



Exploring consumer preferences for home energy display functionality

Report to the Energy Saving Trust

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Centre for Sustainable Energy

August 2009

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Summary

The national roll-out of smart meters is an opportunity to improve consumer information on energy use through the integration of home energy displays with the smart meter technology. This study sought to define a core specification for these real-time energy displays, derived from a qualitative investigation of consumer experience of the electricity displays currently available on the market.

The study recruited a total of 38 participants to five demographically differentiated focus groups, each of which met twice. At the first meeting, each group designed an ideal home energy display based on participants' ideas of what they thought such a display ought to include. Participants then spent a week using existing models at home. At the second meeting, the groups reviewed their experience and revised their designs accordingly. The study found remarkable convergence in the groups' final designs, enabling the clear specification of a core set of features and functionality for home energy displays.

Only one of the displays used in the study, the GEO minim, comes close to meeting this specification. Despite a relatively well developed display industry in the UK, the majority of the home energy displays currently on the market do not have the functionality that consumers identify, in practice, as being critical to display design. Hence 'the market' cannot be relied on to deliver an outcome that is optimal for consumers.

Key design principles

The following design principles, derived from the focus groups' experience, underpin the specification:

- *Changing values are poorly served by numeric displays.* Although participants valued the accuracy of numbers, they also recognised that a changing rate is better expressed as an analogue indicator.
- *Keep it simple.* In all five focus groups, moves to add features or functionality were always countered by the many participants who wanted to prioritise simplicity.
- *A rate explained is complex; a rate experienced is intuitive.* In their first design exercise, participants struggled with the concept of a rate, especially a rate of spend, and how to communicate it but their experience of using the displays rate dispelled these problems. The meaning of a rate of spend is quickly grasped in practice.
- *Everyone understands money.* Watts, kilowatts and especially kilowatt-hours will never be universally understood or accepted as units of energy consumption. Money offers a straightforward alternative for both rate of consumption and historic consumption.
- *Interactivity is lost on those who are scared of losing what they have gained.* Interactivity may be important for those who are keen to maximise the value of their displays but there will always be individuals who do not want to interact with the display for fear of losing the screen that they understand. Careful specification of the default mode of a display is therefore critical.
- *Mobility is valued, but for a limited period.* Many participants valued being able to move around their homes with their displays when they first used them, working out the impact of switching on different appliances. After this initial period, most were happy to leave the display in a prominent position in their home.
- *Different users have similar needs.* Although there were many differences between and within the focus groups, these differences did not lead to fundamentally different solutions. Different people do want different things from their displays but there is a core of information a functionality desired by everyone. The study did not, however, explore the specific needs of people with visual impairment.

The core specification

1. The default display should include

- A clear analogue indicator of current rate of consumption
- Current rate of consumption as a rate of spend in £ per day (numeric)
- Cumulative daily spend in £ (numeric)

2. The display should offer the following options through interaction (by pressing a single button):

- Spend in last seven days, day by day
- Spend in last complete week
- Spend in last complete month
- Spend in last complete quarter

The historic periods should match the utility's billing periods in order that the display is consistent with household bills.

3. The display should offer the option (by pressing a single button) of switching units from money to power, i.e. from £ per day and £ to kilowatts and kilowatt-hours.

4. The display should be mains-powered but have an internal battery to enable mobility in the home.

Target-setting should be considered as part of the core specification but more evidence is needed of the value of such an option over a longer period of use. It is not clear whether this extra functionality warrants the cost of increased complexity.

If interaction with the display is not possible, the following should be the default content of the display:

- A clear analogue indicator of current rate of consumption
- Current rate of consumption as a rate of spend in £ per day (numeric)
- Current rate of consumption in kilowatts (numeric)
- Cumulative daily spend in £ (numeric)

The following issues were not addressed directly by the study but are nonetheless important to the specification of smart meter-integrated energy displays:

Variable tariffs. The priority of cost in the study implies that, under a variable tariff regime, the value of the current tariff ought to be included on the default display in order that users can make fully informed judgements about their current rate of spend.

Gas. The importance of simplicity as a design principle implies that, if a display is to show both electricity and gas, exactly the same means should be used for gas as for electricity.

The study did not find evidence to support the use of carbon dioxide as a proxy measure of the environmental impact of energy consumption, though some participants acknowledged that some measure of environmental impact would be valuable. Carbon does, however, have potential to communicate the relative environmental impacts of electricity and gas.

Microgeneration. More research is needed to identify the best way of presenting the more complex information needed by households who generate their own power including rates of electricity generation, consumption and export.

1. Introduction

This report describes the results of a study into the functionality and impact of real-time home energy displays. The study was commissioned by the Energy Saving Trust to inform the 2009 government consultation on the national roll-out of smart meters which sought evidence to inform the development of policy on this issue.

The objectives of the study were:

- i) To provide evidence of what energy display features are likely to be most effective at encouraging behavioural change.
- ii) To assess whether it may be possible to establish what constitutes 'best practice' in terms of energy displays.
- iii) To make initial recommendations for what minimal requirements smart meter energy displays should exhibit. It is vital that any such requirements would need to be technically feasible at reasonable costs and not stifle competition and innovation in the provision of energy feedback.
- iv) To assess options relating to the positioning of in home displays and the relative merits of fixed versus mobile technologies.

The study sought to address these objectives as fully as possible in the time available. It must be stressed, however, that the evidence produced by the study is qualitative. It offers insight into how people engage with real-time displays, the types of impacts that displays have in the domestic context and the value to users of different types of display functionality. Although it may not be possible to demonstrate conclusively that a singular feature of any display has specific impacts on energy use, it is possible to describe the subtleties of human engagement with these displays and thereby identify an appropriate set of priorities for a future specification.

The study focused on stand-alone real-time home energy displays designed for the domestic environment. It did not explore the potential of other feedback mechanisms for domestic consumers such as the internet or mobile phones.

2. Methods

Two literature reviews were conducted to inform the development of the project and the analysis of the findings. The first, undertaken by Sarah Darby of the Environmental Change Institute at the University of Oxford, focused on the existing literature on real-time home energy displays. The second, undertaken by Clive Frankish of the University of Bristol, examined the wider literature on the psychology of human interaction with visual displays.

Telephone interviews were conducted with individuals from five of the companies that currently sell real-time home energy displays in Britain. Interviewees included company directors, designers and marketing managers. Two other companies were approached but were unwilling to provide information that they considered commercially sensitive.

Five focus groups were recruited from Bristol and the surrounding area using a professional recruitment agency (Quality Fieldwork). Participants were offered the following incentives:

- £25 plus free home energy display to attend first group
- £25 to attend follow-up group, plus £25 to complete and return diary, recording experience of using home energy display

The groups were differentiated as follows:

- Group 1. Prepayment meter users (7 participants)

- Group 2. Under 30 years old (8 participants)
- Group 3. 60-69 years old (8 participants)
- Group 4. 30-59 years old, socio-economic group A/B/C (7 participants)
- Group 5. 30-59 years old, socio-economic group D (8 participants)

Individuals were only recruited if they believed that human-induced climate change is happening, in order to avoid off-topic discussion and disengagement from the theme of the study. However this criterion did not result in any exclusions: among the few individuals approached by the recruitment agency who did not believe that human-induced climate change was happening, none met all the other recruitment criteria.

The focus groups took place in a house in central Bristol. A domestic environment was chosen in order that participants could be shown how to install a home energy display.

At the beginning of the first group, participants were asked to complete a questionnaire which recorded basic information about their knowledge and interest in domestic energy issues and their use of information about energy use. This was also the focus of the initial group discussion which was followed by a short quiz about the power rating of different household appliances. Group members then shared their opinions of real-time displays, prompted by a wide selection of pictures of such displays (scales, thermometers, speedometers, traffic lights, petrol pumps, computer download bars, etc). They then collectively designed a real-time energy feedback display (drawn on a piece of A1 card) which was photographed.

At the end of the focus group, participants were given a real-time home energy display to take home and use for the next eight days. They were shown how to install the sensor on the live cable of their electricity meter. Participants were also given a diary which they were asked to complete and bring back to the follow-up group. The diary asked them to record their interactions with the display, what they learnt from it, what they did in response to it and their general thoughts about it.

The devices used were (clockwise from top left) the Wattson, Current Cost CC128 ENVI, Owl, Eco-eye, GEO minim, Efergy lite and (centre) Owl Micro. Full details of their functionality are described in Appendix 1.



After eight days, each focus group reconvened for a follow-up session. Participants completed another questionnaire at the beginning of the follow-up group, recording their use of, and response to, the display. After an initial group discussion of the general responses to the displays, each group member took it in turn to describe their experience and their views of the display they had taken home. Although the participants did not bring their displays back, one of each type of display was wired up and functioning in the room where the group was run so that all members of the group could reflect on the pros and cons of each display. Finally, the groups reviewed their initial designs and prepared new ones in the light of their experience. These too were photographed. The photographic record provides the clearest evidence of the difference between what participants initially thought they wanted on their displays and what they found in practice to be genuinely informative.

All focus groups were recorded and notes were also taken during the groups. The analysis for this report draws on these notes, the two questionnaires, the diaries and the photographs of the designs.

3. Key points from the literature

The following is a summary of the key points from the two literature reviews commissioned for this study (included in full in Appendices 3 and 4). The first review focuses on the specific literature on home energy display functionality. The second takes a broader psychological perspective on real-time displays.

Real-time home energy display functionality

Real-time home energy displays attempt to communicate something that is relatively 'invisible' to most householders – that is, the extent to which they are using electricity (and gas), either instantaneously or over a period of time.

The effectiveness of a real-time energy display will be related to its ability to:

- make energy usage visible and intelligible to the user;
- complement what the user knows about their home, routines and practices;
- provide actionable information, linking usage levels with specific actions, end-uses or processes;
- maintain user interest by giving useful information and allowing for interactivity and learning;
- be used at a number of levels, from ambient signals to detailed interrogation by the user.

Displays should be consistent in design and manufacture with their purpose, i.e. they should be low-impact in terms of material and in-use energy consumption. There are practical design issues associated with real-time energy displays for those with visual disabilities and for those unfamiliar with ICT.

The location of the display will have an impact on how well it is used, and will also have implications for the amount and type of power it uses. A base from which the display can be recharged (but which allows for it to be moved around the home) would seem to be a good arrangement.

Research to date, including early findings from the UK Energy Demand Research Project (EDRP) trials, tends to show that the importance of very basic 'ambient' signals is probably underestimated. Engineers and energy specialists may tend to forget that the average householder is not familiar with energy units, not very interested in energy for its own sake, and may be alienated by an over-numerical display.

Certain features of consumption are likely to attract particular interest. For example, the scale of baseload or overnight usage, which can be startling; or the maximum and minimum levels of consumption in a given period.

Ideally a real-time energy display will provide information that is accessible, engaging and that can benefit almost everyone to some extent. There are householders who are already frugal with their energy, and feel that a display will add nothing useful to their knowledge or ability to reduce their consumption. This needs to be recognised: there is nothing to be gained by foisting new technologies on unwilling recipients.

A display device does not necessarily have to show everything that a householder might need in the way of information about their energy consumption. Consideration needs to be given to what is best shown on a display and what is best shown on a website, which is likely to have more possibilities for interactive learning.

