in both the control and experimental groups over the six-week study period likely due to increasing day length reducing the need for artificial lighting[8] (analysis of covariance revealed a significant change in energy consumption over time $F(1,74) = 10.56$, $p = .002$). Although the analysis showed that the control group and experimental group did not differ in their overall consumption ($F(1,74) = 1.14$, $p = .288$), the difference in the downtrend of consumption over time was found to be significant between groups ($F(1,74) = 6.62$, $p = .012$), with the experimental groups showing a steeper decline in energy use. The smaller savings could also be a result of the perceived value of the proffered reward (£0.35p / kWh), though this would require further testing with a range of values.

The way participants used energy and the decisions they made to maintain their energy-conscious behaviour were influenced by the type of information presented on the display.

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[8] The effect of day length is not relevant for Experiment 1 as each design type was tested for two weeks six times, and the change in day length over a two-week period was assumed not to be sufficient to introduce a large effect.

In particular, ranking information seems to have powerful and complex effects on behaviour. For comparison, an interesting result from Experiment 1 was that where participants competed with other groups, the high-ranked energy use groups showed a greater tendency to take action to reduce consumption, presumably motivated by a desire stay on top of the displayed rankings. The low-ranked energy use groups, in contrast, showed no evidence of taking action in response to the information on the displays. This suggests that peer comparison does not work for everyone, and that high- and low-ranked energy use groups, when put in comparison, respond differently. High-ranked energy use groups react strongly to the feedback and stay motivated to use less energy. Low-ranked groups, in contrast, lose interest in the face of the challenge and stop trying to improve. A different pattern was seen in Experiment 2, however. Here, participants saw their current energy use compared only with their own past behaviour (though in the context of others' savings) and were more motivated even if the savings were comparatively smaller. It is possible that the advantage for self-referenced information over other-referenced information arises because the outcome of a self-referenced process is entirely within one's control, whereas the outcome of an other-referenced study also depends upon the uncontrollable actions of other parties. Further research might usefully explore this in more depth.

We note, however, that in real settings the introduction of a pure self-comparison system of this sort could effectively penalise people who have previously been living energy-efficient lifestyles: they, unlike people who have been excessively consuming energy, lack ready opportunities to make substantial reductions. In real settings, then, the results of the experiments taken together might suggest that self- and other-referenced feedback systems could both usefully be implemented, with other-referenced information given to those already living more energy-efficient lifestyles and self-referenced information given to those whose current energy use is high.

4. Limitations and future works

a) Time limit: the experiments were conducted in a university residence environment, which posed a restriction on the study period to term times only, post-study monitoring could not be carried out. Future work will include revising the experimental design and repeating the experiment over the coming academic years. Data collected on short-term basis could be useful for resources management at universities to identify the general trend of resource consumption in each term time and to devise external motivations for reductions. Short-term motivations could be more powerful than those that are long-term based, as recurrent feedback, awareness and rewards could keep the interest going and goals achievable.

b) Sample size and type: the experiments were limited to the context of university residences, and a small number of participating groups were involved. Results could therefore be affected by factors peculiar to this population. For example, a recent study on the same population revealed relatively low levels of environmental concern amongst students at this university [23]. Similarly, qualitative research recently carried out on this population confirms a tendency amongst some to consume energy without moderation as a result of the all-inclusive payment scheme

which does not reward energy saving [24]. Studies on energy consumption behaviour in different contexts are also underway. A field trial is being undertaken to study user response to a similar visual presentation of energy data in an office environment. Work is also being planned for a large-scaled residential project including 200 homes over a 12-month period, aiming to promote energy literacy and internal motivations. More experiments are expected – and need to be – to be conducted in real world households and in other types of campus building for an extended duration to establish the validity of these results.

