Comparative Feedback in the Street: Exposing Residential Energy Consumption on House Façades

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Abstract. This study investigates the impact of revealing the changes in daily residential energy consumption of individual households on their respective house façades. While energy feedback devices are now commercially available, still little is known about the potential of making such private information publicly available in order to encourage various forms of social involvement, such as peer pressure or healthy competition. This paper reports on the design rationale of a custom-made chalkboard that conveys different visualizations of household energy consumption, which were updated daily by hand. An in-situ, between-subject study was conducted during which the effects of such a public display were compared with two different control groups over a total period of 7 weeks. The competitive aspects of the public display led to more sustained behavior change and more effective energy conservation, as some graphical depictions such as a historical line graph raised awareness about consumption behavior, and the public character of the display prompted discussions in the wider community. The paper concludes with several considerations for the design of public displays, and of household energy consumption in particular.

Keywords: persuasive computing, public display, urban screen, visualization, sustainability, interaction design, urban computing.

1 Introduction

Residential energy consumption is estimated to account for 11% of energy consumption worldwide and is estimated to grow between 0.6 and 2.4% per year [1]. Electricity currently is the highest contributor to residential energy consumption, and it has been estimated that electricity will account for nearly 60% of overall residential energy growth over the next 20 years [1]. As Australia receives approximately 77% of its electricity demands from burning coal, domestic electrical appliances will be to blame for the largest production of greenhouse gases from all residential energy consumption. While people are becoming increasingly aware of the ongoing “Climate Crisis” [2], they are rarely aware of how their daily activities contribute to greenhouse gas emissions [3, 4, 5]. As a result, the majority of interactions with energy-consuming appliances occur without conscious consideration of their environmental impact [6]. Recent advances in wireless sensor technology, smart metering and electronic displays present an opportunity for advanced forms of behavioral feedback, such as screens that display appropriate, real-time information of the actual energy consumption within the context of everyday life. Commercially available energy usage feedback displays have now become affordable, which typically convey the real-time energy consumption through displaying numerical data, such as kilowatts or financial costs per hour. The idea of feedback is not new, and various forms of energy usage feedback have already been investigated, demonstrating how it has indeed the potential to promote energy conservation to the order of 5-10% in common households [7] or office environments [8]. Moreover, modern communication technology has now the power to act as facilitator for motivating behavioral change through social cues [9], although such interventions typically require the development of novel sensors, visualizations, interfaces or interactions [10]. Several strategies have already been proposed for designing persuasive technologies [11], such as the requirement to converge motivation, ability and trigger at the same moment in time [12]. However, little is known about how energy usage feedback could benefit from the integration of other persuasive means that reach beyond the immediate display of private information, such as inducing forms of social pressure, competition or cooperation by externalizing the feedback beyond the end user. Our study investigates whether turning behavioral information that is normally kept well-hidden and private, explicitly public and even comparable to those of others, can effectively augment persuasive feedback. More concretely, we describe the design, implementation and evaluation of a new public, urban display that presents the individual energy consumption performances of families on their respective house façades.

2 Background

Early studies on the feedback of energy consumption were typically carried out by psychologists, who mainly focused on the reinforcement of certain behaviors through direct intervention. More recently, academic research has shifted to more qualitative studies, in order to understand how people respond to different forms of feedback methods. Research about the performance of environmental feedback is still relatively limited, but ranges from informed billing, smart meters, direct feedback displays [13, 14], numerical read-outs [15], bar graph charts [3], highly detailed information dashboards [16], or ambient cues [17], such as a lights that change color [18]. Several design-based research projects have instead focused on reinforcing the persuasive message of energy usage feedback by including qualities of joy, tangibility or ambiguity, resulting in various design-led projects that are more speculative and risk-taking: some projects dealt with feedback in public space [19], while others proposed novel interfaces for the home [20], or compared graphical forms of feedback [21]. As the potential of persuasive visualization is still relatively unexplored [22], academic research in this realm is still increasing (e.g. the "BeAware" project [23]).

To design successful feedback mechanisms that intent to change human behavior, it is necessary to understand what motivates people. For instance, most commercially available feedback displays rely on an *intrinsic* rational-economic model, which assumes that people can be encouraged to change behavior by the prospect of saving money [24]. Most material incentives and persuasive prompts also have the potential to trigger behavior change [25], but tend to become less effective once the novelty declines or the incentives have been removed [26]. Techniques based on *extrinsic* forms of motivation, such as social reinforcement, can help to discover more intrinsic motivations and even lead to sustained change [24].

