Persuading Consumers to Reduce their Consumption of Electricity in the Home

Alan F. Smeaton[1] and Aiden R. Doherty[1,2]

[1] CLARITY: Centre for Sensor Web Technologies and School of Computing, Dublin City University, Glasnevin, Dublin 9, Ireland.
[2] British Heart Foundation Health Promotion Research Group University of Oxford, U.K.
alan.smeaton@dcu.ie

Abstract. Previous work has identified that providing real time feedback or interventions to consumers can persuade consumers to change behaviour and reduce domestic electricity consumption. However, little work has investigated what exactly those feedback mechanisms should be. Most past work is based on an in-home display unit, possibly complemented by lower tariffs and delayed use of non-essential home appliances such as washing machines. In this paper we focus on four methods for real time feedback on domestic energy use, developed to gauge the impact on energy consumption in homes. Their feasibility had been tested using an experimental setup of 24 households collecting minute-by-minute electricity consumption data readings over a period of 18 months. Initial results are mixed, and point to the difficulties of sustaining a reduction in energy consumption, i.e. persuading consumers to change their behaviour. Some of the methods we used exploit small group social dynamics whereby people want to conform to social norms within groups they identify with. It may be that a variety of feedback mechanisms and interventions are needed in order to sustain user interest.

1 Introduction

The topic of real-time electricity monitoring in domestic environments has recently attracted attention from a range of research communities. Much of the interest in this area is based around smart meters which allow generation of data for per-minute or even finer-grained sampling of domestic energy use. Such monitoring can generate huge streams of data and once usage data is sampled it can be uploaded to utility providers for monitoring and optimisation of the overall power network. Usage data can also be made available to customers directly so they can see their own usage in real time. This offers the potential for incentivising customers to reduce their consumption during the peak demand times, typically between 5pm and 7pm on weekdays. The motivation for this is that utility providers have to build and operate enough power generation capabilities to cover peak demands, and if smart metering can incentivise energy customers to reduce their load during those peak times then less power generation capacity is required, overall costs are reduced, carbon footprints are smaller, and everybody is a winner.

For most of the work in this area, real time usage notification is via an in-home display (IHD) unit, a small device which is typically graphical in interface, with a numeric display and is usually a mono-chromatic LCD. Yet simply deploying smart meters and IHDs falls short of inducing behaviour change. In this paper we report a series of tests on our own deployment. The number of subjects in our study are small compared to others but our work is different from most studies because we exploit social grouping as part of the incentivisation. The rest of this paper is organised as follows, In the next section we briefly review related work also reporting user trials and studies. We then describe a recently-published study reporting evidence from two large deployments, followed by a description of our four feedback mechanisms and then an analysis as to their efficacy in promoting change in behaviour. We conclude the paper with recommendations and pointers to future work.

2 Related Work: Studies on Energy Usage

One of the earliest and most ambitious examples of a smart metering trial is the Olympic Peninsula study on 112 residential homes which were fitted with smart appliances (which could be switched on/off remotely), including heating thermostats, water heaters and clothes dryers. This followed previous work [11] where usage of a single appliance, a domestic washing machine, was the basis for various energy usage feedback to users. In the Olympic Peninsula study, data was uploaded to a central server every 5 minutes with price-plans changing in real-time based on the energy demand requested across the 112 residences, so the cost of energy was spread across the residences. On average, consumers saved approximately 10% on their bills from the previous year and from a power generation point of view the peak distribution load requests were significantly reduced [18]. However one drawback with this project was the need to install sensors and actuators on each plug in each home which is an expensive undertaking.