c) Motivations: the financial rewards for achieving savings in each experiment did not appear to be universally attractive to everyone involved. The intention when providing this financial payment was to simulate the money savings a householder might make by reducing their energy consumption – a step that was likely necessary to increase the validity of this study given that the student participants here paid a fixed amount regardless of how much energy they consumed. The amount of the reward was set based on usual research practice at this institution, and with a view to keeping the amount of money in the same order of magnitude as the householder savings being simulated. The fact the reward was not equally appealing to everybody raises the question of whether participants reduced their energy consumption for a variety of reasons, including self conscience, a "feel good" state of mind, the competition element, the information provided, and/or existing environmental attitudes. However, in real household settings it is likely that a similar range of motivations will be at work, with some people addressing their energy consumption as a result of their environmental values and others doing the same behaviours for other reasons, including pure money saving. Given this position, and given that the motivation might vary in depth across people – with some being deeply motivated owing to their personal values and others being more superficially motivated owing to the short-term financial rewards – it will be useful in the future to explore further the relationship between reward structure and individuals' values and goals, with a particular view to devising motivations – perhaps tailored to the particular values and goals of an individual – for developing long-term behavioural change, particularly with a view to keeping people carrying out energy-saving behaviours until such time as these behaviours become routine or, better, habitual [cf. 22], and so become executed automatically even in the absence of reward or feedback structures.

d) Types of information: one type of information was studied in this work, but it was not clear if the same energy-use reductions would be achieved with information provided in other units, such as CO_2 or cost instead of kWh. It is possible that energy displays will work best to with a mix of information types, so "pure" and "hybrid" studies need to be conducted to get a better understanding of how this works. More studies are also necessary to answer questions on how much information actually influences behaviour, and if users really take advantage of the information provided by the displays, or merely see them as reminders to reduce energy use [12]. Furthermore, studies are needed to evaluate the frequency of updating information and the time length of providing information.

e) Hawthorne effect: although participants might have behaved differently knowing that they were being studied, it is not known how large such effect might be in these experiments. It may be reasonable to assume that it did not last the full length of the experimental period. Similar studies with a longer period will be required to address this limitation.

5. Conclusions

This paper presents two short-term experiments conducted in student residences with small financial rewards for participants. Three smart meter display design types were compared, and the role of self-comparison and social comparison ranking was examined.

Average measured daily electricity consumption reduced significantly more than in control groups for all three smart meter display designs tested in Experiment 1. The same participants showed even further reductions in consumption when a self-comparison ranking display was introduced in Experiment 2. Overall savings were around 8%, and whilst it is not clear yet whether one display design works better than the others to reduce energy use, it is apparent that the mere presence of a smart meter display influenced participants' behaviour. Even though participants reported paying no attention to the displays, and making no effort to reduce their energy use, they nonetheless did lower their energy consumption, although it is not yet clear if this effect would last over longer periods.

Two further insights arose from this study. The first is that the extent to which a design requires conscious effort (and so motivation) from the occupant appears to be an important moderating influence. Previous results from a laboratory experiment showed that when the task was merely to detect changes in the information displayed, this was easier with the numerical design than the analogue dials and the ambient faces design [13]. However, here in a residential setting the three designs performed equally well in reducing energy consumption though the results suggest – tantalisingly – that the ambient faces design may have an advantage. This implies that in real-world settings detecting changes in and understanding energy use information is quite different from a task-driven laboratory environment.

The second insight is that subjective preferences for display design are not a good indicator of their actual performance. This raises the question of whether it is better to use a design that works to reduce consumption but is less preferred than others or to leave the selection to personal choice given that all three designs considered here worked to reduce energy consumption.

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Inducing [sub]conscious energy behaviour through visually displayed energy information: A case study in university accommodation

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Figure 1: Tablet installation setup