In particular, providing *comparative* feedback may have a positive effect on behavior change by triggering feelings of competition, social comparison or social pressure [26]. However, the usefulness of comparative feedback, which contrasts the consumption of multiple people against each other, is still relatively contested. While some early field studies have shown positive effects [3, 27], there has been some evidence that people tend to express concern about the apparent validity of the comparison groups [5]. Other studies also demonstrated that while high and medium consumers conserved energy, some low consumers tended to increase their consumption, as they felt less encouraged when noticing the higher apparent average usage [27]. The study of *Wattsup*, a Facebook application for energy monitoring, indicated that competitive feedback is more enjoyable and more effective compared to individual feedback [28]. *EnergyWiz*, a mobile phone application, employed different forms of social comparison in order to gain insights into the design of comparative feedback [29]. With the recent advances in networked tracking devices, public comparison of behavior for cooperative or competitive purposes has become possible. For instance, the commercially available Apple iPod/Nike+ pedometer promotes competitive running between athletes, even when they are physically separated. Several initiatives based on social media have specifically focused on externalizing energy consumption, ranging from dedicated websites such as *Make Me Sustainable* [30] and *Carbon Rally* [31], through embeddable widgets such as the *Google Powermeter* [32], to augmented energy bills [33]. Most comparative feedback thus still occurs in the online realm, shifting the context of feedback away from physical reality, in which energy usage actually occurs.

In this paper, we propose a new form of *urban display* [34]: a public display that represents information that is relevant and contextualized to its immediate surroundings. While electronic displays are becoming increasingly ubiquitous in today's public space, the majority serves mainly commercial, artistic or entertainment purposes. In contrast, our project foresees a future in which public displays offer information that is socially relevant, and encourages local support or cohesion.

3 Design

The general aim of the study was to measure the persuasive effectiveness of public feedback. We decided to apply our research to the issue of energy consumption, because energy usage is relatively simple to relate to behavior and changes can be detected accurately. Other behavioral data such as from water or gas consumption are less detailed, and relatively cumbersome and expensive to capture. Due to the encompassing context of sustainability, the design constraints became manifold and complex, as, ideally, any (public) feedback display of sustainable behavior should be: 1) *Sustainable* in and by itself, as the construction and maintenance of the system should not negate the intentions it attempts to promote. This constraint proves to be extremely restrictive, as it means the consumption of materials or energy should be minimized, or even completely avoided; 2) *Affordable*, as supporting sustainable behavior should only induce costs that can be earned back over a reasonable amount of time; 3) Respectful to *privacy*, as any communication of behavioral information in public might introduce unintended, yet significant, risks; 4) *Intuitive*, as any feedback should be easy to understand and enjoyable to use, even for occasional passers-by; 5) *Robust*, including a resistance to uncontrollable aspects such as severe weather conditions, vandalism or carelessness when located in the harsh reality of semi-public space; 6) *Aesthetic*, as public feedback should be presented in a form that is acceptable by all its stakeholders while being unobtrusive to everyday activities; 7) *Updatable*, as feedback should be provided shortly after the occurrence of behavior, allowing people to immediately link the impact of their actions; and, 8) *Persuasive*, as feedback should also reveal the meaning behind the information shown, and highlight specific relevant aspects that can more deeply influence intrinsic motivation.

3.1 Public Display Design

The public feedback display was developed through a design-oriented research approach. This involved the execution of successive designs on the basis of iteratively refined constraints and requirements, and the production and evaluation of various low-fidelity sketches, mockups and working prototypes. We decided on the house façade as the ideal location for conveying feedback in a public context: a large sign mounted on a house façade intuitively refers back to the inhabitants that cause the behavior, while it also ensures uninterrupted visibility to neighbors or passers-by. We investigated existing forms of social competition that typically take place in the semi-public domain of the house façade, porch or front garden, including gardening and vegetable competitions, garden gnome collections, Christmas decorations, and the like (see Figure 1, Left). This approach further convinced us of choosing a 'non-electronic' display medium, which seemed to be better suited to the physical language of the street; avoided complex and expensive construction issues (e.g. wiring, casing); and solved most of the previously listed (public) feedback design requirements. While searching for a physical material that can display and be easily updated, we arrived at *chalkboards*. Chalkboard surfaces are associated with many positive qualities in terms of our everyday experience: they naturally imply some sort of dynamism and time-variance, exemplified by signs that advertise the changing menus of cafés or restaurants; they convey a warm, handcrafted charm through the often clumsy but sympathetic handwriting and low-fidelity chalk aesthetic; they are surrounded by an aura of playfulness, reminding people of their childhood with activities like doodling, street graffiti, doorstep games, and so on; and they infer a personal and small-scale context, which many of us unconsciously use to, for instance, distinguish the neighborhood coffee bar from the large, international coffee chain franchise. Chalkboards have already proven to be an ideal platform to convey dynamic information, such as game scores, supermarket prices, or the water temperature in the public swimming pool. Even more, we expected that the manual act of updating a chalkboard could open up the opportunity for people to casually interact with the writer, so that a 'data update' has the potential to grow into a true 'social event', contrasting the unnoticeable millisecond blip of an electronic display.

Figure 1. Left: Existing forms of social competition in the semi-public domain of the house façade and front garden. Right: A neighborhood map highlighting the participating households.