Design of real-time home energy displays: a psychological perspective

The design of data displays must consider both the 'what' and the 'how' of information presented to users. The design of a display has to begin with questions about what the user is trying to do and what effect the designer wishes to have on the user's awareness and subsequent behaviour. In the context of domestic energy displays there are potentially both short- and long-term goals. For example, the short-term goal might be to provide a prompt for immediate actions (such as turning off lights, lowering the thermostat), whilst also helping to establish longer-term habits and behaviour change. In considering means of achieving these objectives, psychological literature concerned with decision-making behaviour – particularly with regard to economic decisions – and ergonomics is extremely relevant.

Consumer decision-making behaviour

The microeconomics decision model of consumer choice is based on maximising utility as defined by a fixed set of options and preferences (values). It essentially assumes that consumers make rational choices, guided by their evaluation of outcomes, where 'utility' can be derived from sources other than money (for example, social values or environmental concerns). If this was the case, the best strategy for intervention would be to improve net benefits of the desired behaviour, and to ensure that accurate information about cost/benefit relations is readily available. However, behavioural economics research shows that individuals do not make consistently rational decisions, as defined by utility of outcomes. There is no guarantee therefore that providing users with the information needed to make a rational choice will actually increase the likelihood of that choice being made.

Deviation from rational consumer choice behaviour arises for a number of reasons. Of most relevance to this study is: *loss aversion* – consumers overvaluing a potential loss relative to other options (curtailment of energy usage may be viewed in this way); and *habit* - a significant proportion of everyday consumer consumption, including of energy in the home, is based on habitual cognitive or affective responses, rather than rational deliberation. The general implication is therefore that to support consumer decision making, the ideal formulation of classical utility theory must be combined with psychological insights of behavioural economics.

Display design

The immediate focus of this study is on the design and functionality of real-time home energy displays. A key point that has emerged from empirical research into design principles is that there are no 'off-the-shelf' design solutions. This is firstly because display design must always be viewed in the context of the specific task and user characteristics, and secondly, because advances in technology are constantly generating new possibilities.

Ergonomics literature has historically been driven by research in avionics, where applications focused on expert (and highly motivated) users performing complex control tasks, with user goals and criteria for task efficiency generally well defined. However, in the context of this study, these characteristics do not apply: the user group - domestic energy consumers- is broad; goals may differ from one person to the next; and a balance has to be achieved between control issues in the immediate term, with longer term behaviour change. However, an important lesson that can be taken from ergonomics research literature is that the display needs to be consistent with users' intuitions and provide clear, task-appropriate representations of information – i.e. information that will support energy-efficient user behaviour.

A key question to consider in the design on a real-time energy display is, therefore, what information does the user need, in order for them to adopt energy efficiency practices and behaviours? This will affect the type of information that is conveyed by the display: it may be quantitative (e.g. current electricity

consumption) or qualitative (e.g. 'too high'); and may present information in the past, present, future (predicted); or any combination of these.

Quantitative information could be conveyed through digital or analogue displays. The former provides advantages such as quicker reading times and fewer errors in readings, but the latter can enable the user to make a quick qualitative assessment. It may be harder to read the exact value represented by an analogue display, but it can directly convey the difference between current and target values ('check reading') in a direct and readily interpretable manner. In a system that is under user control, it is this mismatch between where they are and where they want to/should be, that provides a cue for action, and also conveys information about the importance and/or urgency of that response. Other display options could include: warning/ indicator lights; audible alerts; and pictorial displays. In general, the question whether digital is better than analogue thus depends not only on the type of information to be displayed, but also on the nature of the task being carried out (Green, 1988). In complex real-world environments, the need for check readings, evaluation of future states and other factors related to 'situation awareness' can override simple considerations of speed and accuracy of quantitative readouts. Including analogue and digital approaches to communicating information on a home energy display could provide an optimal combination.

There are also trade-offs to be made, for example including options for navigating to different screens, thereby providing all the information a user may require on the display, versus maintaining simplicity in design, and avoiding the risk of deterring users who lack the confidence to interrogate the device. Either way, it is essential that the default screen provides the information required for consumers to act.

4. Interviews with suppliers of home energy displays

The following are key points from the telephone interviews with current suppliers of home energy displays.

Current Cost (Current Cost Ltd)

The Current Cost was designed with an eye to minimising the need for interaction to obtain information – “no fiddling with buttons”. Consequently it has a large screen which presents concurrently: power consumption in Watts, current rate of spend (which switches automatically between cost per day and cost per month), an indication of the change in cost when an appliance is switched on or off, a graphic of the previous day's consumption over three periods, cumulative energy consumption in kilowatt-hours (which switches automatically between three periods), time and temperature. This is the only display currently on the market which has sought to balance comprehensive communication of information with minimum interaction.

Efergy (Moeller Ltd)

The designers of the efergy display came from a background of developing whole house systems which control multiple services, such as lighting and heating, together. Consequently the display is relatively sophisticated and many different display options are accessible through the four large buttons on the top of the unit. The company aims to improve this interactivity further by maximising the value of a USB link from the display to a PC and thus to the internet.

GEO (Green Energy Options Ltd)

The GEO range of displays are designed to communicate in “an iPod fashion”, i.e. intuitively, with an emphasis on providing “usable information rather than data.” The explicit model for the display is the car dashboard, combining analogue and digital numeric components. The distinctive analogue components are the ‘speedometer’, describing current consumption, and the target bar which clocks up daily consumption towards a preset target. The company's own market research revealed the need for a clear, intuitive display which de-emphasised numbers – “plain digital numbers don't do it.” Hence the dashboard analogy which ensures that “nobody gets confused.” However, the market research also revealed that many people also want more detailed information. To this end, the company has developed a range of products including devices that pick up appliance-specific data.

Owl (2 Save Energy plc)

The Owl is the modern incarnation of the first home energy display, the Electrisave. The company that bought out the Australian developers of the Electrisave was happy with how the original display did the job but sought to improve the build quality of the device. Although ideas are always being generated about how to improve functionality, the company has been keen to keep the display simple and cheap and so has largely remained true to the original design.

Wattson (DIY Kyoto)

This display is the invention of three graduates from the Royal College of Art and Design and is distinctive as a result. According to its designers, its unique selling point is pleasure: it is designed to be a desirable object which is attractive to live with and easy to use. The design focus is on visual communication of real-time information, particularly through the changing colours. The simplicity of the design aims to involve and excite everyone including “the average Joe”. The company is now complementing the product with the development of an online community through which users can upload, compare and learn.

5. The impact of real-time energy displays

A core objective of the study was to assess the impact of real-time energy displays on energy-related knowledge and behaviour. These impacts were substantial. Participants rapidly learnt about the differences in power consumption of the lights and appliances in their homes. They were often aghast at what they found and, in most cases, this led to specific actions to reduce energy. These included single actions with lasting effects, such as changing light bulbs, or changes in on-going behaviour, such as only filling the kettle with the water that is needed. Those who did not make changes usually said they had no scope for change because they were already frugal in their energy use. As the trial period was only eight days, the study could not explore the important issue of the long-term impacts of using a home energy display.

The important issue here is the range and type of impacts rather than their extent, which is as much a reflection of individuals’ participation in the study as it is of the specific impact of the displays. Everyone kept a diary and everyone came back for the second focus group (and received their financial incentive for doing so). Hence they were all motivated to interact with their displays to some extent. Nonetheless it was striking that the experience of using the display was much more powerful than the educational experience of the focus group. For example, many participants expressed amazement at the power consumption of a kettle when this was revealed during the energy quiz in the first focus group, but when they returned for the follow-up group they expressed even greater amazement at having found out exactly the same thing through using their display. The experience of seeing the numbers, bars or colours change when they flicked their switches was far more powerful than the focus group discussion.

Learning about domestic energy

Participants knew very little about their energy consumption. Those on prepayment meters had the best sense of what they were spending but this did not translate into an understanding of what used more or less energy in their homes. Consequently, the displays enabled all participants to learn about the differences in the power consumption of different lights and appliances.

The types of knowledge that participants gained included:

- The power consumption of lights and appliances in Watts or kilowatts
- How much it costs to run different appliances
- Household baseload consumption. “I’m now getting used to the display and numbers. I know that it mostly sits at 0.129kW with just the TV on and it’s 0.048kW with everything off.”

- The range of their energy consumption levels and therefore what constitutes a high level of consumption (at least for them)
- Typical daily consumption or spend. “I remembered values from previous days. You get to know your daily consumption level. The most I ever used in one day was 40p.”
- Patterns of energy consumption over the week. “A lot of energy gets consumed on weekends with everyone home. This is usually taken for granted but now we’re trying to do something about it”.
- The link between individual and collective energy consumption. “If everyone turned their fridge down, it would make big difference.”

Actions that reduced electricity consumption

The displays motivated participants to act in a wide variety of ways to reduce the energy consumption of their lights and appliances. Their direct actions can be classified as follows:

- Turn it off
- Use it less
- Use it more carefully
- Improve its performance
- Replace it / use an alternative

Turn it off

“I used it to find out stuff at first – now I turn everything off and know it costs nothing at night and when I’m out”.

“I learnt how lazy I am with lights – I’m always leaving them on. I used to leave a light on at night, because I didn’t like the house to be in darkness, but now I turn them off as it’s just not necessary”.

Items that were turned off that would normally have been left on included:

- Lights
- Appliances on standby (TV; DVD player; Sky box; PC monitor, speakers, printer; PDA)
- Games consoles
- Disconnected chargers
- Water features in garden

Use it less

“I had the cooker and washing machine on at the same time – I was so shocked at the amount of kilowatts I was using! I am only going to wash when I have a full load”.

Strategies for reducing use of appliances included:

- Using the clothes airer or washing line instead of the tumble dryer
- Only running the washing machine on a full load
- Using the kettle when it has boiled instead of repeatedly reboiling
- Cooking all meals at the same time rather than separately
- Adjusting timers for lights and heating

Use it more carefully

“We used to charge things through the night – but realise this is unnecessary, as it only takes a couple of hours to charge, but the charger uses electricity even when it’s finished charging. So now I don’t leave it to charge overnight.”

Strategies for more careful use of appliances included:

- Not charging electrical gadgets overnight

- Boiling just enough water in the kettle
- Turning the fridge down (i.e. the temperature up)
- Using the washing machine on a shorter cycle and lower temperature
- Only turning on the specific lights that are needed for a task rather than everything available, e.g. under kitchen units.
- Avoiding opening and closing the fridge door all the time

Improve its performance

“When using my vacuum to clean my car it got very hot. It seemed to be using a lot of electricity. I cleaned out all the filters and the monitor went down.”

Strategies for improving the energy performance of existing appliances included:

- Replacing the faulty hinges on an oven door
- Installing a new element in an oven
- Cleaning the filters on a vacuum cleaner

Replace it / use an alternative

“I made a mental note to question all white goods on energy used in the future.”

Strategies for cutting consumption through switching to lower powered alternatives included:

- Replacing light bulbs
- Using the microwave rather than the main electric oven
- Looking for energy efficient ratings when buying new appliances

6. Social context: stories of change

The changes in energy-related behaviour reported by the participants were clearly a response to their enhanced understanding of household energy consumption, gained from using the real-time energy displays. However this central mechanism of change is triggered in a social context where many other forces, supportive and otherwise, come in to play. To fully understand the changes described above, we need to consider the wider stories of engagement with the displays. These include impacts on domestic life which are far removed from matters of energy consumption.

The following is a short typology of narratives drawn from participants’ diaries. They reveal a range of obstacles and opportunities to maximising the impact of the displays on energy-related behaviour.