Another study showing the benefits of real-time feedback by Dada *et al.* [3] demonstrated that providing energy consumption information to users can help in deciding when to switch on/off household appliances, pointing out the benefits of real-time information as opposed to static, post-hoc carbon calculators. Recently the Irish Commission for Energy Regulation published results from an 18-month smart metering trial on a representative sample of 5,028 residential consumers which included Time-of-Use (ToU) tariffs and customer-side management stimuli such as a detailed bill with explanations and a real time usage monitor. The findings were that 82% of participants made some change to the way they use electricity as a result of knowing more about their energy consumption and the average overall reduction in use was 2.5% with demand at peak times reducing by 8.8% [10]. Other smart meter' trials have similarly shown that increased awareness of energy use, and helping consumers interpret that data, consistently leads to reductions and flattening of the peak demand curve which can lead to a typical saving of 5-15% [4, 19] or 5-12% [5] and a summary of the work done in this area can be found in Hazas *et al.* [8].

The results of these and other findings have convinced many major electricity providers to roll out smart meter programs, e.g. the main Italian energy provider, ENEL, has already installed about 30 million metering units [14] and according to an EU single market electricity directive (2009/72/EC) at least 80% of Europe's consumers must be equipped with smart meters by 2020, subject to positive economic assessment of all the long-term cost and benefits.

The above evidence suggests that smart metering can play a vital role in helping electricity generation companies reduce their carbon footprints through better predicting overall electricity demand and also through customers consuming less energy or less energy at times of peak demand. However what has not been established are the types of methods to actually inform customers of their energy use [6]. Fischer comments that *"... implementation of feedback is lagging way behind knowledge ... "* [5].

From the design point of view there is a general agreement as to the criteria required specifically when informing users of their domestic energy usage, namely:

- give real-time feedback [2, 16]
- include colour coding [20, 13]
- build in a comparison to baselines & contextual information [2, 13, 16]
- relate usage to actual costs [2, 13]
- provide self-comparison [16, 20]
- include good asthetics [9, 16]
- ensure availability on mobile devices, anywhere, any time [13, 20]
- include easy access to historical data [16, 20]

However, while some of the work referenced in the guidelines above has produced prototype systems incorporating many of the aforementioned considerations, they have not yet been evaluated by participants in user studies [13, 20] and most large-scale user trials or studies have used the simple IHD at best, as the mechanism to feedback usage information. Clearly we should focus on mechanisms to change participant habits/behaviour rather than merely report electricity usage [15, 17].

In this paper we discuss our own design and experimental setup experiences where we have gathered *minute-by-minute* electricity usage data from 24 households over an 18-month period and we introduced 4 different interventions to try to induce a change in behaviour. The lessons we learned are important as we will see later on. but before introducing our own work, in the next section we will summarise other recently-published work reporting two large field trials.

3 Social Norms for Incentivising Behaviour Change in Energy Consumption

One of the most significant experiments in recent times in terms of exploring what influences human behaviour, was the work by Goldstein *et al.* [7] on increasing the rate at which guests recycle bathroom towels in hotels. This experiment used a variety of messages in hotel rooms to encourage guests to recycle their towels rather than throwing them on the floor thereby indicating a need for clean ones when their room was made up next day. Their results found that by using messages which introduced the guests into social groups they thereby exploited our natural tendency to follow the behaviour of others with similar characteristics to ourselves. By using simple messages with text like *"other guests who stayed in this room ..."*, or *"join the men and women who are helping ..."* rather than the usual *"help save the environment"* message, which they refer to as provincial norms, they observed a significant increase in participation in the recycling program.

This idea of binding participants to form some social grouping was exploited on a much larger scale in a series of recent trials on 170,000 domestic energy consumers, reported in [1]. Two studies in the Sacramento Municipal Utility District of California and the Puget Sound area of Washington state, provided feedback to customers on their home electricity and natural gas usage, with the novelty being a focus on peer comparisons. Customers were provided with monthly or quarterly feedback reports which compared their usage to those of their neighbours in similarly-sized houses and these formed the peer groups.

The net outcome of the peer comparison intervention was that households in receipt of the peer comparison reports made significant and lasting reduction in their energy usage, so much so that if the savings were extrapolated to the whole of the city of Sacramento then energy bills would be reduced by over $15M per year [1]. There are of course caveats with these results, such as the fact that the focus has been on single family, detached homes at the higher end of the market rather than on apartments or in areas of less affluence, but still the findings are significant in that they show peer comparison feedback can yield sustained behavioural change and can be scaled.