We deliberately chose a neighborhood in the city of Sydney that is characterized by a distinct building typology of so-called 'terrace houses' and enjoys high pedestrian traffic. The strong similarity in dimension and geometrical layout of terrace house façades allowed us to create displays that were mostly identical, thereby reducing construction complexity and avoiding potential bias in visual perception. However, as in many other cities, altering the appearance of an exterior façade requires explicit approval from the city council, a laborious and time-consuming process that would significantly complicate our intended time planning. An elegant solution was found by replacing our initial concept of traditional wooden blackboards in favor of lightweight twin wall polypropylene sheets. The explicit temporary character of this material allowed us to install the displays with the exemption of the so-called "State Environmental Planning" policy (section "General Sign Provisions"). We retained the typical visual look and feel of traditional chalkboards by printing a greenish washed-out background pattern. This material also proved to be much easier to install, was cost-effective, weather-resistant, and is certified as being completely recyclable.

The aim of our design was to augment the existing terrace house architecture with a striking visual accent that was physically adapted to the aesthetics of the existing environment. We took inspiration from similar boards that are commonly used for real estate notices or commercial advertising, while avoiding the visual occlusion of cars or trees. Our display was specifically designed to be able to fit to any façade width without affecting the overall layout: each display can be sized to perfectly fit with any existing balustrade, and it can fit the narrowest townhouse (< 3m), while still looking intentional and well-balanced for much wider houses (3-4.5m). We chose to print a permanent background template (including a grid and text) to provide for a strong recognizable visual framework on which the more messy handwritten information would visually stand out. These predefined graphic elements also made the display look more professional and less random, as the displays needed to convey a high level of trust to all stakeholders. The fixed background template also ensured a more efficient updating process, as fewer elements had to be manually redrawn. In short, it was important to create a visual design that balanced a level of trust and seriousness with a degree of fun and happiness: a chalkboard on a residential façade – as simple as the physical components seem to be – is still an unusual combination and would indeed become a small neighborhood attraction.

3.2 Persuasive Visualization

The design of the data visualizations faced the complex dilemma of representing the differences in energy usage between individual households in a fair and honest way. Energy usage depends on many factors, such as the number of people living in the household, the inhabitable surface area, the type of appliances used, whether gas or electricity is used for heating, and so on. Any fair comparative feedback should ideally avoid showing factual usage data, and instead be based on some form of normalized data, i.e. the actual *change* in energy consumption over a specific period of time [29]. Focusing on change instead of actual electricity usage also provides for a certain degree of public privacy: communicating "*no, or little change*" conveys a different meaning from "*no, or little usage*", for instance in the case when a household is absent for a long period of time. However, focusing on relative change does not take into account whether the usage is generally low or high in comparison to others, while it also hides any longer-term trend supporting the change. 'Change' also implies a comparison to a point in time, which is relatively difficult to determine. For instance, while comparing one's energy usage to that of last week seems the fairest method (e.g. accounting for different living patterns in weekends versus weekdays), we deemed it difficult to invoke immediate comparison or encouragement (i.e. who actually remembers their activities of last week?). To ensure people were able to relate their recent decisions and activities to the actual performance shown on the displays, we preferred to compare daily (vs. weekly) energy usage: even when, for instance, most common households would show a 'negative' trend from Friday to Saturday, this trend would still be shared by most others and thus be comparable in a truthful way. In order to provide a more detailed view of the energy usage patterns in multiple varying positive, encouraging and visually attractive ways, we chose for the following combination of textual and graphical depictions (see Figure 2).

a. **Marginal Notes** for personalized messages or persuasive captions, which could be written in the areas on the sides that were deliberately left blank.

b. The **Daily Performance**, shown as a numerical percentage value, conveyed the change in energy consumption over the last 24 hours of a single household.

c. The **Neighborhood Ranking** summarized the daily performance in terms of change of all participating households in a single numerical ranking. It aimed to encourage competition, while also reduced the need to compare individual displays.

d. The **Historical Graph** showed the actual usage trends over time, and conveyed the time-varying, complex character of household energy consumption. The line graph was horizontally divided by weekdays, and was vertically normalized by the maximum usage measurement, mainly for privacy reasons. The graph was never wiped out, but extended at each update. The data for successive weeks were drawn on top of each other in different colors, so that the historical performance of the same household could be easily compared and contrasted.

e. The **Pictorial Bar** highlighted the occurrence of any sustained change, such as a succession of positive or negative changes in energy use by way of an explicit visual reward. The pictorial system acted similarly to common stock market iconography: it only counted 'better' or 'worse' performances based upon predefined thresholds (e.g. it ignored changes less than 10%), but still recognized sustained lower energy usage levels, even after drastic changes. A reward or discouragement was depicted as a simple emoticon, which conveyed a degree of negative or positive emotions. Each day of the month, an emoticon was added within a preprinted circle. Facial emoticon expressions were chosen, as they are universal and intuitive to comprehend.

f. **Private Display**. Households were also provided with a common electricity monitor, embedded in a custom-made blackboard (Figure 5, Right). We decided on giving explicit access to the monitor device in order to entice the trust that the information shown on the public display was based on continuous and accurate measurements. The small, custom-made blackboard aimed to encourage participants to take notes about appliance usage or other energy-related observations, similar to keeping a journal, which can support self-reflection and in turn, the discovery of intrinsic factors of motivation [24]. The private display was pre-printed with weekday abbreviations to accentuate the daily update cycles embodied by the public display.