Those who are already careful may have little scope for action

Emma finds it easy to set up the display and is immediately much more aware of how much electricity she is using. She is particularly shocked by how much her shower uses. But she is used to turning things off so her awareness does not translate into significant behaviour change. She has, however, started to put only enough water in the kettle for what she needs.

A domestic energy champion needs to tread carefully

David installs the display and quickly decides he is using too much electricity. He starts turning off appliances. However by day 4 his enthusiasm begins to have an effect on other family members who complain that he keeps telling them to turn things off. By day 7 he has achieved domestic equilibrium and feels that the others in the house have learnt and changed, despite their resistance.

Unreliable performance wrecks any opportunity for change

Amanda and her husband struggle to get the display to work. They succeed eventually but by day 5 they are convinced that the readings are wrong as they keep changing rapidly with nothing on in the house. By day 7 they have lost confidence in the validity of the readings and have given up using the display.

Poor information leads to poor conclusions

Alethea is keen to learn from her meter but is baffled by what it tells her. She puts everything on in the house to see what the effect is, but the meter swings from telling her it is costing her 20p per day to £1.87 per day. She eventually concludes that she does not use much electricity but this belies the fact that she has failed to understand the display.

Consumption may be lower than anticipated but the information remains powerful

Chloe likes the display and soon starts making changes – not boiling the kettle so often and turning off lights when they are not needed. By day 4 she is taking a closer interest in her daily spend and is surprised by how low this is. On day 5 she is amazed at how little she has used despite having people over in the evening. She does not, however, ‘relapse’ but is happy to continue turning more appliances off.

Information without motivation goes nowhere

Lesley finds the display interesting on day 1, exploring the relative costs of different lights and appliances, but she rapidly gets bored. She is happy with how much she is spending on her monthly direct debit so is not motivated to use the information from the display to change her behaviour.

The systematic enthusiast thinks of everything

Ron likes his display and starts acting on it immediately – changing the time on his security light, changing all his lights to low energy bulbs and trying to get the current cost down to zero at night. He puts in his correct tariff with the intention of checking his bill. By day 5 he is turning everything off except his radio because this uses almost nothing. He turns his fridge and freezer down and cuts back on his use of the dishwasher and tumble dryer.

Even an effective evangelist can tire of his own good news

James is slightly obsessed with his display and places it in a prominent position in his home. A stream of visitors is introduced to it and his enthusiasm evidently rubs off. Some visitors ask to borrow it when he has finished with it. Having learnt quite a lot, James begins to wonder if the display has any long term value or is really just a gimmick.

Those used to budgeting know exactly what to do

Anne makes meticulous notes from her display about how much she is spending per day. She narrows this down to the cost of running single appliances such as the tumble dryer, and resolves to use her clothes airer instead. She records her cumulative spend progressively through the week. Her final total on day 7 gives her a clear target for the next seven days.

Small interventions can have big effects

Louise likes her display and is proud to show it off to her family when they visit. She makes small changes to her own behaviour, such as only turning on exactly the lights she needs, but her son asks to borrow it for a week so that he can see how much it costs him every day to heat his pool.

The smallest device can become a domestic weapon

Charles takes charge of the display and his wife is soon giving him dirty looks when he tells her to change the programme on the washing machine. On day 3 he sets himself a target for the day but, four cycles of the washing machine later, his target is blown. He tells his family off, then is disappointed when his wife and daughter show no interest in the display.

A family gets addicted

Eve sets the display up with her family and they all try turning things on and off to see what difference they made. Visitors to the house are also interested and experiment with the appliances. On day 3 Eve starts

using the oven only once a day and the children start turning televisions off in their bedrooms. Eve is surprised by how much some appliances use (the toaster) and how little others use (the extractor). By day 7 everyone in the family is still fascinated and constantly checking the effects of different combinations of appliances. They are addicted.

These stories illustrate the many pathways to change within British households. However no-one will make much progress along a pathway to change if their basic navigation tools fail or are inadequate. All participants in this study succeeded in getting their displays working and made some effort to use them across the week. Nonetheless, impacts were inhibited if the display was unreliable, difficult to read, difficult to comprehend or did not provide appropriate information. These issues are likely to be far more important in an everyday context where individuals and households have no incentives to use their displays.

7. Designing the ideal real-time energy display

What people think they want and what they actually want are not always the same. This study offers valuable insight into this difference in its record of the changes that participants made to their designs for real-time energy displays following the eight days they spent using commercially-available displays at home. This experience helped to clarify for them what was genuinely informative and useful and what was superfluous.

Participants' views were inevitably influenced by the features and functionality of the displays they took home. As each participant had a different display, 'show and tell' feedback in the follow-up group gave all participants an opportunity to reflect on the pros and cons of a wide range of potential design features, some of which they had not always considered at their first meeting.

The first-round designs were also influenced by the initial discussion of energy use in the home. This discussion included the quiz about the different power ratings of household appliances, which prejudiced participants to thinking about energy in Watts, and the review of different methods of displaying real-time information, which at least made participants consider the value of communicating information using methods other than numbers.

The following accounts provide a summary description of the process of design, review and redesign in each of the five groups. The first round designs are diverse; the follow-up designs are remarkably similar.

Group 1: Prepayment meter users

Baseline questionnaire

There were seven members of Group 1, five women and two men. All used prepayment meters to pay for their electricity. All were tenants except for one owner-occupier.

All members of the group had at least a rough idea of how much money their household spent on electricity (the only group universally to say this) but only three had any idea of how much electricity their household used. They were all interested in their household's electricity consumption. None of the group felt confident that they could explain what either Watts or kilowatt-hours are.

All but one of the members of the group said they tried to save energy at home and wanted to keep their energy costs down. Five said they wanted to save energy but did not know how and six said they would like advice about how to make their home and lifestyle more energy efficient. Only one felt that there was nothing more she could do to save energy at home.

Focus group 1

Everyone was interested in how much they paid for their electricity and had a good idea of what they were spending on a weekly basis. They were all happy to be using prepayment methods. One participant, who had changed from direct debit to prepayment, felt that everyone should be on a prepayment meter as it made you more careful in your use of energy and stopped you getting into debt.

This familiarity with weekly payments did not translate into an awareness of what was actually costing them money in their homes. A few simple heuristics were mentioned – tumble dryers are costly; anything with an element is costly. One participant had tried to work out what her tumble dryer cost by looking at her key meter before and after she ran it – and concluded that it only cost her 10p (she reckoned her washing machine cost 50p). This was an isolated example, in this group, of someone trying to work out the facts of their energy use using poor information. The two male participants had noticed their meter wheels spinning faster when more appliances were on.

Nobody understood either Watts or kilowatt-hours. Everyone understood money. After an explanation from the facilitator, two participants said they understood kilowatt-hours for the first time but most remained baffled. Their knowledge of how much power familiar household appliances consumed was poor. For example, they guessed the power consumption of a kettle to be: 60W, 155W, 800W, 1kW (twice) and 60kW.

The group had mixed views about the methods illustrated for representing real-time information. They recognised the value of an analogue device, such as a speedometer, when you only had time to glance quickly at the display but felt that digital numeric displays were more accurate and so preferable in many cases. In general, they felt that their attitudes to the range of real-time displays in daily life simply reflected what they were used to.

Although members of the group grasped the idea of a rate of consumption, and put it at the centre of their design, they were more interested in how much any appliance actually costs to run. They did not like the idea of expressing current consumption as a rate of spend, recognising that this would change when something was turned on or off. They wanted to know their actual spend, in detail. Their design therefore includes an hour by hour account of money spent over the day, with a button to switch to previous days to enable comparisons. This was their way of coping with the fact that the display could not provide device specific information. Their design also includes the information that they currently get from their key meter: how much money they have left to spend before it needs topping up.

The group struggled with the tension between functionality and simplicity. Some participants suggested that people could write down their patterns of consumption; others felt that historical information ought to be retrievable from the display. The latter view won the day but temperature was excluded from the design in order to keep the display uncluttered.

Focus group 2

On their return, all group members reported that they had found the devices easy to install. Every participant reported learning from their displays and five said they had done something in response. However, the group generally felt that their scope for action was limited because they were already cost conscious and careful with their energy consumption.

The following are instructive points from the feedback on using the devices:

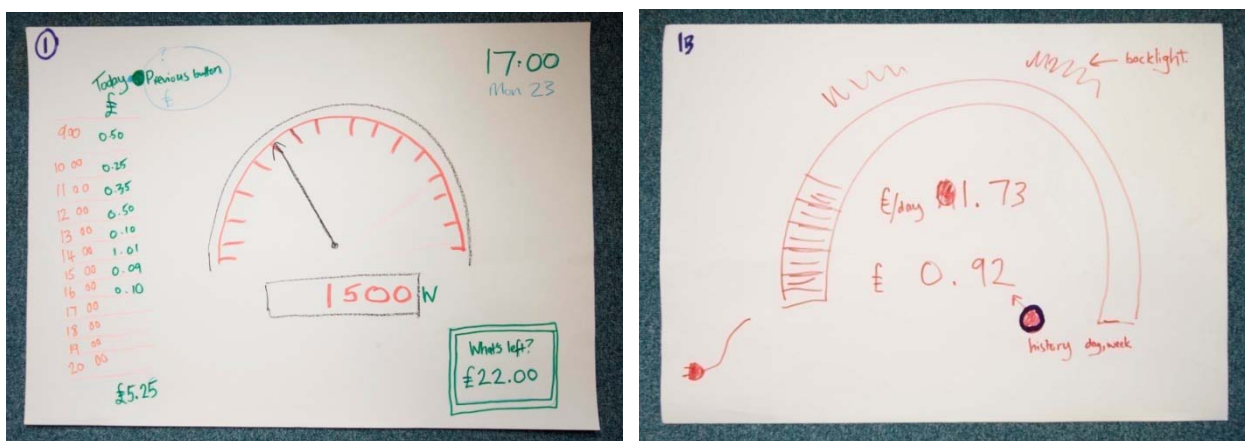
- **Current Cost.** User was aware of values fluctuating substantially when nothing was changing in the house, leading to worries about the accuracy and reliability of the display and her electricity connection.
- **Eco-eye.** User felt it was “fool-proof” and used the one button to switch between Watts, £/day and £/week. “Liked the simplicity of it – easy to use. If I were to have one on display, I would want it to look nicer.”
- **Efergy.** User failed to understand the display, especially when switching units. She was confused by the buttons and disliked the alarm, which she felt she had no control over. She wanted to know how much she was spending but could only get information in kW.
- **GEO.** User did not use historic information but liked the cumulative daily spend figure. She remembered the values of her consumption from day to day. The speedometer was good at catching her eye. “Nothing is there that shouldn’t be there and it showed everything I wanted to know.”
- **OWL.** User also remembered values from day to day rather than looking for historic information. Annoyed that he had to turn a light on to see the display at night.

- Micro Owl. User misunderstood the display but still found it useful to see the effects of turning on and off different appliances.
- Wattson. User hated it (“Bin it!”) because it offered too little information. The only financial information, the rate of spend as £/year, was unhelpful: “It tells you how many Watts and cost per year if you keep everything on but I wouldn’t have my washing machine on all the time!” She did not have access to a computer to download historical information.