The theory of small-group peer comparison tells us that people tend to form bonds with smaller groups with which they feel more connected and which turns into higher trust values so they are more likely to conform to the norm in that group. Other work on studies of peer comparison has tended to reveal the "boomerang" effect where those with less-than-normal usage then tend to increase their consumption, as well as the free riders who tend to emerge when we find out that everybody else is saving. This theory of conformance to social norms has been espoused and developed in seminal work by Nobel Laureate Elinor Ostrom [12]. Yet when we interpret this theory and try to put it into practice there are many unanswered questions. What makes the best criteria for peer group composition ... geography, social networking, demographics, virtual ? Should peer group membership be anonymous or revealed ? How should we manage the free riders, should we just tolerate or expose them ? Can or should people be members of more than one peer group ?

These issues are deep questions for any attempt to use peer groups and social norms to persuade people to change their behaviour. Meanwhile, in our own study we don't have access to 170,000 users but we did develop two interventions in our feasibility trial of domestic energy usage which exploited provincial norms, and two interventions which did not. In the next section we introduce these 4 interventions which are each based on current technology available today.

4 Four Feedback Interventions for Electricity Consumption

4.1 Intervention 1 – Simple Web Interface

From the onset, our households expressed a strong desire to have web access to their data. Therefore as a natural initial step to maintain household interest and momentum, a simple web chart was developed. Data was captured into a central database repository and displayed online as a web application.Households were able to select their (known but anonymous) ID number from a drop-down box to then view near real time electricity consumption (in KW/h units) via a web browser.Similar near real-time feedback of usage is now available with systems developed and marketed by companies like CurrentCost[3] and AlertMe[4]. While this intervention did have limited accessibility, it did help to build user trust in the overall logging system,

4.2 Intervention 2 - In-Home Touchscreen Display

Interaction platforms such as a touchscreen in-home display, wall-embedded screen or interactive digital picture frame all offer possibilities for providing continuous, always-on, *ambient* feedback of electricity usage. This satisfies many of the user interface design criteria mentioned earlier and thus a simple standalone application running on a touchscreen computer was our next choice of display platform as it allowed us to develop and deploy, then define and re-deploy. Figure 1 shows a screenshot from the application showing 'day view' (upper panel) with the hourly breakdown of today's usage in bars and grey line indicating the average usage of that time in the past, and 'hour view' (lower panel) showing the minute breakdown in thin bars. Bar charts provide historical (past) information along with the current real-time usage. The user can click on the arrow buttons (right end of the top bar chart) to change the current focus to other hours and the bar charts scales (default is 'day view') to weekly or monthly views. Cost information (measured in Euro) is provided providing baseline and contextual information in an easily appreciated form. Each horizontal bar in all the charts is colour-coded so that if the usage is below the user's average it is in yellow-green, and if it is above average it turns to orange.

[3] http://www.currentcost/com
[4] http://www.alertme.com

Fig. 1. The touchscreen display.

4.3 Intervention 3 - monthly e-mail awards

To build up peer groups, we devised a monthly e-mail awards scheme among the group of 24 households in our study who were divided into three social groups based on geographic region thus building on local rivalries among the groups. Individuals were rewarded for the savings made in comparison to their previous month, contributing to their group score. The e-mails informed individuals of their relative percentage savings and drew comparisons between themselves and their peers and their rivals in the other groups, and this was done in an encouraging and humorous manner.

4.4 Intervention 4 - public web portal

In our final intervention we provided our households with anytime anywhere real time access and allow households to review how they were doing in comparison to everyone else. Figure 2 shows the Silverlight web interface we developed. Initially the user is presented with her own hourly electricity usage as a bar chart, with yellow-green bars indicating under-use and orange bars indicating over-use compared to her own norms. The user can change the visualisation to daily, monthly, or yearly and can also look at the other 23 anonymised households by selecting from a drop-down box thus allowing comparison with others. Household location is indicated on a map on the right panel, providing a sense of proximity with other households being compared against.