Figure 2: Tablet affixed to cabinet
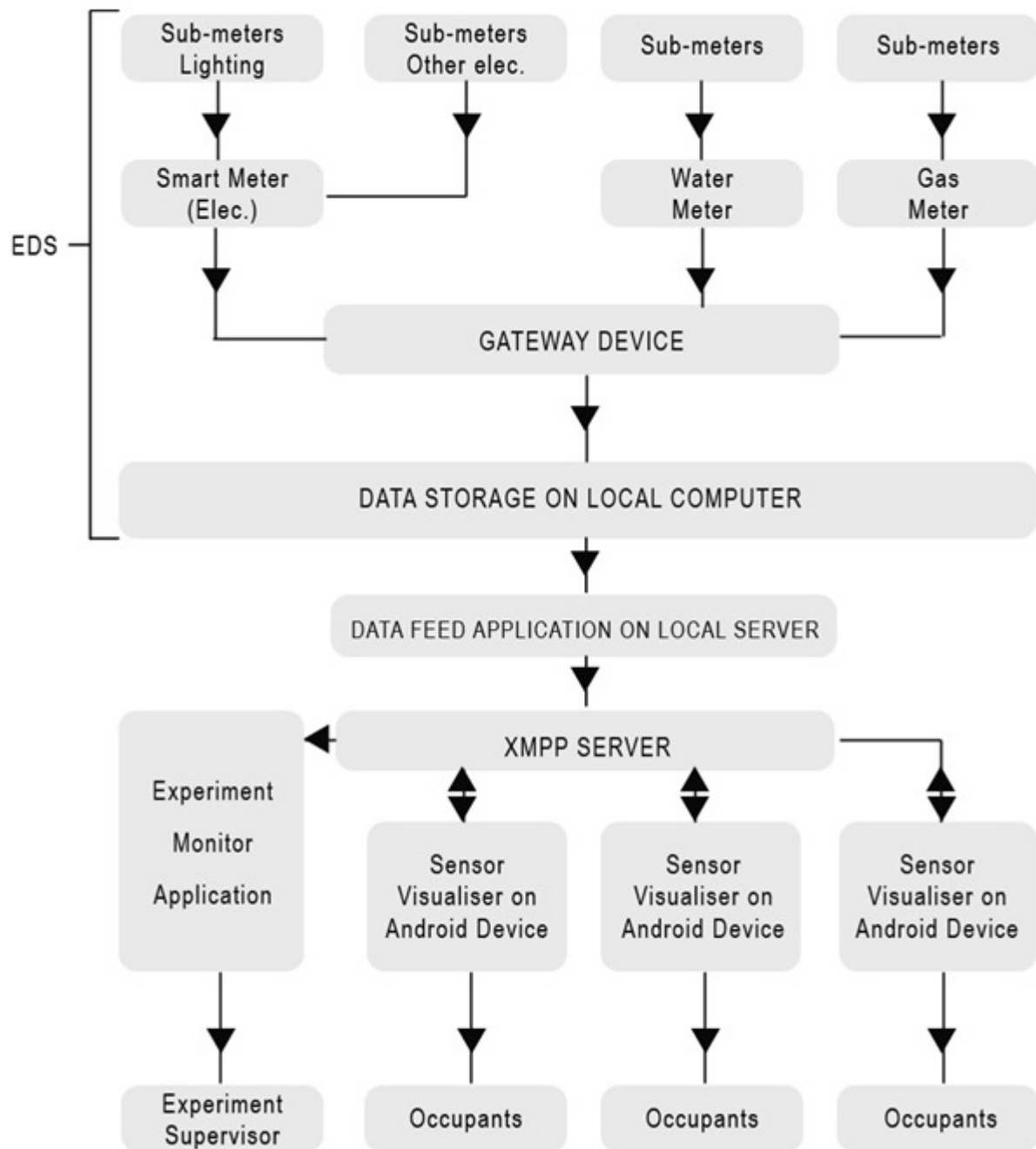
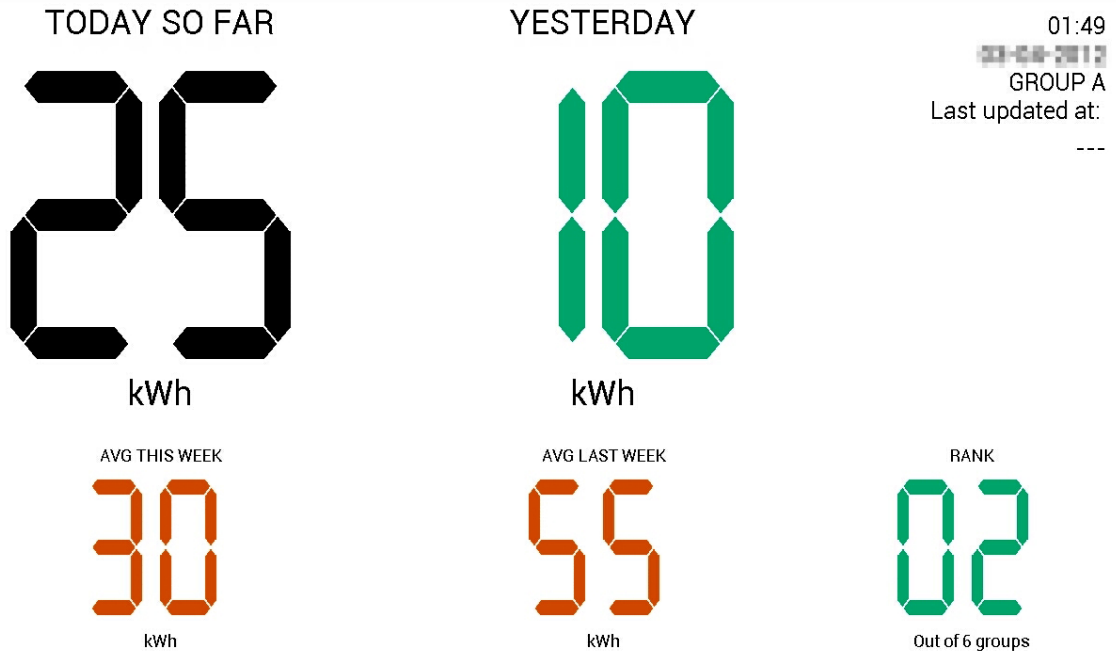