When reconsidering their design, the group quickly dispensed with their hour by hour record of their spending. They now felt that a combination of current spend and cumulative daily spend was all they needed to make sense of the relative costs of their appliances. They gave up on Watts as the measure of rate of consumption in favour of £/hour. They included one button to enable the cumulative spend figure to move back through previous days and the previous week. They added another button for a backlight. They replaced their analogue pointer with the GEO’s speedometer bar, which they all liked. They decided they wanted a mains connection to avoid problems with batteries.

The final design is true to the group’s primary interest in cost and resolves their difficulties at the outset in using rates of consumption to work out the cost of using specific appliances. It also better serves their desire to ‘keep it simple’.

Figure 1. Home energy display designs of Group 1 (before and after home testing of current models)



Group 2: Under 30 years old

Baseline questionnaire

There were eight members of Group 2, four men and four women. Six members of the group were owner occupiers, two were tenants. All paid their electricity bills by direct debit except one who used a prepayment meter.

Three members of the group said they had no idea how much their household spent on electricity, all but one said they had no idea how much electricity their household used, and two said they had no interest in how much electricity they consumed (the only group where anyone said this).

Five members of the group said they never looked at their electricity meter; the three who did, did so less than once a month. Only one member of the group was confident that he could explain what Watts and kilowatt-hours are.

Six members of the group said they tried to save energy at home and seven wanted to keep their energy costs down. Six said they wanted to save energy but did not know how and seven said they would like advice about how to make their home and lifestyle more energy efficient. Only one felt that there was nothing more she could do to save energy at home.

Focus group 1

Attitudes to energy use in this group were quite diverse with some members already taking a keen interest (including a fireman who was motivated by fire safety to turn everything off) and others who had no

interest and were happy for their direct debits to take care of the issue. They recognised that they knew very little about the electricity they consumed at home but had mixed feelings about whether an in-home display would help or just cause arguments. Those who looked at their meters only ever did so when asked by their supplier to provide a reading. One member of the group remembered once having an old meter where you could tell how much you were using by the rate the disc spun round. Their knowledge of the power consumption of different household appliances was poor. Their estimates for the power rating of a kettle were 300W, 400W, 700W, 1kW (twice), 1.6kW, 2kW and 9kW.

The group recognised that familiarity conditioned their responses to everyday real-time displays. The speedometer in particular had “been around forever”. A particular strength of the speedometer identified by the group was that “you can see where you are coming from and where you are going to”, unlike a digital numeric display. However for a static reading, such as that provided by a set of scales, a digital numeric display was considered preferable because it is easy to read. The display on a petrol pump prompted a discussion of targets, which most felt would be useful as a cut for a petrol pump (and already exist as such in some filling stations). There were mixed feelings about targets for electricity consumption, some liking the challenge of keeping consumption low, others worrying about arguments and “sitting in the dark listening to the radio”.

The group put the rate of power consumption in real time as a dial at the heart of their design in order to see this going up and down easily. They then moved on to consider the various options for describing spend: rate of spend, today’s cumulative spend, historical spend and target spend. As this discussion progressed, and more options were considered, appeals for simplicity were made. Their resulting design dispenses with rate of spend, as this is similar to rate of power consumption and was felt to be misleading, and instead prioritises cumulative daily spend, with a comparison to yesterday’s spend (they considered, and rejected, a comparison to a generic average household spend). They gave themselves the option of cycling through previous days’ spend and switching the period of historic data from day to week or month. They also included a target-setting button and chose to make the background of the figure for cumulative daily spend change colour according to whether or not they were on target.

Focus group 2

On their return, six members of the group said they had found the device easy to install; two reported this being ‘neither easy nor difficult’. Everyone had learnt from the display and all but one had done something in response.

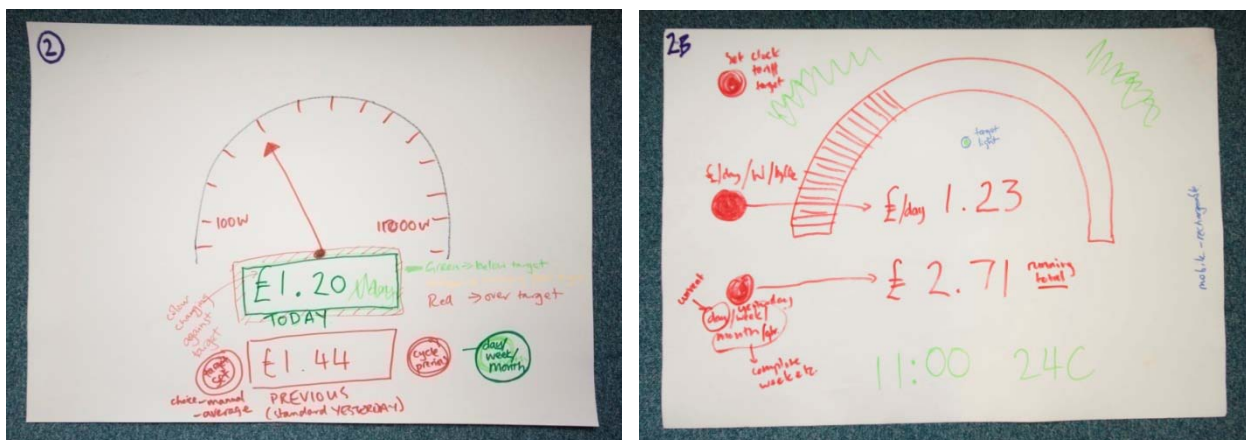
The following are instructive points from the feedback on using the devices:

- **Current Cost.** User liked having everything on one display because she was not confident of changing it. “All you need on one screen – didn’t fiddle with it because didn’t want to lose the display”.
- **Eco-eye.** User found switching through the many rate options easy but left it on £/day rather than kW. “It didn’t bother me when it went up when I had the kettle on cos I wouldn’t have the kettle on all day.”
- **Efergy.** User only explored consumption rates using kW setting but expects to use it in future for historical data on £ setting. Would have liked a night light.
- **GEO.** User appreciated the speedometer: “I liked the dial as I could see it go up and down. I don’t understand Watts so the visual was useful.” Quickly learnt the meaning of the rate of spend: “Flicked between £ and Watts – used £ more because I understand that. I understand that current consumption in £ is as things are at that point.”
- **Owl.** User liked having everything on one display including time, date and temperature.
- **Owl.** User did not understand full functionality of display but had little interest. “Played with it, but happy with how much paying on direct debit so not really bothered”. Nonetheless she learnt from it.
- **Owl.** User was not technically competent and had installation problems. “Once installed was frightened to press any buttons because it kept going to something I couldn’t understand!”

- Wattson. User liked the colours, and acted on them, but disliked the limited information. Wanted to see £/day but this was not an option. Also wanted a clock mode, given the aesthetic appeal of the device.

The group did not include a measure of current rate of spend on their original design but several members now felt that this was a useful option as it had made sense to them in their experience with their displays. However, not everyone agreed – one member felt that Watts made better sense than a fluctuating rate of spend. So they agreed to put the rate at the centre with a button to choose the units. They replaced their dial with the GEO speedometer bar, thereby separating the moving part of their dial, which they recognised was a good visual indicator, from the numbers, which were better described accurately in digital numeric form. They kept the cumulative daily spend and the button to enable cycling through yesterday/ previous 7 days/ month. They added time and temperature (after taking a vote on the issue) plus a nightlight. They wanted the device to have a rechargeable internal battery so that it could be mobile but not be dependent on batteries.

Figure 2. Home energy display designs of Group 2 (before and after home testing of current models)



Group 3: 60 – 69 years old

Baseline questionnaire

There were eight members of Group 3, five women and three men. They were all aged between 60 and 69 years old. Six members of the group were owner occupiers and one was a tenant (one did not report). Five paid their electricity bills by direct debit and three paid in cash or cheque when they received the bill.

Three members of the group said they had no idea how much their household spent on electricity, and six said they had no idea how much electricity their household used, but everyone had some interest in how much electricity their household consumed.

Three members of the group said they never looked at their electricity meter; of the five who did, one checked at least once a week, one at least once a month, and two less often. This group was the most confident that they could explain units of electricity: six said they could explain what Watts are and three said they could explain kilowatt-hours. In discussion, however, only two were clear about these units.

All of the members of the group said they tried to save energy at home and all but one wanted to keep their energy costs down. Six said they wanted to save energy but did not know how and six said they would like advice about how to make their home and lifestyle more energy efficient. Only one felt that there was nothing more she could do to save energy at home.

Focus group 1

The members of this group were all actively interested in their energy use, principally because they were concerned about the cost but also because they wanted to do the right thing for the environment. They tended to pay attention to their bills and three members had noticed improvements in the way information on their bills was presented. Two had watched their meter discs to try and get a sense of what used more

or less electricity in their homes. They knew about energy labels on appliances but wanted to know the actual cost of running the appliances and were wary of complicated information. Their knowledge of the power consumption of different household appliances was poor. Their estimates of the power rating of a kettle were: 10W, 50W, 60W, 80W, 100W, 500W, 1kW and 2kW.

When considering real-time displays in their daily lives, a majority of the group (5) said they preferred the old-style scales with a pointer to the digital scales. They liked the fact that you can see the pointer moving towards a specific weight and the inclusion of both units of weight on the same dial. They also felt that this device did not need to be accurate. Those who preferred the digital scales did so largely because it looked better – “modern looking” – and was more accurate. The car speedometer was appreciated because it communicated change and could be read at a glance, though this was thought to be largely due to familiarity. All but one liked analogue watches for the same reason.

The group wanted to keep their design simple and achieved this. They prioritised current rate of consumption but did not think this would make sense as a rate of spend so stuck to Watts. However, reflecting on the effectiveness of traffic lights, they introduced a light to the middle of the display which would change colour (green through amber to red) as current rate of consumption increased. Money made sense as an amount spent, so cumulative daily spend was placed at the top “because that’s where you look first”. The options for historic spend were discussed in some detail but the group recognised that some comparisons, such as summer vs. winter, would be interesting but unnecessary because they already knew this was different. They introduced one button to switch cumulative daily spend to cumulative weekly, monthly and annual spend but were happy that if you didn’t want to press any buttons, the display would still provide you with the core information you needed. It was also important to them that it looked good.

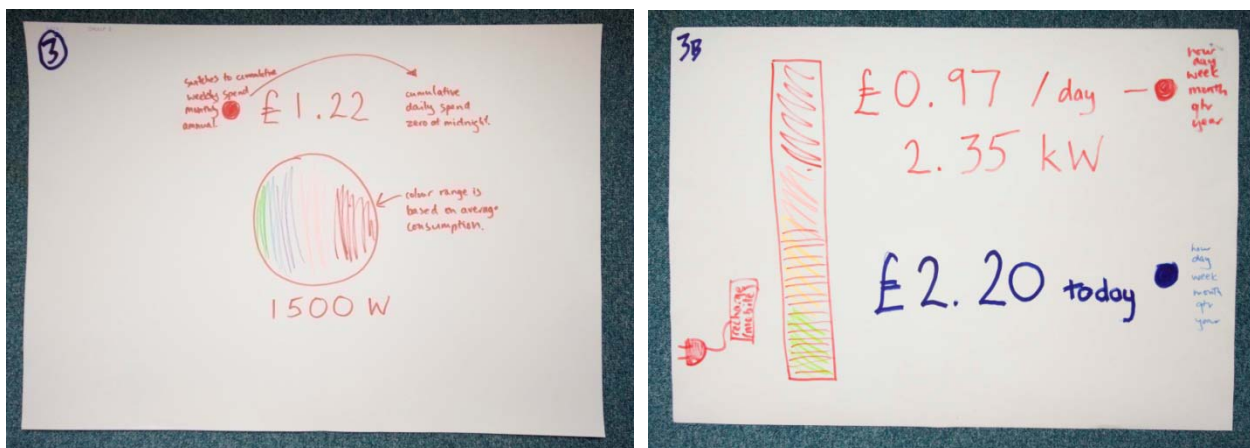
Focus group 2

On their return, four members of the group said they had found the device easy to install; the other four all found it difficult to install. Everyone had learnt from the display and all but one had done something in response.