5 Experimental Setup

To monitor electricity consumption of each individual household, we make use of the commercially available EpiSensor ZEM-30[5] data logging unit illustrated in Figure 3. The ZEM-30 includes a mains power supply, waterproof enclosure

[5] http://www.episensor.com/products/wireless-nodes/zem-30/

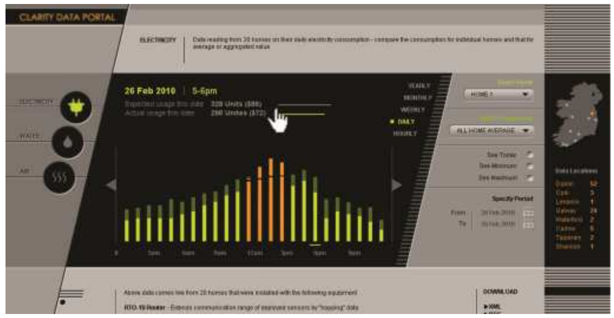


Fig. 2. Sensor Data Portal

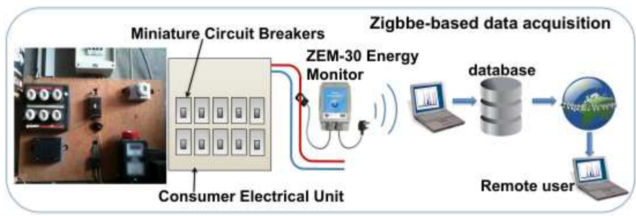


Fig. 3. Overview of capturing home electricity usage data and uploading to a central server

and a CT clip which is attached around the live wire running into a given household's main fusebox. This measures 11 different electrical parameters including *RMS/Peak/SAG current/voltage, real/apparent power* and of most relevance *Watt hours*. This information is relayed across a local Zigbee network to a computer every minute which logs the data onto a local relational database. This computer then uploads data every 10 minutes to a central web server, thus backing-up the data and also making it available for access from anywhere.

For a trial of 18 months duration, we recruited 24 households to log minute-by-minute electricity consumption data. The households differ in terms of geography (city vs rural), demographics (families, couples and singles), and household type (house, apartment). The captured data amounted to over 67.9 million parameter readings. Tables 1 and 2 summarise the data collected, with the "Typical Weekly Consumption" column visually shows the widely varying electricity consumption lifestyle patterns across all the households[6], with the x-axis being the 24 hours in a day and the y-axis being the 7 days in the week (Monday to Sunday, top to bottom). Households with a * in the table indicate those used to evaluate methods mentioned later in the paper.

[6] Household 3 is in fact a University chemistry lab, hence the concentration of electricity usage between 9am and 5pm, Monday to Friday