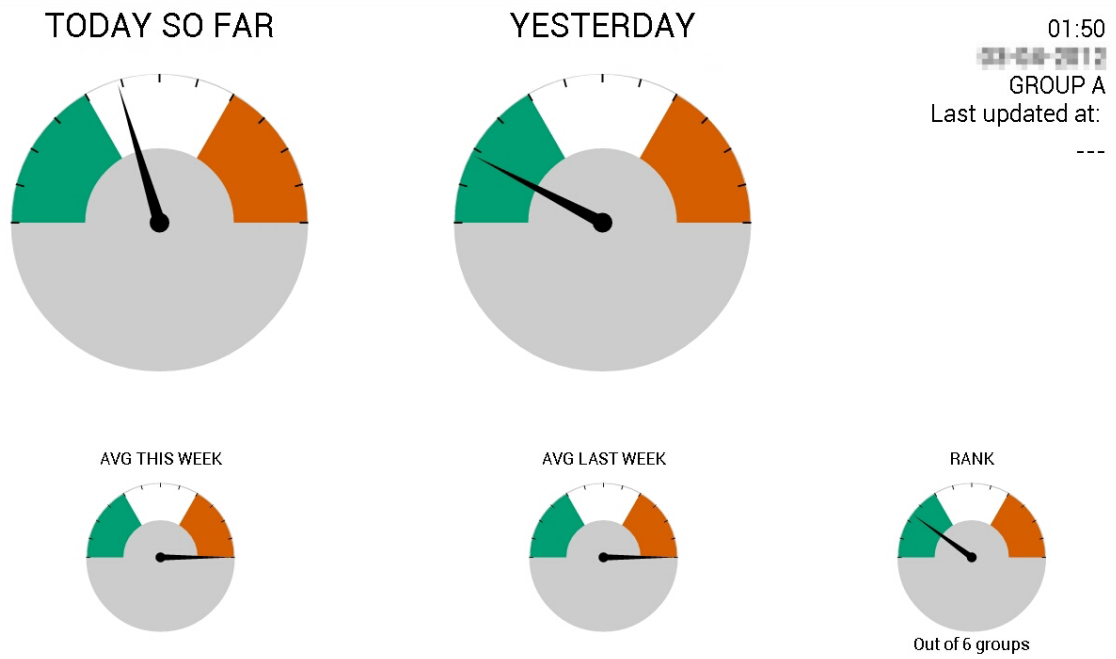**Figure 3: Integrated architecture of the experimental setup and the existing infrastructure (EDS)**