The following are instructive points from the feedback on using the devices:

- Current Cost. User liked everything on one screen and soon got used to the automatic switching of the spend rates. “Cost per day was adequate – I didn’t want to get too deeply in to cost per hour because it varies so much.”
- Eco-eye. User liked the single button to switch display options. “I used every mode on it, looked at all of it. Though CO₂ not so much because I’m not that up-to-date on CO₂ – it’s not something you can see, it’s not tangible. I can’t quite get my head around it. I preferred kW. My wife preferred £ though – she was happy with this.”
- Efergy. User misunderstood the display – she thought the ‘daily average’ was the spend so far that day. Moved it around but only to get a decent light to read the display.
- GEO. User liked the speedometer more than the group’s own idea of a colour changing light. “It draws attention, you can see it easily from across the room.” Found target useful in thinking about daily use.
- Owl. User found it very complicated. “I found it so complicated, even the instructions were complicated, so I just left it as it was.” However, she still learnt from the default setting (rate).
- Owl. User struggled to get it to work – it kept reading zero Watts: “Thought my house was dodgily wired! Eventually it kicked in”.
- Owl Micro. User couldn’t read the units but still learnt from watching the numbers change.
- Wattson. User (and family) enjoyed watching it and realised the household used a lot of electricity. But only twigged why it might be red most of the time in the group discussion: “We leave the immersion heater on all the time – had forgotten about it – maybe that’s why we use so much! Will tell my husband to do something about it.” Husband wanted retrospective information.

Figure 3. Home energy display designs of Group 3 (before and after home testing of current models)



After experience of using the displays, the group was converted to the idea of communicating rate of consumption as a rate of spend, with the period changeable via a button, but they wanted to keep Watts as well. They were also much less interested in historical information – “You can’t do anything about last week”. Nonetheless, they retained this as an option accessed through a button, as before. They were keen for everything critical to be on one screen so that no buttons needed to be pressed. No button was needed to change units as both spend per day and kilowatts were displayed and no-one was interested in kilowatt-hours or carbon. The colour changing light was converted to a rising bar (red at the top), largely thanks to the impression that the GEO had made. They wanted an internal rechargeable battery so that it could be both plugged into the mains and mobile.

Group 4: 30–60 years old, Socio-economic group ABC

Baseline questionnaire

There were seven members of group 4, four women and three men. They were all aged between 30 and 60 years old and were in socio-economic group A, B or C. Six members of the group were owner occupiers and one was a tenant. Five paid their electricity bills by direct debit, one paid by prepayment meter and one paid in cash when he received the bill.

One group member said he did not know how much his household spent on electricity, and four said they had no idea how much electricity their household used, but everyone had some interest in how much electricity their household consumed.

Three members of the group said they never looked at their electricity meter; the four who did, did so less than once a month. Only one member of the group was confident that he could explain what Watts and kilowatt-hours are.

All of the members of the group said they tried to save energy at home and wanted to keep their energy costs down. Four said they wanted to save energy but did not know how and all seven said they would like advice about how to make their home and lifestyle more energy efficient. Only one felt that there was nothing more she could do to save energy at home.

Focus group 1

The majority of the members of this group had little understanding of their electricity consumption and paid little attention to either their bills or their meters: “the bill is very complicated with the reading in Watts...as long as it doesn’t look ridiculously different from others then I don’t query it.” However the one member of the group who had a prepayment meter was very aware of how much she used and the patterns in her consumption. She had switched to this method relatively recently, when she moved house, but felt it was a much better way for her to watch her spending and avoid getting into debt. However her knowledge of rates of consumption of household appliances was as poor as the others’. The group’s estimates of the power rating of a kettle were: 25W, 120W, 800W (thrice) and 1kW.

The group did not have strong opinions about the pros and cons of everyday real-time displays, feeling that the effectiveness of the displays was largely a matter of familiarity. They preferred digital numeric readings for accuracy but realised this was not always needed. They recognised the value of dials such as speedometers in communicating both changing values and the direction of change. They liked a computer download bar, because it provided a clear visual indication of the wait time, but also wanted the percentage figure next to it.

The group prioritised current rate of consumption on their initial design, but they were worried that Watts would be confusing. They recognised that £ would 'ring more bells', so complemented the current rate of consumption in Watts with the cumulative daily spend. They wanted to see consumption by appliance or by room but recognised that this information could be achieved with a single whole house reading by systematically turning lights and appliances on and off. They were unsure of the value of historic information but chose to include a button that would cycle through the last seven days in place of current cumulative consumption. They wanted to include kilowatt-hours as an alternative display option, even though they did not understand the unit very well, and also included kgCO₂, which they understood even less. In both cases they thought that these units would become more meaningful through regular use and they saw some value in this learning process. A colour-changing band above the main power display figure was included to provide a visual indicator and warning of high consumption. They wanted the power reading to glow in the dark.

Focus group 2

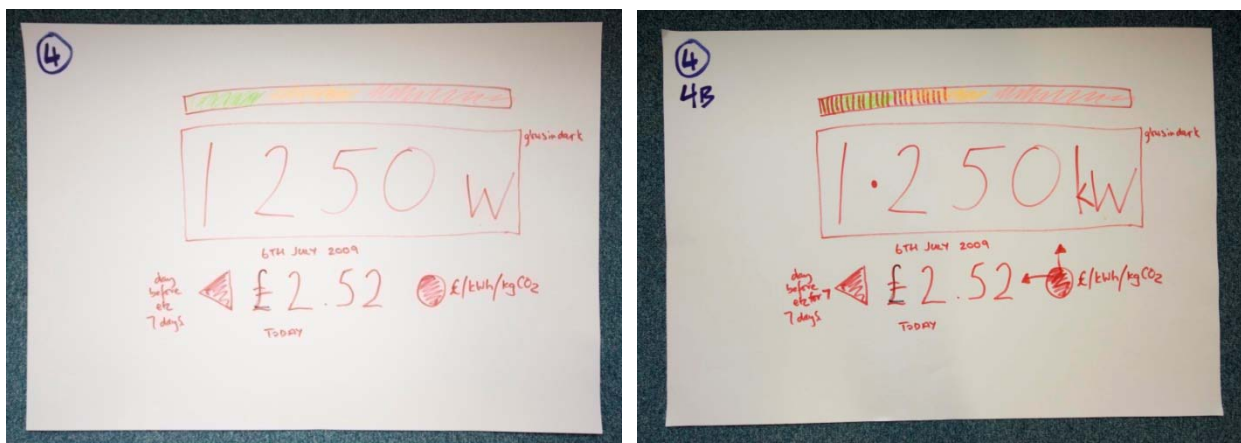
On their return, all members of the group said they had found their devices very easy to install. Everyone had learnt from the display and all but one had done something in response.

The following are instructive points from the feedback on using the devices:

- Current Cost. User liked the graphic representation of the previous day, evening and night consumption but did not like the automatic switching of spend rates.
- Eco-eye. User liked kW as he felt it better expressed energy consumption than a rate of spend: "When switching stuff on and off it's better in kW". Found it easy to use but felt the display was too big to be on regular display in the home.
- Efergy. User left the display on £/hour because he felt this is what his family would understand (as an electrician, he preferred Watts). He found the daily average confusing and the display hard to read.
- GEO. User liked the design: "Small, clear, no flashing lights but that's fine. Dial was good – children liked that too, could watch it whizz up"
- Owl. User found it fascinating but struggled to get it to work. "Reset it and lost signal – had to start again. Did have problems with re-establishing signal – it was a bit traumatic!" It was several days before she worked out how to see historical data.
- Owl micro. User found the small display hard to read. Only used it to check power rates of appliances.
- Wattson. The only Wattson user to download software and connect to computer, which she found slightly labour-intensive but on the whole gratifying to have that level of information and would do so again. "Was bit of a pain and took a while".

This was the only group to conclude that they had done a good design job the first time round. However they made some small tweaks to their design. They wanted to be able to see the rate as £/day as well as Watts (which they changed to kilowatts), so changed their units button to control both the rate and the cumulative consumption figure. They liked the GEO, so turned their glowing colour bar into a progressing bar, in the manner of the GEO speedometer. They considered having a target option but decided that this would have limited value as you would soon get to know where you should be, in terms of cumulative consumption, at different times of the day. They added a night light and wanted a rechargeable internal battery.

Figure 4. Home energy display designs of Group 4 (before and after home testing of current models)



Group 5: 30– 60 years old, Socio-economic group D

Baseline questionnaire

There were eight members of Group 5, four women and four men. They were aged between 30 and 60 years old and were in socio-economic group D. Seven members of the group were owner occupiers and one was a tenant. They all paid their electricity bills by direct debit except one who paid in cash when he received the bill.

One group member said he did not know how much his household spent on electricity, and all but one said they had no idea how much electricity their household used, but everyone had some interest in how much electricity their household consumed.

Four members of the group said they never looked at their electricity meter; of the four who did, one checked at least once a month, the other three less often. Two members of the group were confident that they could explain what Watts are and two said they could explain what kilowatt-hours are (only one person was confident about both units).

All of the members of the group said they tried to save energy at home and wanted to keep their energy costs down. Four said they wanted to save energy but did not know how and all eight said they would like advice about how to make their home and lifestyle more energy efficient. All members felt there were still things they could do to save energy at home.

Focus group 1

Everyone in the group showed interest in their energy consumption with both cost and environmental concern cited as motivation. They were aware that they knew next to nothing about the electricity demand of the various appliances in their homes. Energy labels on appliances were perceived to be useful but did not provide detail about actual consumption (one member of the group pointed out that they do but you have to look hard to find out). Bills were not considered to be informative, beyond the basic spend, and meters were typically used only to check bills, if at all, though one member of the group said her husband had shown her the disc spinning when the tumble dryer was on. They had some idea that heaters and dryers used more than other appliances but, when tested, only one member had a consistently good grasp of the rates of consumption of household appliances. The group's estimates of the power rating of a kettle were: 50W (twice), 100W, 350W, 400W, 1kW (twice) and 2kW.

In their review of everyday real-time displays, the group came out strongly in favour of digital numeric displays, even for the car speedometer which all other groups were happy to leave as a dial. Digital numeric was perceived to be more accurate, easier to see and 'more in your face'. However they did not object to the traditional speedometer, acknowledging that this was what they were used to. Similarly, for both computer download bars and petrol pumps, they appreciated the visual indication of change but wanted the numbers too.

The group followed through by designing a display with numbers rather than graphics prominent. In considering their priorities, the group agreed that the most important things were current consumption and current spend. However they struggled with the problems of showing current spend and eventually chose not to display it. They recognised there might be scope for an indicator of environmental impact but realised that this would be proportionate to their power consumption anyway (unless, as one member pointed out, you factored in different power sources such as coal and nuclear). Nonetheless they agreed to include carbon, though only half the group wanted this, as an option for retrospective information along with money and kilowatt-hours. They were interested in appliance-specific information but felt that this might be too complex. Alarms were thought to be too irritating but they included a light bar which would change colour and glow red when consumption was high. This would be calibrated against the household average. They wanted to have the option of a mobile or fixed display.