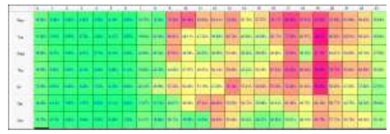
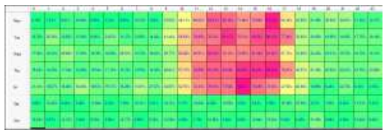
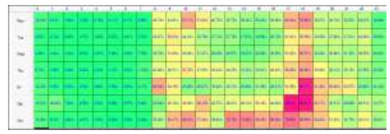
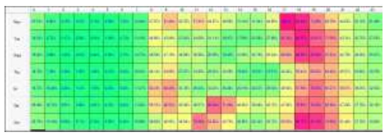
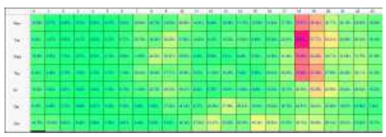
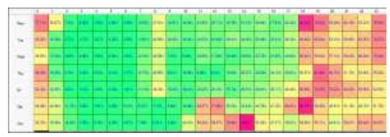
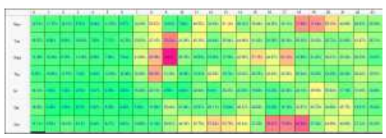
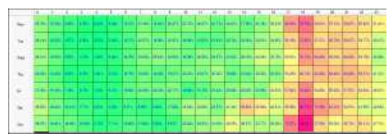
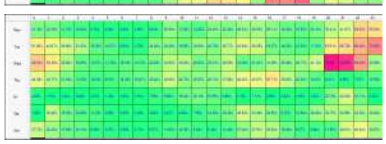
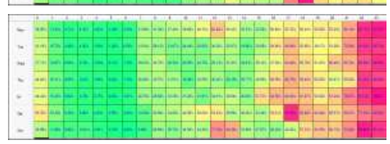
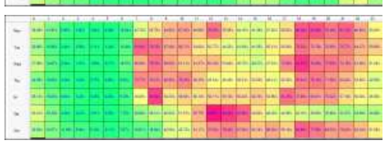
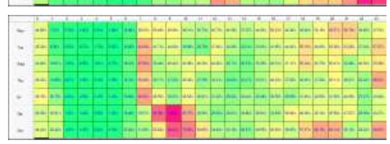
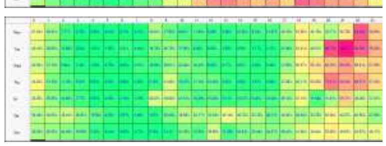
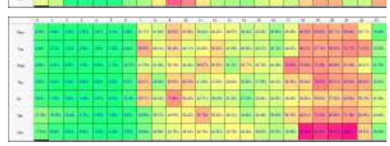
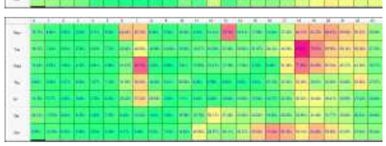
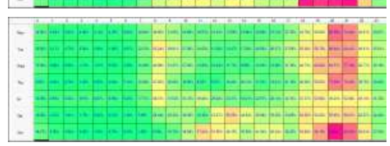
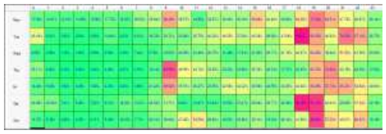
Home # (number of occupants) and Visualisation of Typical Weekly Consumption			
1(4)		2*(2)	
3*(10)		4*(3)	
5*(4)		6*(1)	
7(3)		8*(2)	
9(3)		10*(5)	
11(2)		12*(2)	
13*(4)		14*(3)	
15*(3)		16*(5)	
17*(2)		18(4)	

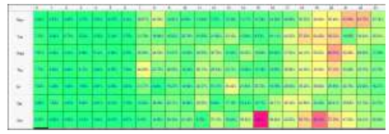
Table 1. Electricity data captured by 18 of our 24 households.

Home # (number of occupants) and Visualisation of Typical Weekly Consumption

19(3)



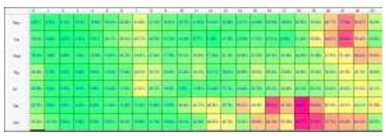
20(5)



21(1)

22(5)

23(2)



24(5)

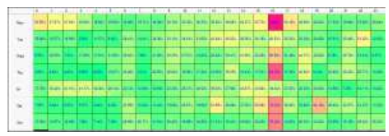


Table 2. Electricity data captured by remainder of our 24 households.

6 Results of Feasibility Tests

6.1 Intervention 1 Anecdotes - simple web chart

As this stage was just an interim measure to help learn typical consumption behaviours, we did not gather data from households. However it is worthwhile to note that a handful of the households (only 3 or 4) accessed the web page multiple times per day, however the others infrequently accessed the data.

6.2 Intervention 2 Anecdotes - home computer display

When many of our households were initially recruited, we captured some background usage information, so as to build up a profile of their energy consumption behaviour. Thereafter, we presented our users with the touchscreen application and noted savings in the months afterwards. Our 13 regular households (marked with a * in Tables 1 and 2) saved 14% on average one month after receiving access to the desktop display, 9% two months later, 14% three months later, and 16% four months later.