TODAY SO FAR

YESTERDAY

25

10

kWh

kWh

AVG THIS WEEK

AVG LAST WEEK

RANK

30

55

02

kWh

kWh

Out of 6 groups

Figure 4: Numerical design

TODAY SO FAR

YESTERDAY
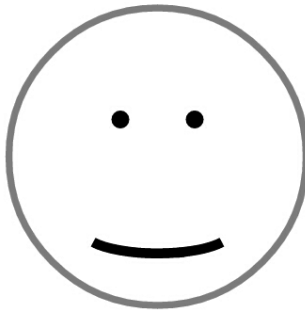
AVG THIS WEEK

AVG LAST WEEK

RANK

Out of 6 groups

Figure 5: Analogue dials design
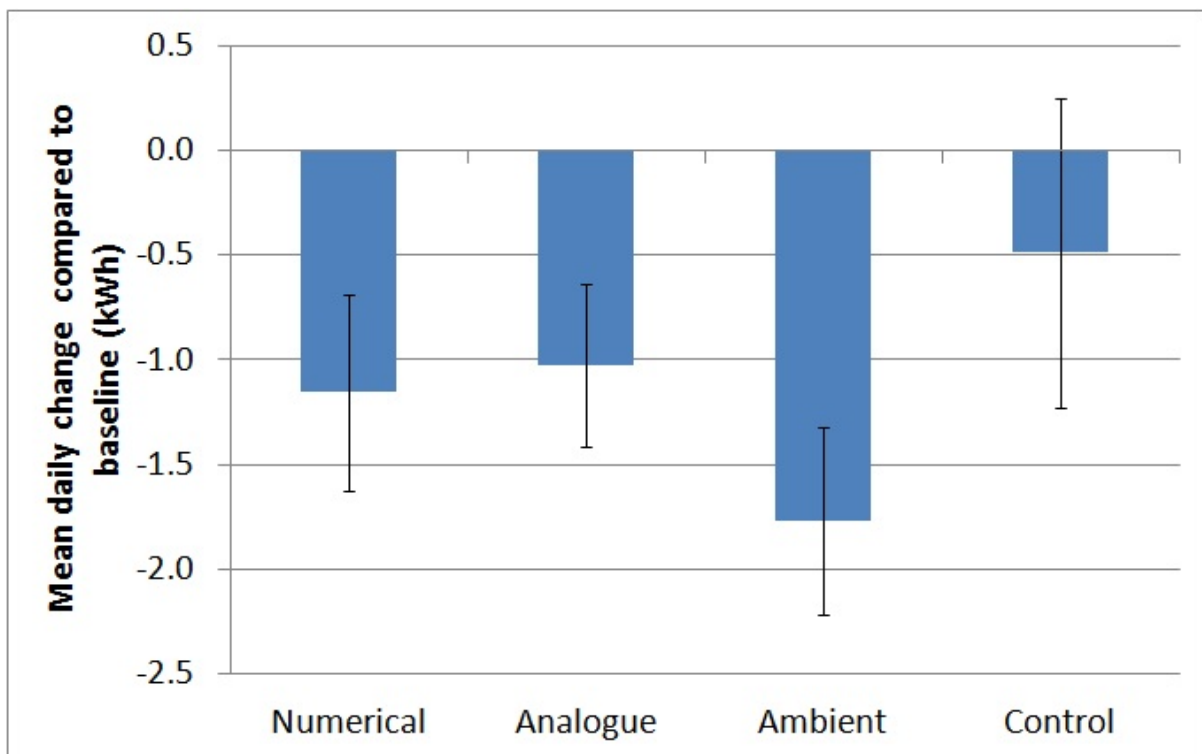
Figure 6: Ambient faces design