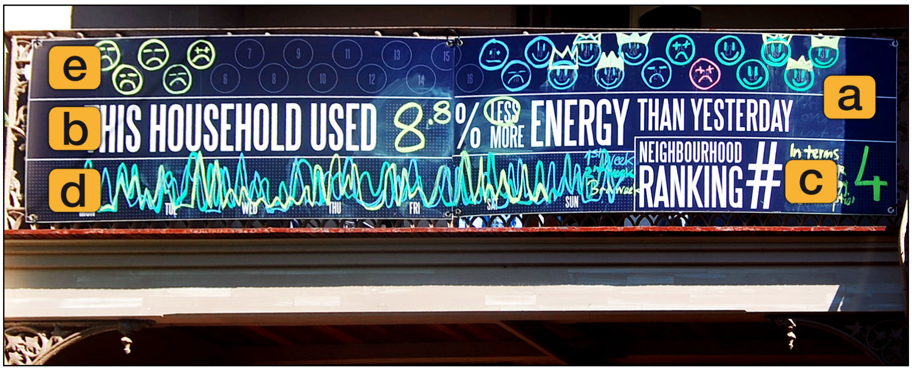

Figure 2. Overview of the graphical depictions on the public feedback display: Marginal Notes (a), Daily Performances (b), Neighborhood Ranking (c), Historical Graph (d), Pictorial Bar (e).

3.3 Technical Implementation

Our extensive design efforts resulted in a fairly simple technical implementation. A commercially available Efergy E2 device, consisting of a sensor, wireless transmitter and wireless monitor, was used for measuring the actual electricity consumption. The monitor captures the energy consumption per hour, which can be downloaded via a USB connection. To ensure easy and uninterrupted access to this data, we left one dedicated monitor outside the house, e.g. in the electricity box or in a rainproof plastic container (Figure 3, Left). To download the electricity data, we used a Netbook running Windows 7 (Figure 3, Center). The public feedback displays were produced using Corflute®, a light material made of twin wall polypropylene sheets (with an average size of 3.3x0.8m). Simple eyelets were used to mount the sheets onto the terrace fences with standard cable ties. The content was written and drawn using standard liquid chalk pens, which have the advantage over common chalk to be fairly water resistant. A 14-tread ladder was necessary to reach the displays (Figure 3, Right). A second Efergy E2 wireless monitor was used for the private display. The blackboard that encompassed the private display unit was custom-made with a size of 26x23cm and a chalk tray attached to the front (Figure 5, Right). The blackboard came with a detachable stand and a small hook for placing or hanging the display anywhere inside the home. The display could be set to reveal instant kilowatts, carbon emissions or costs per hour (with an update rate of 8s), as well as show the historical trends for the previous seven days.

Figure 3. Left: Hidden storage of a separate electricity monitor allowing uninterrupted access to the data. Center: Netbook and electricity monitor used for downloading and updating displays. Right: The manual update of the daily neighborhood ranking using a ladder.

4 Methodology

4.1 Setup

For our study, we aimed to recruit about twelve households, six for the treatment (with public display), and two control groups of three households each (see Section 4.2). First, we selected two streets in a high pedestrian traffic area, featuring terrace houses of comparable size. Both streets were located in the vicinity of our university, in order to accomplish the manual updates more efficiently. Some households were selected based on the fact they were located on an intersection, so that the house façades were visible from a longer distance (Figure 1, Right). We used leafleting and door knocking to recruit households [35], which also allowed us to experience the study environment as a rich physical and social context, observe the actual community, and learn about the local attitudes regarding the topic of sustainability. The Efergy E2 electricity monitor (valued AUD$134) was offered as an incentive to participate. We then physically visited the neighborhood at times when it was most likely that people would be at home, and systematically knocked on all houses that featured a terrace and were of comparable size, and had no trees or other obstacles blocking the view. After returning four times, we recruited six households in each street, and arranged one dedicated contact person per household. Just before commencement, two households dropped out for individual reasons, one of which was replaced, leaving us with a total of 11 households (see Table 1).

Table 1. Participating households, their characteristics, and conditions (Group A: public and personal displays; Group B: private display; Group C: no feedback).

No	Occupants	Ownership	Group
H1	2 adults (couple)	Owners	A
H2	2 adults (couple)	Owners	A
H3	3+ adults (students)	Renters	A
H4	3 adults (shared)	Renters	A
H5	3 adults (shared)	Renters	A
H6	2 adults, 1 child	Owners	B
H7	2 adults (couple)	Owners	B
H8	2 adults (couple)	Owners	B
H9	6 adults (students)	Renters	C
H10	2 adults (shared)	Owners	C
H11	3+ adults (students)	Renters	C

4.2 Evaluation Study

We used a between-subject design study with three separate conditions. Two of the conditions were used as control measure. In condition A (n=5), both the public and private displays were installed. In condition B (n=3), only the private display was installed, which offered the same features as the private display used in condition A, but without the blackboard for note-taking. Condition C (n=3) was identical to B, but the energy monitor was not made accessible or visible to the participants. The continuous energy measurements ran for a total period of 10 weeks, during which the public displays were updated for 7 weeks. We interviewed all participants at the beginning and at the end of the study.