Focus group 2

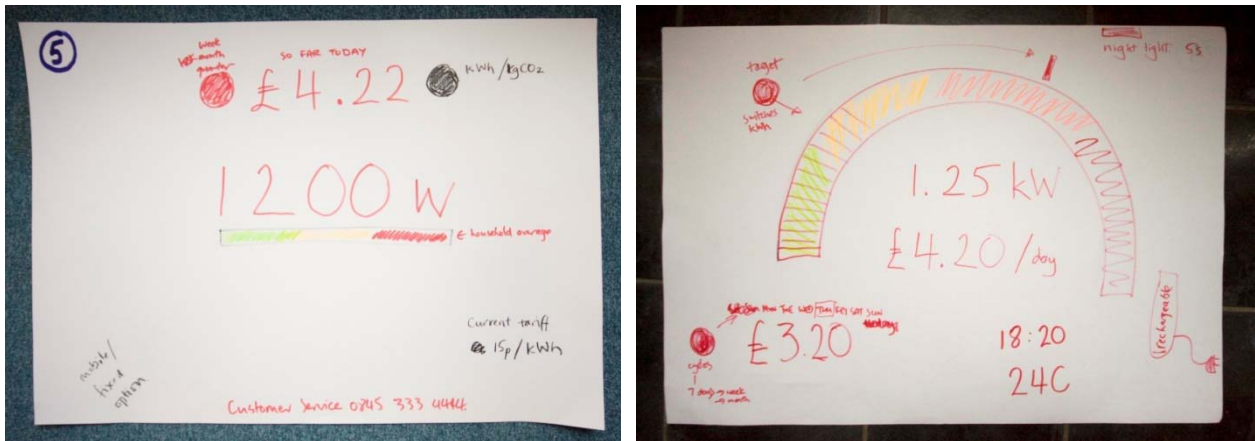
On their return, seven members of the group said they had found their devices very easy to install; one had found it difficult to install. Everyone had learnt from the display and everyone had done something in response.

The following are instructive points from the feedback on using the devices:

- Current Cost. User found the automatic switching of the rate of spend between different periods confusing but liked the fact that you didn't have to press any buttons – everything you needed was on the one screen. Did not think the chart of the previous day's consumption was very interesting.
- Eco-eye. User found switching between rate display options straightforward but chose to leave it on kW because he didn't want to see how much he was spending. Found the display too big: "It's in your face the whole time!"
- Efergy. User set current rate at £ per hour but flicked to the Watts as well. Looked through historic data (last seven days) in £. Did not find the daily average helpful.
- GEO. User focussed on the bar describing cumulative daily consumption and set targets for himself, using previous daily consumption figures as a guide. Liked both of the graphic indicators, though his children tried to get the speedometer to go as high as possible.
- Owl. User liked it but didn't use buttons much. Preferred the Current Cost (which she'd seen in a friend's home, provided by a utility) because it had everything on one screen. "I was a bit worried about pressing buttons."
- Owl. User kept it on the money mode because this was "more dramatic" and Watts meant nothing to his wife. Wasn't keen on having to press buttons for some of the information.
- Owl Micro. User found it handy to carry around but nonetheless wanted something bigger.
- Wattson. User loved it, especially the changing light. But would have liked to know about spend per day. Spend per year was not helpful. Wanted to be able to get more information from the device itself, rather than having to plug it in to a PC.

With no strong advocate for keeping things simple in the group, they expanded on their original design, adding rate of spend in £ per day alongside rate of consumption (now in kilowatts rather than Watts) and turning their colour-changing bar into a colour version of the GEO speedometer. After some debate, they decided to add a target for daily cumulative consumption but instead of having a second graphic indicator, as on the GEO, they added a button to switch the speedometer to a 'milometer' with a target. They resolved the issue of historic data by having all seven days as scrolling options on the cumulative consumption indicator, such that today's cumulative consumption was indicated by the day (Monday through to Sunday) with other periods (week and month) following the seven day cycle on this same button. They added date and temperature, a night light and an internal rechargeable battery so that the display could be plugged in to the mains but still mobile (as per their original design).

Figure 5. Home energy display designs of Group 5 (before and after home testing of current models)



8. Key design issues

Changing values are poorly served by numeric displays

Every one of the final designs included a graphic indicator of the current rate of electricity consumption. These designs were all influenced by the speedometer on the GEO which was universally liked. Groups 1 and 2 both included a dial on their first design, simplified on their final designs to the GEO's form. Groups 3, 4 and 5 had changing colours in their initial designs, all of which were converted to rising and falling indicators, though retaining their colours as well. Even the group that, in the first discussion, was most dedicated to the digital numeric display, (Group 5), gave way to the intuitive power of the GEO speedometer in their final design.

The speedometer worked for participants for all the reasons they identified when reviewing familiar real-time displays in the initial focus groups: it catches your eye when it moves, it shows the relative scale of the change (without the need for mental arithmetic), it shows the direction of change, and it offers an immediate impression of where, in the range of values, you currently are. Changing numbers can be used to achieve these functions – for example, the Wattson deliberately flickers through numbers when changing in order to attract attention – but they are rarely as effective.

All the final designs separated digital numeric information from their graphic indicator of rate. The graphic was understood to provide an impression rather than an accurate reading, for which a number was needed. Group 2 included a dial in their initial design with numbers on the dial. In their revised design, the numbers were removed from the dial and presented as a single digital numeric reading.

Keep it simple

The single most common recommendation made by participants in both rounds of the design exercise was to 'keep it simple'. This principle relates to a variety of issues: mechanisms of interactivity, the units used, the number of items on the display, and the extent of the information offered overall. A display can fail for a user in any or all of these areas. Yet all the final designs included buttons, they all had more than one digital numeric figure on display at once, they all combined numbers with graphics and all but one offered a range of units. There is an evident tension between keeping it simple and satisfying multiple needs. Each design is a compromise between these demands, though it is notable that the most complicated final display (Group 5) was produced by the group which had the weakest internal advocacy for keeping it simple. As a result, features were added without anyone asking about the potential costs for overall design efficacy.

A rate explained is complex; a rate experienced is intuitive

In discussion, every group struggled with the concept of a rate of consumption and especially a rate of spend. Their understanding was influenced by the group discussion of energy units and in particular by the power rating quiz: having grasped that Watts expressed what was going on right now, per second, all the groups opted for this as their means of expressing current consumption. None chose a rate of spend because this had to be expressed in terms of a period of time that was not 'right now', such as an hour or day, and this did not fit with a pattern of electricity consumption which varied within these periods. This was despite the fact that most participants felt that money was the clearest way of expressing energy consumption.

Without exception, and with negligible internal dissent, every group changed their collective view after their week away with the displays. They all put a rate of spend at the centre of their revised displays. Group 1 dispensed with Watts altogether, groups 2 and 4 introduced a button to switch units from Watts to £ per day, and groups 3 and 5 put both Watts and £ per day on the same display. The participants had rapidly learnt what a rate of spend meant through using their displays. They saw the rate of spend changing as the power load changed and understood that this was a real-time rather than historic indicator. Their experience with their displays had dispelled confusion over the difference between this rate of spend, which went up and down, and cumulative spend, which just went up. They recognised that rate of spend was transient and not an accurate prediction of what you would spend that hour or day but nonetheless liked it because it provided more meaningful information than the power figure in Watts (though some still preferred this). The only exception was the Wattson's use of £ per year as the rate of spend which no-one liked; they had grasped that a rate of spend is not a realistic approximation of what you will actually spend but still wanted the period to be meaningful – and a year was not.

A rate is understood in practice when it changes: when the numbers change, or the dial goes up (on the GEO), or the colours change (on the Wattson). Participants grasped the nature of the rate of power consumption, or rate of spend, as they saw changes in their display match changes in what was on or off in their homes, just as changes in a speedometer match changes in the experience of travel in a car. Although speed is expressed in miles per hour, drivers do not expect to travel the given number of miles in their next hour of driving; this is simply not how speed is understood. Similarly, a rate of spend per hour is quickly understood on its own terms, not as a measure of actual spend over the given period.

Everyone understands money

It is fortunate that a rate of spend is so quickly grasped in practice because it is unlikely that Watts will ever be universally understood. The discussions of the units of power in the focus groups revealed just how baffling they are to people. Even those who stated in the questionnaire that they could explain what Watts and kilowatt-hours meant demonstrated little, if any understanding in the group discussions. It is particularly unfortunate that the unit that expresses a rate, the Watt, sounds like a unit of quantity while the unit of quantity, the kilowatt-hour, sounds like a rate. In the discussion of the power ratings of different appliances several participants asked if we were talking about 'Watts per second' and the kilowatt-hour was as often referred to as 'kilowatts per hour' as it was correctly described.

In practice, participants grasped that Watts and kilowatts expressed a rate of consumption because they saw them going up and down in real-time on their energy displays. However no-one warmed to the kilowatt-hour, not least because money is such a straightforward way of describing an amount of energy consumed and expenditure remained an overriding concern. Hence the final designs all focused on £ as the unit of cumulative consumption and usually included both Watts and £ per hour as the rate, though the members of Group 1, who had the most acute focus on money, removed Watts from their design altogether.

Although kilograms of carbon dioxide and its equivalent rate were optional views on the majority of the displays used by the participants, they were ignored by almost everyone. A few participants acknowledged that some measure of environmental impact or carbon footprint might be valuable on the display but this

unit was considered to be either incomprehensible or meaningless: “To be honest the carbon footprint thing goes over my head. I know I should be interested, but it is the power use and the money it saves me that interests me. If we help to save the planet at the same time, then it is a bonus”. There was a suggestion, albeit by only two participants, that measures such as kWh and kgCO₂ had an educational value and a lack of understanding of these units at present should not be a reason for excluding them from the display; indeed they felt they ought to be educated about what these measures mean. This view was not, however, supported by the majority of participants.

There was no evidence that using money to express a rate of power consumption leads to significant perverse outcomes. Nobody was unconcerned about a relatively high rate of spend and so chose to carry on regardless. However participants did learn that some appliances have very low costs or power consumption. One participant reported that she chose to leave her radio on for this reason.

Interactivity is lost on those who are scared of losing what they have gained

All of the final display designs included buttons for changing the display, usually for cycling through different periods of historic consumption or for changing units. However, none of these buttons were felt to be critical to the communication of the core information offered by the display. Several participants recounted their nervousness about changing the displays they took home in case they entered a mode they could not get back from and so lost the information on the default display. In some cases, this followed a difficult experience installing and setting up the display. Most of the participants did interact with their displays, with mixed results.

Although a well-designed display ought to offer interested users clear and intuitive options for interactivity, there will always be users who do not want to interact. For the sake of these users, it is critical that the default mode for any display provides the core information needed to understand energy use in the home.

Mobility is valued, but for a limited period

The majority of participants placed their home energy display in the kitchen (42%) or the lounge (47%) for most of the week. Two had it in their bedroom, one in the hallway and one in the study. Location was important in helping the user to get the most out of their display and in encouraging other household members to look at it:

“I kept it in the kitchen because everyone is in and out of there all the time”

“I kept it in the living room where we could all watch it, next to the TV!”