Figure 7: Comparison of mean reductions across conditions in Experiment 1
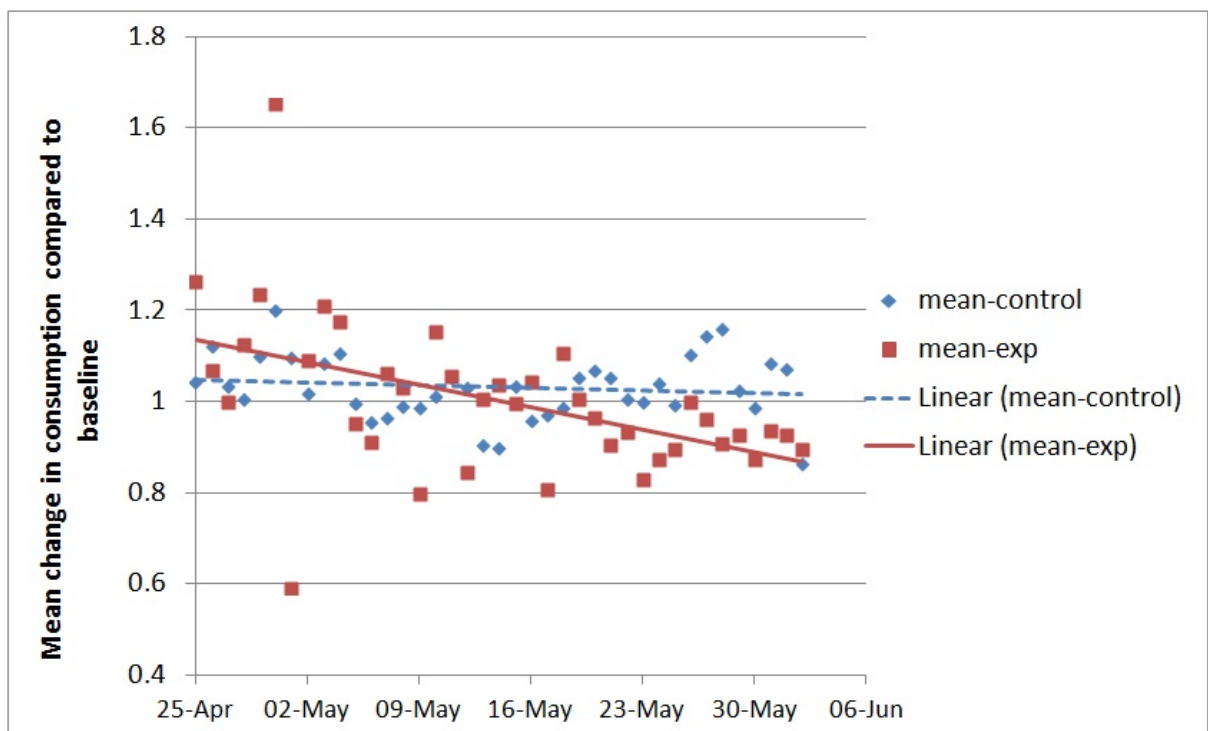
Figure 8: Ranking design