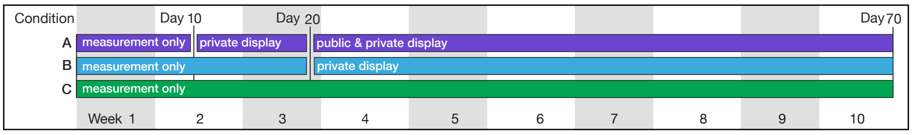

Figure 4. Duration of measurement phases for the three between-subject study conditions.

Pre-study Interviews. Each pre-study interview (taking between 6-23 minutes) was conducted with the contact person from each household, in their house. Where possible we made arrangements that all other household members were present as well. In the interviews, we collected general information about the household, attitudes towards global warming, privacy, and the relationship with neighbors.

Energy Measurements. The study used a total of 16 electricity monitors: one per household in conditions B and C, and two per household in condition A (i.e. one inside and one hidden outside). As shown in Figure 4, in condition A, the energy data collection started for a period of 10 days, after which the private displays were installed. After another 11 days, we installed the public displays and continued recording for 7 weeks. In condition B, we measured without intervention for 21 days, after which the private displays were made available for the remaining 7 weeks. In condition C, we measured without intervention for the entire period of 10 weeks.

The energy usage data was cleaned to eliminate obvious errors or outliers, for instance for two separate cases where the electricity monitor experienced a technical failure (see Table 2). Any erroneous (i.e. 0.0kWh) or outlier (i.e. a household consumption of less than 75% of the average consumption of the same weekday) measurement was replaced with the average value of correct measurements for the same weekday over the entire respective study phase. Outliers represented abnormal situations, such as participants being absent for one or more days, or a significant change in the number of people staying in the house. This systematic approach for cleaning the data was tested and validated against the anecdotal evidence from households where we were aware of the exact dates of abnormal events.

Table 2. Errors and outliers per household in number of affected days.

Household	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11
Errors	-	-	-	11	-	-	-	10	-	37	-
Outliers	19	15	11	14	9	9	7	8	11	2	10

Display Updates. The public displays were updated every single day for a period of four weeks, after which the historical graph area was wiped clean to avoid visual clutter. The graph from the fourth week was then reapplied before continuing with the updates. We used a custom-made software tool that visually simulated the public display, to determine the exact graphical depictions based on the actual sensor data. In total, each manual update session took between 1.25 and 2 hours (or 15 to 24 minutes on average, per house). The update time depended on the number of researchers involved (varying between one and two), the day of the week (with updates in the beginning of the week leading to increased repositioning of the ladder), and weather conditions. The updates generally took place in the late afternoon. The public displays were not updated during four distinct days, due to heavy rain conditions.

Observations. While we were present in the neighborhood, we kept a journal of observations and conversations with any participant or passer-by. We occasionally asked passers-by who approached us some informal questions regarding their understanding and perception of the displays.

Post-Study Interviews. After the study, we conducted another round of semi-structured interviews with all participants in their respective homes. The questions covered their awareness of energy consumption behavior and their perception of the displays. Participants also rated the public and private displays regarding their attractiveness, usefulness, ambientness, and enjoyment. These interviews took approximately one hour for condition A, and 6-12 minutes for conditions B and C.

5 Results and Discussion

5.1 Awareness

During the pre-study interviews, all households stated they were well aware of the climate crisis. Everyone expressed some opinion on global warming and most participants stated that they were trying “*to do their bit*”, which included switching off lights (n=11), switching off appliances at the power plug (n=6), replacing bulbs with energy-efficient lighting (n=3), replacing electric water heating or stoves with gas ones (n=2), and partly switching to green energy (n=2). None of the households was regularly checking their electricity meter to monitor consumption. However, all households were monitoring their energy bills regularly, at least to check the total costs, while some also checked other data provided on the bill, such as greenhouse emissions. Nine households stated that they compared their consumption from bill to bill, mainly to see whether the costs had increased, and then would decide whether to look into the information provided on the bill in more detail. Only one household (H10) had actually compared their consumption with those of others.

Figure 5. Left: Neighboring public feedback displays during the last week of the study. Right: A private feedback display embedded in blackboard showing notes on appliance usage.

In the post-study interviews, we identified several anecdotal reports about the effect of the feedback displays on the general awareness of energy consumption. One household was using the private display blackboard to take handwritten notes about appliance usage (i.e. of kettle and laptop, and even of the difference between a hot and cold washing cycle), while nobody used the pre-populated grid of weekdays. Another household invented a game using the blackboard during which the goal was to turn on or off appliances in order to reach a certain score, which they then recorded on the blackboard. This household described the private display as *“a point of conversation for us, bring[ing] us together”*, to which was added: *“bringing us together as a team”*, referring to the neighborhood ranking, where they saw themselves competing as team against the other households.