Three of the displays, the Current Cost, Wattson and GEO, were mains powered, though the Wattson had an internal battery and could be unplugged and moved around. All the other displays were battery powered and mobile. Lack of portability was a problem for some as it meant they could not see the immediate impact of turning something on and off anywhere in their home. Those who did have a portable display found this useful at the beginning of the week, when testing how much different appliances used, but by the end of week they usually preferred to keep the display in one place.

The means of powering the device – battery versus mains – was a more prominent topic of discussion than mobility. Although batteries offered mobility, participants recognised the long-term problems of any device which needed regular battery replacement. Consequently three of the final designs are mains powered but have internal rechargeable batteries, in the manner of the Wattson. This eliminates the need to replace batteries but offers the option of mobility if desired. It also addresses concerns over information being lost from the device in the event of a power cut. One individual suggested a solar powered device would be most desirable.

Different users have similar needs

The designs of all five focus groups show remarkable convergence. Although there were differences between and within the groups, these differences did not lead to fundamentally different solutions. The members of the prepayment group (Group 1) showed the greatest interest in the costs of their electricity use, to the extent that their final design only presents information in £, but the other four groups also ensured that rate of spend and cumulative daily spend were prominent on their final designs. The members of the older group (Group 3) were the strongest advocates of the principle of ‘keeping it simple’ but this principle was expressed in all groups and in all designs. In general, men showed more interest than women in power consumption expressed in Watts but not exclusively so. All but one of the final designs included both power and rate of spend on the same display, either concurrently or with a button to switch between the two. The groups included people who were technically competent and complete ‘technophobes’; the final designs satisfied the needs of both by combining a default display offering core information with interactive options for deeper investigation, for those who are happy to press buttons.

The study was not designed to explore differences in need beyond the basic criteria that differentiated the focus groups. In particular, there was no scope to explore the needs and interests of individuals whose first language is not English. However the experience of one participant of South Asian ethnicity is telling: he reported that he had used the display effectively to educate his mother, who spoke no English, about the costs of the various appliances in their home. All he had to do was set the display to a universally understood language – money – and his mother immediately grasped what it was communicating.

None of the participants were visually impaired but the issue of ensuring that visually impaired people would benefit from the displays was raised in the groups. There was a tension between making the display big enough to be easily seen (both for the visually impaired, and for the able sighted from a distance) and the risk of putting people off with something that was too big and ugly for their homes. Participants also suggested that sound could be used creatively to communicate crucial information.

9. The core specification

The following is a recommendation for a core specification for real-time energy displays based on the outputs of the focus groups. This specification assumes integration with a smart meter such that tariffs, time and other settings will be automatically updated by the utility through the smart meter.

This is a minimum specification. It describes features that ought to be common to all smart-meter displays but does not constrain display design to these features only. Consumers will learn from their displays and some will demand more features as a result. However, given the importance of the principle of simplicity, extra features and interactivity should always be added with great care. The clarity and simplicity of the default display should, above all, be maintained.

Interactive display

1. The default display should include

- A clear analogue indicator of current rate of consumption
- Current rate of consumption as a rate of spend in £ per day (numeric)
- Cumulative daily spend in £ (numeric)

2. The display should offer the following options through interaction (by pressing a single button):

- Spend in last seven days, day by day
- Spend in last complete week
- Spend in last complete month
- Spend in last complete quarter

The historic periods should match the utility's billing periods in order that the display is consistent with household bills.

3. The display should offer the option (by pressing a single button) of switching units from money to power, i.e. from £ per day and £ to kilowatts and kilowatt-hours.

4. The display should be mains-powered but have an internal battery to enable mobility in the home.

Three of the groups included a target-setting option in their final display. This should be considered as part of the core specification but more evidence is needed of the value of such an option over a longer period of use. It is not clear whether this extra functionality warrants the cost of increased complexity. Simplicity and clarity in design should always be prioritised.

Non-interactive display

If interaction with the display is not possible, the following should be the default content of the display:

- A clear analogue indicator of current rate of consumption
- Current rate of consumption as a rate of spend in £ per day (numeric)
- Current rate of consumption in kilowatts (numeric)
- Cumulative daily spend in £ (numeric)

Other considerations beyond the scope of the study

The groups were not asked to consider the implications of variable tariffs but the emphasis on cost implies that, under a variable tariff regime, the value of the current tariff ought to be included on the default display in order that users can make fully informed judgements about their current rate of spend.

Although the study focused on electricity use, the same design principles apply to gas. Following the argument for simplicity, if a display is to show both fuels, exactly the same means should be used for gas as for electricity. These options could either be presented side by side or be toggled with a dedicated button.

Extending the specification to cover gas also strengthens the case for including an option to view carbon dioxide emissions on the display, despite the lack of support for this within this study. Consumers who are interested in the environmental impact of their energy use will only gain meaningful information about the relative impacts of their electricity and gas use if this is expressed in carbon.

The needs of households that generate their own power will also have to be addressed in the specification of the home display. Again, this was not addressed in this study. Further research is needed to identify the best way of presenting the more complex information needed by these users including rates of electricity generation, consumption and export.

10. Conclusion

This rapid study offers substantial evidence to inform the development of a core specification for real-time home energy displays. It also strengthens the case for setting such a specification within the smart meter roll out. Despite a relatively well developed display industry in the UK, the majority of the home energy displays currently on the market do not have the functionality that consumers identify, in practice, as being critical to display design. Hence 'the market' cannot be relied on to deliver an outcome that is optimal for consumers.

The study also provides invaluable insight into how householders interact with, and respond to, home energy displays. The evidence presented is qualitative, promoting a deeper understanding of the role and functionality of home energy displays, rather than making any claims for their impacts. Nonetheless, the range of impacts described by the (incentivised) participants is striking.

The focus of the study was the functionality of home energy displays. However the evidence from the focus groups points to a more fundamental issue which underpins the rationale for promoting these displays, namely that British householders know next to nothing about their energy consumption. Although many people have a grasp of how much money they spend on electricity, especially prepayment meter users, this knowledge does not translate into an understanding of the relative costs and consumption of individual lights and appliances. Many people work with basic heuristics about daily energy use but struggle to obtain meaningful information from the limited resources available to them. Utility bills and meters offer little insight beyond the bottom line.

The convergence of the designs of the five focus groups, following participants' experience of using real-time energy displays at home, is encouraging. For all the differences between and within the groups, a clear consensus emerged about what a real-time home energy display should deliver. The core specification described above is drawn directly and without compromise from all five final designs. It is notable that, of all the existing home energy displays used in the study, the display that was most popular and most closely matches the core specification – the GEO – is the only display to our knowledge to have been designed following substantive market research.

The core specification defined by this study is consistent with other evidence, including the literature on the effectiveness of home energy displays and the wider literature on human interactions with real-time displays of all kinds. The former literature stresses the importance of making something that is invisible to the user both visible and intelligible, complementing what the user knows about their home, routines and practices. The participants in this study made abundantly clear how this should be achieved: focus on money, on the cost of energy use, and not on power. The wider psychological literature points to the importance of achieving a balance in display design between quantitative (numeric) information and qualitative (analogue) information and also between simplicity and extended functionality. In every focus group in this study, these issues were recognised and addressed, resulting in final specification that makes clear the importance of analogue communication alongside digital numbers, and that includes a clear and sufficient default setting alongside options for further interrogation through interaction.

The roll-out of smart meters offers an excellent opportunity to improve the limited energy information available to domestic energy consumers in Britain. In order to maximise the value and impact of this information, technical implementation should be complemented by an appropriate package of household and community support. Participants in this study learnt from their displays but they also learnt from each other and from their common experience of using the displays. The national roll-out is an opportunity to enable such conversations.

This study provides a strong foundation for the specification of real-time home energy displays. Future research should build on this foundation by investigating the multiple effects of real-time home energy displays within households over a longer period and the value of combining energy displays with other domestic control systems. The design specification developed in this study should also be more rigorously tested, especially with individuals, such as visually-impaired people, for whom visual displays may be difficult to use. More work is also needed to identify meaningful ways of communicating environmental impacts.

Appendix 1. Functionality of energy displays used in study

- ✓ Feature always present
- ✓* Feature present as one of several display options
- X Feature not present

Model	Current/ historic modes	Current rate				Cumulative and past periods					Other	Notes
		Power	Cost	Carbon	Graphic/ analogue	Energy	Cost	Carbon	Graphic/ analogue	different periods		
Current Cost CC128 ENVI	both present at once	✓ W	✓ £ per day + change in current cost (when power level changes)	X	X	✓ kWh	X	X	bars: yester- day night/ day/ eve	cumulative day/ 7 days/ 30 days: changes every ten seconds or toggle with button no past periods	time, temperature	
Eco-eye Elite	toggle with button	✓* kW	✓* £ per hour/ day/ week/ month/ year	✓* kgCO ₂ per month	X	✓* kWh	✓* £	✓* kgCO ₂	X	cumulative hour/ day/ week/ month/ year: scroll with button press again for past periods		
Efergy lite 1.0	toggle with button	✓* kW	✓* £ per hour	X	X	✓* kWh	✓* £	✓* kgCO ₂	small bars: yester- day and today (kWh)	cumulative day/ week/ month: scroll with button or scroll through past periods with button	daily average (in £ or kWh) – effectively a target to compare cumulative daily spend time, date	option to set dual tariff

Model	Current/ historic modes	Current rate				Cumulative and past periods					Other	Notes
		Power	Cost	Carbon	Graphic/ analogue	Energy	Cost	Carbon	Graphic/ analogue	different periods		
GEO minim	both present at once	✓* kW	✓* £ per hour	✓* kg CO ₂ per hour	'speedo- meter': crescent -shaped moving bar	✓* kWh	✓* £	✓* kgCO ₂	horizon- tal bar with target; cross/ tick depend- ing on relation to target	today/ yesterday/ last 7 complete days/ last 30 complete days: scroll with button		target based on daily average or set by user
OWL	both present at once	✓* kW	✓* £/pence per hour	✓* kg CO ₂ per hour	X	✓* kWh	✓* £	✓* £ tonnes CO ₂	X	cumulative day/ week/ month/ quarter/ year: scroll with button past periods on same scroll	date, temperature	option to set multiple tariffs
OWL Micro	both present at once	✓* kW	✓* £/pence per hour	X	X	✓* kWh	✓* £/pence	X	X	cumulative since last reset		
Wattson	toggle by tilting unit	✓* W	✓* £ per year	X	baselight changes colour	X	X	X	X	X	has numbers only, lights only and numbers & lights modes: toggle with button	historic data can be uploaded to PC and viewed using proprietary software

Appendix 2. Summary of participant responses to displays after one week of use

Model	Pros	Cons	Average score out of ten (range)
Current Cost	<ul style="list-style-type: none"> • Had all information required • All information on one screen – don't have to press buttons • Looks nice • Time and temperature shown 	<ul style="list-style-type: none"> • Display (figures) not easy to read for some • Quite complex display – lots of information • No backlight 	8.6 (7 - 10)
Eco-Eye	<ul style="list-style-type: none"> • Simple and easy to use • Very clear display • One button to scroll through display • Had all information required 	<ul style="list-style-type: none"> • Doesn't look very nice • Too big 	8.0 (7 - 9)
Efery	<ul style="list-style-type: none"> • Appropriate size • Had all information required • Backlight 	<ul style="list-style-type: none"> • Alarm annoying • 'Daily average' confusing 	7.6 (7 - 8)
GEO minim	<ul style="list-style-type: none"> • Speedometer provides clear visual and draws attention • Had all information required • Target bar a useful 'quick glance' visual • Easy to use 	<ul style="list-style-type: none"> • No backlight 	9.4 (8 - 10)
Owl	<ul style="list-style-type: none"> • Had all information required • Time, date and temperature on same display 	<ul style="list-style-type: none"> • No backlight • Overly complex display • Too many decimals • Complicated instructions • Problems with installation – 'pairing' the device and transmitter 	7.8 (5 - 10)
Owl Micro	<ul style="list-style-type: none"> • Easy to carry around • Easy to use 	<ul style="list-style-type: none"> • Too small - Units too small to read • Limited information 	6.9 (6 - 8)
Wattson	<ul style="list-style-type: none"> • Figures very clear, easy to see • Looks nice • Colours draw attention • Internal rechargeable battery so portable but still mains powered • Only one button 	<ul style="list-style-type: none"> • Spend per year is an unhelpful measure • Information on the display limited to current usage • Require PC/ laptop to see detailed consumption information – only one user was motivated to do this • No clock display 	5.6 (including one who said she 'couldn't rate it') (0 - 9)

Appendix 3. Literature review: real-time energy display functionality

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Real-time energy displays attempt to communicate something that is relatively 'invisible' to most householders: the extent to which they are using electricity and gas, either instantaneously or within a short period of time. As discussed below, they may also be able to display patterns of usage over time and other relevant information.