6.3 Intervention 3 Anecdotes - monthly email awards

Monthly e-mails with awards for most saving were administrated for the three different social groupings. These generated email discussion but did not generate any noticeable effect on electricity consumption.

6.4 Intervention 4 Anecdotes - public web portal

When our web portal was deployed, all our households were informed of its availability and encouraged to use it. There was no measurable effect on the electricity consumption habits of our 13 most regular households, with an average daily consumption for the 2 months before the introduction of the web portal of 11.58 units vs. 11.23 units for the 2 months after this intervention was introduced.

7 Discussions

Touchscreen display (method 2): Anecdotally all households regarded our desktop-display as being easy to use. Households did consume less electricity after receiving access to the desktop display, however these savings could be as much to do with seasonal effects as access to the information. We could find no strong evidence that more usage of the browser has a direct effect on electricity consumption. Compared to our **initial web page (method 1)**, the computer display supports more continuous, less-effortful access to electricity monitoring, but even following best practice HCI guidelines, there still remains the significant challenge in supporting households to sustainably break the 5-15% savings barrier.

Monthly e-mails awards (method 3): The primary challenge was to maintain sensitivity towards those households who saved the least in a given month, i.e. good performances were highlighted and praised while bad performances were not commented on. Initially there was much fun with many group e-mails being sent around and well-spirited comments showing competitive instincts. However, after initial interest, our households rapidly became less engaged over time. Winning households in the later months still felt a strong sense of achievement but as with the touchscreen display, the monthly e-mail awards failed in breaking the sustainable 5-15% savings barrier.

Web portal (method 4): The biggest challenge with this intervention has been in generating excitement among the households and getting them to use it. Our households have anecdotally noted that they use it to show to their friends but our 13 regular households appear to have hit a barrier in terms of further reducing their consumption. Perhaps an easier access through a mobile app may have helped here but the energy savings (just 3%) have plateaued during usage of this intervention.

8 Conclusions

Much literature has focused on the savings that can be made via continuous feedback of electricity consumption, but there is a lack of research focusing on the details of what those feedback mechanisms should consist of. In this article we concentrated on the design and implementation of four feedback mechanisms, discussing the strengths and weakness of each on a pilot sample of households. Two of these were based on exploiting peer norms that come from membership of peer groups and two were independent. The interventions have not been evaluated as behaviour change interventions due to a number of factors including the absence of control/baseline data, no structured randomised control trial to assign deployments to participants, the elimination of almost 45% of the original study cohort from data analysis due to various technical issues, no adjustment for confounding factors such as weather, season, etc., and the limitations in deploying four interventions in succession without controlling for learning effects and other interactions between conditions that might confound quantitative results. So with all those negatives, is there anything we have learned from this work ?

Through this experience we have found that our proposed interventions are feasible to deploy. Furthermore no one intervention method was preferred by all the participants, rather a combination of the methods allowed the participants access their electricity consumption information depending on the context of the circumstances around them. We have also found that a variety of feedback mechanisms and interventions are needed in order to sustain user interest and that the challenges of changing user behaviour in this domain still remain. While peer grouping which exploits "Big Data" from smart metering is recently shown to be scalable [1], the composition of groups, membership visibility, ability for users to opt in/out of groups etc., all need to be addressed. However, the rewards of getting this right will be significant in terms of reduced carbon emissions and reduced consumer energy bills.