While the private display affected the awareness of energy consumption on an appliance level, we found that the public display allowed participants to understand their consumption on a more general level. For instance, several participants noticed how the patterns on the historical graph related to their behavior: *“The graph was interesting, because you could see that we had patterns ... you know, always take showers at the same time and we did see when we took a shower because of the hot water thing”* (H1); or noticing spikes: *“We don't have routine anyway, we never do the washing until we run out of underwear and then we do four loads in one go”* followed by the participant’s partner’s comment: *“Then the following day on the* *graph, we see that it goes BEEP – 'oh that's our washing day'"* (H2). While the historical graph was mentioned as being most useful for identifying patterns, numerical indications also played an important role. For instance, one household (H5) mentioned how they attributed a 70% increase to the fact that they did three wash loads that day. Another household (H2) related a sudden negative neighborhood ranking to a similar event. Most participants reported how the public display prompted many conversations on energy consumption and environmental issues with other household members or people visiting and noticing the public display.

5.2 Behavior Change

During the post-study interviews, households generally stated that they perceived the private display as more influential to their behavioral changes than the public display, mostly because of its real-time nature. These findings (in conditions A and B) are in line with other studies on smart energy monitors, which found that all participants reported changes [14]. In particular, the monitoring device led to discoveries relating to the electricity consumption of individual appliances. As such insights have been previously reported, this section instead focuses on the impact of the public display.

We observed that the public display induced or reinforced behavior change. For instance, one household mentioned how the patterns observed from the private display correlated with those on the public display, which led to the suggestion to replace the water heater and a form of long-term and sustained conservation behavior: *"I would try to use less and less and less [to come first], so in the beginning we were often number one; … but then I realized that I was just using less and less every day, which is not going to work out, because eventually I needed to do the laundry"* (H1). While this household became frustrated by the ranking system being based on change rather than factual consumption, they still showed the highest conservation behavior by consuming 25% less energy during the first week, maintaining this conservation for another week, after which they gave up and increased their consumption by 21%.

Behavior change was often triggered by the competitive nature of the public displays, and in particular by the neighborhood ranking. However, the neighborhood ranking also led to less sustained behavior, like strategically clustering washing cycles in time, in order to end up first in the ranking the day after (e.g. H2). In another case, the neighborhood ranking triggered more spontaneous short-time behavior change: *"One day we were [away] and got a message from our housemate saying 'we are number five..., the people next to us are number one!' and I sent back a text [telling them] to quickly switch of all our power points!"* (H5). We also observed the excitement about the competitive aspect during our manual update sessions, when we often noticed occupants coming out of their house after we finished updating their display to check their own ranking. For instance, we once noticed how H4 checked their ranking (first that day), and then ran back into the house announcing their achievement loudly and proudly to the other inhabitants.

Overall, findings from the interviews suggest that the private feedback led to valuable intrinsic insights, which allowed participants to develop long-term strategies for reducing their consumption. In contrast, the more competitive aspect of the public display was seen as an extrinsic factor of motivation, as participants often aimed to reduce their consumption in order to 'win': one household described how they specifically focused on the ranking, since they *"wanted to come first"* (H2), while H4 revealed that they paid most attention to the neighborhood ranking. Overall, the ranking aspect worked well to encourage people to 'start' with changing their behavior, although the behavior seemed to decline after people got used to its competitive aspect. One household commented on how there was definitely more behavior change noticeable due to the neighborhood ranking after the public display went up, but that at the end they tended to pay less attention to the ranking since it changed almost daily (H5). This finding suggests that the design of the pictorial bar seemed to have failed in encouraging longer-term or sustained behavior. A possible solution could consist of adding ranking variations, such as adding weekly or monthly charts, so that long-term goals would be more explicitly and intuitively recognized than the graphical nature of the emoticons. Only one household mentioned that they did not pay much attention to the neighborhood ranking since they found it less useful, yet they considered the ranking to be "*cool*" and actually did look at the displays of other households. One should note competitive behavior is not for everyone, an important sentiment any comparative feedback should be aware of.

5.3 Energy Conservation

A data analysis of weekly consumption per condition revealed patterns related to the feedback. Figure 6 shows a considerable reduction of energy usage in week 4, around which households received their feedback displays (Condition A: -13.2%; Condition B: -12.1%). Households in condition A maintained their conservation behavior for the following week (-0.4%), while condition B showed an increase of energy usage (+10.8%). This might be best explained by the decline of the electricity monitor's novelty factor, or because many naïve conservation strategies are difficult to sustain longer-term (e.g. washing clothes less often). These reasons might also explain the energy usage increase of condition A in week 6 (+5.7%). In this week, household H1 stands out: they came to understand how the ranking was based on change, which they described as *"competing against yourself"* and gave up competing. The consumption of both control groups (conditions B and C) remained approximately the same throughout week 6 (-3% and -1.6%) and week 7 (-1.4% and 0.7%), while the condition A's consumption was declining in week 7 (-7.3%). For the remaining weeks, condition A's consumption remained almost unchanged or even declined further (between -0.2 and -1.1%). The little change in these three weeks could be attributed to the data corrections in week 9 and 10 for H1 and H4, which accommodate some technical failures with the measurements. However, an analysis of the data excluding H1 and H4 showed little effect with the overall decrease in week 8-10 changing -3% or larger. Condition B showed a very similar usage pattern, with an increase in week 7 followed by two weeks of considerable to little decrease. It is unclear what caused the increase in week 8 in condition C, which was however counterbalanced by a constant decrease over the following two weeks. The remarkable decline in energy usage for conditions A and B in week 2 could possibly be attributed to an increase of the minimum ambient temperature during that week, as compared to the previous week. However, as most households from condition A stated that they would rarely to never use electric heaters, this change is best explained by receiving the private display in that week. It is unclear what caused the increase in week 3, and while it might have naturally led to a decrease in week 4, condition A maintained this level throughout week 5, so that it can be attributed to the public display. The average change per week over the deployment period (week 4-10) was -2.5% for condition A, -1.0% for condition B, and -0.5% for condition C.