Figure 9: Comparison of mean daily change in consumption between control and experimental groups in Experiment 2. Here, 1 represents no change, data value above 1 represents an increase, data value below 1 represents a decrease.
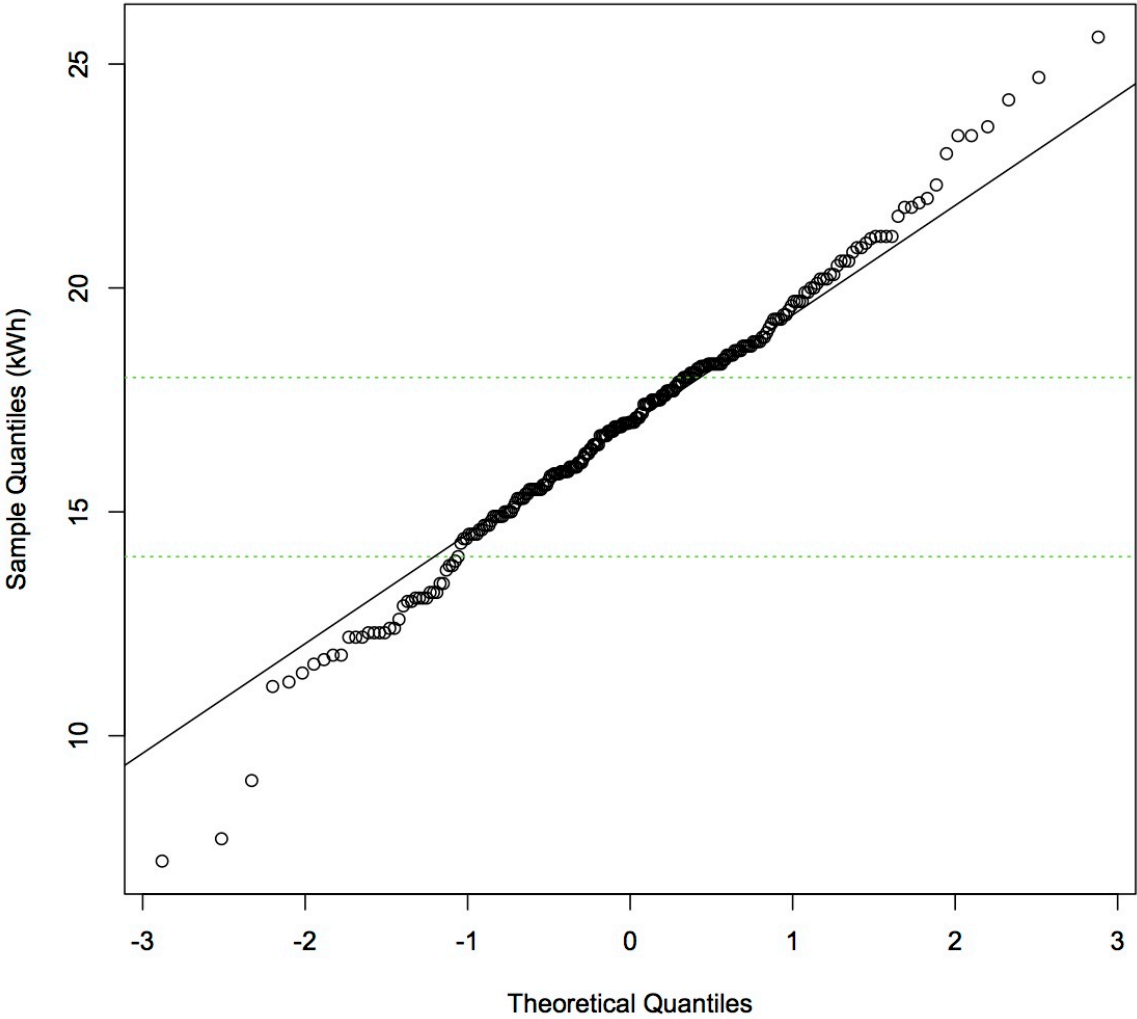
Figure 10: Normal probability plot of metered data (kWh) used to construct range information for the displays. Dotted horizontal lines indicate thresholds for the selected ranges.

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Table 1: Display designs on two-weekly rotations

	Group A	**Group B**	**Group C**	**Group D**	**Group E**	**Group F**
Weeks 1-2	Numerical	Numerical	Analogue	Analogue	Ambient	Ambient
Weeks 3-4	Analogue	Ambient	Numerical	Ambient	Numerical	Analogue
Weeks 5-6	Ambient	Analogue	Ambient	Numerical	Analogue	Numerical

Table 2: Results of Experiment 1 by display design type

	Mean daily change[a] compared to baseline (kWh)	95% confidence interval for difference		**Effect size (d)**
		Lower interval boundary	**Upper interval boundary**	
Numerical	-1.16	-1.82	-0.50	0.37
Analogue (dials)	-1.02	-1.60	-0.45	0.32
Ambient (faces)	-1.77	-2.40	-1.14	0.56
Control (no displays)	-0.49	-0.55	1.53	0.13

[a] negative value indicates a reduction in electricity consumption