Acknowledgements The authors thank Science Foundation Ireland (grant 07/CE/I147) and (AD) the Irish Health Research Board (grant MCPD/2010/12)

References

1. Ian Ayres, Sophie Raseman, and Alice Shih. Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. *Journal of Law, Economics, and Organization*, 2012. [Online: published August 20, 2012].
2. Marshini Chetty, David Tran, and Rebecca E. Grinter. Getting to green: understanding resource consumption in the home. In *UbiComp '08: Proceedings of the 10th international conference on Ubiquitous computing*, pages 242–251, New York, NY, USA, 2008. ACM.
3. Ali Dada, Thorsten Staake, and Elgar Fleisch. The potential of UbiComp technologies to determine the carbon footprints of products. In *Workshop on Pervasive Persuasive Technology and Environmental Sustainability, Pervasive 2008*, pages 50–53, 2008.
4. Sarah Darby. The effectiveness of feedback on energy consumption. Technical report, Environmental Change Institute, University of Oxford, 2006.
5. Corinna Fischer. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, 1(1):79–104, 2008.
6. Geraldine Fitzpatrick and Greg Smith. Technology-enabled feedback on domestic energy consumption: Articulating a set of design concerns. *PERVASIVE Computing: Special Issue on Environmental Sustainability*, 8(1):37–44, 2009.

7. Noah J. Goldstein, Robert B. Cialdini, and Vladas Griskevicius. A room with a viewpoint: Using social norms to motivate environmental conservation in hotels. *Journal of Consumer Research*, 35(3):472–482, 2008.
8. Michael Hazas, Adrian Friday, and James Scott. Look back before leaping forward: Four decades of domestic energy inquiry. *Pervasive Computing, IEEE*, 10(1):13 – 19, jan.-march 2011.
9. Tiffany Grace Holmes. Eco-visualization: combining art and technology to reduce energy consumption. In *C&C '07: Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, pages 153–162, New York, NY, USA, 2007. ACM.
10. Gary Martin. Smart metering information paper 4 - results of electricity cost-benefit analysis, customer behaviour trials and technology trials. Technical report, Irish Commission for Energy Regulation, 2011.
11. L.T McCalley and Cees J.H Midden. Energy conservation through product-integrated feedback: The roles of goal-setting and social orientation. *Journal of Economic Psychology*, 23(5):589 – 603, 2002.
12. Elinor Ostrom. Collective action and the evolution of social norms. *The Journal of Economic Perspectives*, 14(3):137–158, 2000.
13. Dane Petersen, Jay Steele, and Joe Wilkerson. Wattbot: a residential electricity monitoring and feedback system. In *CHI '09: Proceedings of the 27th international conference extended abstracts on Human factors in computing systems*, pages 2847–2852, New York, NY, USA, 2009. ACM.
14. Paola Petroni, Marco Cotti, and Oscar Bono. The new edge for the enel telegestore: An integrated solution for the remote management of electricity and gas distribution allowing a total management of the energy consumptions. In *Electricity Distribution, 2009 20th International Conference and Exhibition on*, pages 1–5, June 2009.
15. James Pierce, Diane J. Schiano, and Eric Paulos. Home, habits, and energy: examining domestic interactions and energy consumption. In *CHI '10: Proceedings of the 28th international conference on Human factors in computing systems*, pages 1985–1994, New York, NY, USA, 2010. ACM.
16. Yann Riche, Jonathan Dodge, and Ronald A. Metoyer. Studying always-on electricity feedback in the home. In *CHI '10: Proceedings of the 28th international conference on Human factors in computing systems*, pages 1995–1998, New York, NY, USA, 2010. ACM.
17. Yolande Strengers. Smart metering demand management programs: challenging the comfort and cleanliness habitus of households. In *OZCHI '08: Proceedings of the 20th Australasian Conference on Computer-Human Interaction*, pages 9–16, New York, NY, USA, 2008. ACM.
18. The Olympic Peninsula Project. Gridwise demonstration project fast facts. Technical report, Pacific Northwest National Laboratory, 2007.
19. Daniele Velte and Ana Martin. Energy services: Reducing the energy consumption of residents by behavioural changes. Technical report, BewareE, 2009.
20. Markus Weiss, Friedemann Mattern, Tobias Graml, Thorsten Staake, and Elgar Fleisch. Handy feedback: connecting smart meters with mobile phones. In *MUM '09: Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia*, pages 1–4, New York, NY, USA, 2009. ACM.