The energy consumption before and after the installation of the feedback displays shows a decrease in usage from week 3 to week 4 of -13.2% for condition A and -12.1% for condition B, while condition C remained the same. Interestingly, the conservation performance of condition B declined towards the end of the study period with an increase in energy consumption of +8.5% in week 10 compared to week 3, while condition A decreased their usage further to the amount of -17.0% (condition C: -4.3%). This phenomenon implies that households with public display positively changed their energy consumption behavior, while the traditional real-time energy monitor worked for short-term change only. However, due to the small sample size, these results can only be considered to show trends. A one-way ANOVA test did not reveal any significant differences, which can be attributed to the small sample size.

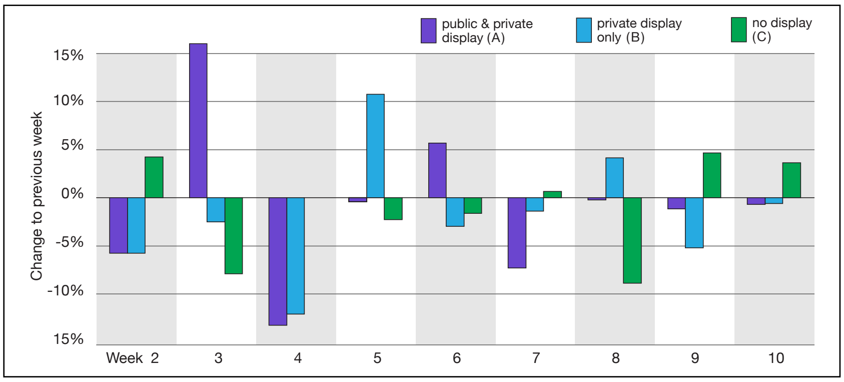

Figure 6. Weekly change in energy consumption per condition (corrected measurements).

5.4 Representation Methods

Only one household (H5) used the small blackboard that came with the private display for its intended purpose, yet all households wanted to keep the blackboard. H2 even removed the monitor from the blackboard to place it closer to their appliances in the kitchen, while they placed the blackboard near the phone for general note taking. Others stated they might eventually start using it together with the electricity monitor after the study. Not everyone appreciated the aesthetics of the private display, with H4 stating that they thought it looked “tacky” and “ugly”, and the public display was “attractive” and “playful” compared to it. In general, we received varying responses regarding the design of the displays, with some households judging the private display to be more aesthetic, while others rated the public display higher. H2 and H5 particularly mentioned that they liked the visual style of the chalk colors, H2 added how they appreciated the way the display became messier and messier over time. H5 described how they thought that the display made their house look "*more modern*". Similarly households' responses regarding the ambientness of the displays varied. H4 stated that "*you got used to it being on the house and then it's just there*". Others rated the ambientness low, saying that the display was not designed to be unobtrusive.

The different visualization techniques on the public display were rated positively. However, H2 found the emoticons on the pictorial bar "*too judgmental*": they even wiped out the neutral face they received on the first day and left a message for us saying "*no more sad faces please*". We consequently changed their pictorial representation to flowers, with different colors and sizes representing different levels of energy conservation performance, similarly to the original emoticons. When asked in the final interviews, none of the other households expressed any concerns regarding the emoticons. Some households found the fact that the display showed change rather than factual usage counter-intuitive. All but one stated that they would have preferred factual data to check how their actual energy consumption compares to their neighbors'. These attitudes went straight against our initial assumptions, as nobody seemed concerned about the severe privacy implications of displaying energy usage data, which might be explained by the playful nature of the study. Basing the ranking on change also led to some confusion regarding the neighborhood ranking, so that as H1 was initially puzzled about being ranked third after being away for three days. Although they came first in the ranking the day after they left, there was no change in consumption for the following 2 days of their absence, which thus resulted in a low overall ranking. While the pictorial bar was meant to solve such issues by visually rewarding persistence and sustained good behavior, its understandability suffered from the fact that all other elements were updated in the late afternoon for the previous 24 hours, while the emoticon represented a summary of the entire day.

6 Conclusion

Our quantitative measurements indicate the apparent potential of public visualization and neighborhood competition to encourage behavioral change. Households that received a public display for a period of 7 weeks decreased their energy usage on average by 2.5% per week (compared to a decrease of 1.0% in control group B and 0.5% in control group C). The presence of a public display further led to a more sustained conservation behavior compared to only having access to private feedback. Our qualitative results confirmed the effect of the competitive neighborhood ranking as being ideal for initiating behavior change. However, the competitive aspect also led to several unexpected side effects (e.g. clustering energy-intensive activities to specific strategic times). All stakeholders appreciated the competitive features, and the expressive playfulness of the visual design. Unfortunately, it became clear that the single, numerical ranking played a too overwhelming role in motivating people into short-term competitive behavior, while the pictorial bar, a feature that was specifically designed to support sustained behavior, was not sufficiently accepted as a longer-term reward. Although the historical graph could be exploited to reveal daily activities such as showering and washing, there was little to no notion of privacy concerns expressed by the participants. The chalkboard-like approach proved to be successful in keeping deployment costs low, but also allowed us for ad-hoc personalization (such as replacing emoticons with flowers when people disliked them, or adding written explanations when we noted how some households misunderstood the data). The fact that the public display was updated only once a day was seen as less a problem than we expected, which could be attributed to how the private displays compensated for more 'immediate' information needs. The manual updates turned out to be an important aspect of the study, since they required us to visit the site daily, allowing us to come into contact with households and passers-by. These informal conversations provided a rich source of feedback regarding the performance of our system and helped us to better understand the driving principles behind the data.

However, we greatly underestimated the required effort to update the displays on a daily basis, as it took one to two researchers more than an hour per day to complete the task of updating only 5 house facades. The update process was complicated by the physical height as well as the relatively large amount of visual elements that had to be drawn. At the start of the study, households were often confused regarding the meaning of certain visual elements. Passers-by – while recognizing that the display was about energy consumption – often asked questions about the meaning of some depictions. Providing explicit explanations to the public about the visualizations could possibly have helped the overall performance of the public display. In this study, we approached public feedback from a more realistic scenario of a council or energy supplier installing publicly accessible information boards on houses. However, even when we used customizable chalkboards, a more participatory design process involving the community might have led to a more successful design that invoked stronger feelings of ownership. Based on the generalized findings from this study we suggest the following design considerations for public representation of energy usage:

Privacy. Even though our study did not discover any apparent privacy concerns, the visualization of energy usage data inevitably reveals when inhabitants are at home or not, when they shower, or when they go to sleep. Possible solutions are: 1) removing detail: for instance by averaging the data over longer time periods; or 2) normalizing the usage data, which still reveals some detail but removes the possibility to compare the size of trends from one occurrence to another, or from one household to another. The biggest issue, however, is that people will show a very strong tendency to assume any time-based graph to represent real usage, even when the data is averaged or normalized, and labels, legends or captions provide other information.

Fair. A visualization should compare variables that are indeed comparable, taking into account influential differences (e.g. size of household, inhabitable area). Therefore, showing relative changes instead of real measurements seems most suitable, but they are difficult to intuitively understand. For instance, people need to relate to a historical time period that is never really representative or objectively comparable (e.g. even contrasting weekdays instead of successive days suffers from differences in weather). Numerical rankings might be a possible solution, as they can hide more complex formulas from view. However, people cannot easily relate rankings to personal effort, as other people's performances come into play.

Trust should be conveyed, in that people believe that the data shown is indeed accurate. Trust can be typically gained by way of appearance (e.g. from expensive or professional materials), direct associations (e.g. associating a trustworthy organization with the display), or persistence (e.g. updates occur regularly and without fail).

Encourage and Sustain Change. While access to information provides insight and motivation in one's behavior, some form of visceral experience is required to support the sustainment of positive behavior over longer periods of time.

Ability. It is one thing to become more aware of one's behavior, and to be enticed to change, it is another to know what action to take. Clear indications should be provided of 'how' to change behavior, to avoid feedback to become frustrating.

Immediate. While behavioral change should ideally be made apparent as quickly as possible, people seem patient to be informed of their competitive performance when also having access to alternative means of immediate feedback.

Understandable. Many issues relate to conveying complex, time-varying data to lay people, including visual density (i.e. showing not too much or not too little information), cultural sensitivity (e.g. emoticon iconography might lead to different sentiments), and aesthetic preference (e.g. relating to the sensitivity of one's own house façade). Here, it might help to allow personalization in terms of aesthetics, or deliberately restrict the overall visual complexity to basic elements.

Collaboration and Competition. A public display on behavior should be sufficiently dynamic and allow different forms of competitive behavior to ensure continuous and persistent interest. Due to the long-term goals, public displays of energy consumption need to incorporate elements of both short-term and long-term comparison, in order to facilitate immediate as well as sustained saving, while minimizing the long-term effects of exceptional circumstances (e.g. households being away, starting competing later). However, any public competition should emphasize a playful and positive character to induce cooperation and "friendly" discussion, rather than envy and shame, by establishing a common ground amongst all stakeholders.

Our study indicated the potential as well as the many challenges for the public visualization of household energy usage. It adds new knowledge to the field of urban computing, particularly regarding the real-world use of communal and sociable screens in the urban domain. In the future, we foresee similar applications, either more minimalistic and integrated in the façade typology, or more personalized and free to accommodate more individual approaches towards sustainable living.

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