This review looks at what is known about the functionality of real-time (or near-real-time) energy displays and at what energy display features are likely to be most effective at encouraging behavioural change. It covers:

1. The research literature on feedback
2. Theoretical background
3. Appropriate feedback for different end-uses and fuels
4. The display: powering, durability, accessibility
5. Gaps in the research
6. Summary: pointers to minimum requirements

The review concentrates on feedback to individual households and on in-home dedicated energy displays. It only touches on group feedback, billing, tariffs, goal-setting, and web-based displays. However, these are all worth noting as adjuncts to display-based feedback that may add to its effectiveness.

1. The research literature on feedback

Research into feedback on energy consumption, given by way of written communications, displays or personal contact, began in the wake of the first oil crisis in the late 1970s. It was carried out largely by psychologists. These early studies established that feedback can have measurable effects on behaviour, that it 'works' to encourage energy conservation. But they were experimental in nature, not suitable for replication on any large scale, and the feedback was typically given over a fairly short period of time (up to three months).

Since that time, the research literature has become more diverse, reflecting the differing aims behind a given piece of research, along with differing theoretical perspectives. For example, electricity feedback can be used to reduce demand, or to encourage people to use less at peak times; the goal will affect the outcome in terms of overall usage and its timing (King and Delurey, 2005). From a theoretical standpoint, feedback may be understood by researchers in terms of motivating a 'rational-economic consumer' to behave in a certain way, and then reinforcing that behaviour (a relatively mechanistic or 'behaviourist' approach); or in terms of encouraging householders to learn how to control their gas and electricity consumption more effectively, through trial and error (a more 'educational' approach). Other theoretical contributions may also be helpful, such as that from behavioural economics (e.g. Schultz et al, 2008).

Mostly, though, the starting-points for feedback research are pragmatic observations and needs. A seminal paper by Kempton and Layne (1994) pointed out how selling energy is very different from retailing commodities in shops. The kWh is easy to meter, for the utility, but 'irrelevant' to the buyer. A normal economic research paradigm would focus on the relationship of price and demand, ignoring the mechanisms by which buyers know the price and their own consumption. But this does not work if we are trying to understand energy demand. The authors point out that two types of system are logically desirable: a method of billing per end use (i.e., demonstrating the relative importance of different end-uses), and a method for reporting the results of efforts to use less energy. They proposed a division of

labour, by which the utility uses its superior information and number-crunching power to provide better data for individuals who can then apply the information to what they know about their own situations. This ideal is still very relevant to the debate about the future of energy feedback.

Large-scale feedback trials, carried out in real-life conditions over a year or more, are of course cumbersome and expensive to conduct. There have been very few until recent years. The largest, at present, is the set of UK Demand Reduction trials. Results are however now beginning to emerge from a number of trials of displays, such as the recent trial of 30,000 Power Cost Monitors in northern Ontario), although they do not go into any detail on users' experiences of using the devices. At the other end of the scale, there are a few in-depth qualitative studies that concentrate on developing our insight into how people actually use a feedback device and what they learn from it (e.g. Kidd and Williams, 2008).

While they do not qualify as research literature, it is also worth mentioning on-line user reviews of different feedback devices. These supplement what we can learn from other, more structured, sources and may suggest new lines of inquiry.

Four reviews strongly influence this one: those by Lutzenhiser (1993), Abrahamse et al (2005), Darby (2006), and Fischer (2008). Other references come mostly from the literature on energy and buildings, with contributions from specific trials and from those involved in education.

2. Theoretical background

Three theoretical approaches are relevant to this review, and are sketched below: sociological, psychological and educational. Some implications of each for display design are given in italic.

The invisibility of energy use and the nature of daily practices

Modern usage of gas and electricity in buildings is largely 'invisible'. People do not normally notice that they are using gas or electricity as they might notice that they are using a fire, which requires feeding with fuel and will go out if untended. Energy use is also determined by a complex array of factors – physical systems/infrastructure, social norms, comfort preferences, and options for control. A small but growing body of sociological research has demonstrated how patterns of energy consumption are shaped by a range of factors, many of which are normally beyond the control of householders; how people do not typically act like the rational-economic individuals of classical economic theory; and how environmentally-significant behaviour usually consists of 'relatively inconspicuous actions in the context of everyday life' (Lutzenhiser, 1993; Shove, 2003; Burgess and Nye, 2008). Improved feedback can bring more consumption within the perceived control of the energy user and can demonstrate the success or otherwise of different actions, behaviour patterns and investments. Ideally, it also needs to be designed in such a way as to make an appeal that goes beyond economics, and recognises that many people have difficulties in dealing with numbers and are unfamiliar with scientific terms¹.

An effective display 'works' by bringing the invisible and the routine into focus, showing what is happening, what has happened in the past and what patterns of energy usage look like. NB: This type of service needs to be available to householders with limited vision, or none.

Psychological responses to feedback

The early research on feedback demonstrated how people respond to feedback in ways that are influenced by context but are still fairly predictable. Fischer, in her review of energy feedback from a psychological standpoint, identifies the following 'likely features for successful feedback (... effective in stimulating conservation and satisfying to households). Such feedback

- is based on actual consumption² (ie, accurate and trustworthy)
- is frequent (ideally, daily or more often)
- involves interaction and choice for households

¹ Around a fifth of adults in the UK are estimated to have difficulties with basic numeracy.

² Or, for building-integrated renewables, on actual generation or water heating.

- involves appliance-specific breakdown [the review relates to electricity]
- is given over a prolonged period
- may involve historical or normative comparisons (although the effects of the latter are less clear)
- is presented in an understandable and appealing way.’

(Fischer, 2008)

As Fischer points out, the more clearly someone can link consumption to specific appliances and activities, the more clearly behaviour patterns become relevant to consumption (and the size of the energy bill). In the longer term, we could add that feedback over time can demonstrate the benefits of better insulation and more careful use of timers and thermostats, or the energy cost of new equipment or increased living space.

Abrahamse et al (2005) cover a wider spectrum of research in their review of ‘intervention studies’ aimed at home energy conservation, taking into account ‘antecedent information’ as well as feedback (consequent information). They point out that information may increase knowledge, but does not necessarily affect behaviour. Feedback is effective to the extent that it provides highly specific, relevant, actionable information.

An effective display ‘works’ by being trustworthy, interactive and having meaningful points of reference for comparison. It engages attention by being attractive and interesting, and holds attention over time by being part of a process that is worthwhile for the householder.

Feedback as a factor in learning

The constructivist approach to education is based on the view that people construct meaning continually and incrementally, experimenting and building on what they know already (e.g. Kolb 1984; Chaiklin and Lave 1993). They also ascribe different meanings to the information they receive: the same information will be used in different ways according to the awareness of the person who receives it (Williams, 1983).

Energy users are not a uniform category of learners but a mixed-ability class. They have differing levels of skill and understanding, and different motives for learning. For example, they may be looking for understanding and ‘right action’ in relation to the environment; looking for what is ‘wrong’ with their consumption (and bills) with a view to saving money; doing what their neighbours do, as a part of normal citizenship, looking for enjoyment from operating a new type of gadget, or some combination of the above. (For an example of this approach to technology adoption and use, see Aune, 2001).

Feedback has a role in teaching energy management skills, and in giving people a sense of their ability to control usage better. If they can experiment with energy in their homes or workplaces and see the consequences of their usage, the research literature demonstrates that they typically learn something from it, increasing control over their consumption and forming new habits. The conservation effect varies considerably according to the situation, but participants in feedback trials have typically reduced their energy consumption by up to 10% when given ‘indirect’ feedback (processed for them and presented through a bill or statement, or via the web) and between 5 and 15% when they use more ‘direct’ feedback³ (Darby 2006). This effect may be diluted when an entire population, rather than a sample of volunteers, has access to feedback, but the aim is to realise as much as possible of the potential.

An effective display works by adding to what householders already know about their own ‘energy system’ – the nature of their home, appliances, comfort preferences, daily routines and exceptional events. It helps them discover what is within their power to change, day by day or over longer periods, such as switching off, cutting ‘default’ usage by altering settings, investment in efficiency measures or home alterations. It takes into account the mixed abilities and motivations of users, offering information that ranges from simple and general to the complex and specific.

³ ‘Direct’ is used here to describe feedback that is available to the end-user in real time, through the meter or a dedicated display.

3. Appropriate feedback for different end-uses and fuels

The twin aims of improving feedback are here assumed to be (a) to assist the user in reducing demand for fuels and (b) to optimise the use of energy from renewable sources.

Different end-uses, with their associated fuels and modes of payment, will be better suited to some types of feedback and metrics than others. A basic distinction for the UK and other cool climates is that between space heating, water heating and other end-uses. Where the home is heated by gas, this is dealt with straightforwardly by displaying gas usage separately – which may or may not also include water heating and cooking. But when a dwelling is all-electric, it is important to separate space heating from the other end-uses. If this is not done, the size of the heating load is likely to drown out the real-time feedback signals that would otherwise show up clearly when an appliance was switched on or off, or began cycling. Mountain (2006) found that the configuration of heating, water heating, and air conditioning had a critical impact on the behavioural response to real-time displays in family homes in Ontario. This finding was reinforced in parallel trials in other regions of Canada (Mountain, 2007). The strongest response came from households with electric water heating (a dramatic, very visible impact on consumption levels when seen in real time), but without electric space heating.

Electrical appliances and lighting lend themselves to real-time feedback, for maximum impact on the householder; space- and water-heating are best suited to next-day feedback, so that the user can see the pattern of usage at a time when they can remember what they were doing (or not doing) that might account for such a load curve.

As pointed out by Wood and Newborough (2007), appliances may be grouped according to the ways in which they are used and controlled. Ideally, the feedback style could correspond with the appliance type, or with a specific set of activities (cooking, home office, laundry etc):

- a. cookers, taps etc., with low levels of automation and many settings, needing the user to be present. A display for a cooker should have at least one frequently-updated data point, to show effect of current setting.
- b. appliances with low levels of automation but few settings eg lights, vacuum cleaners, TVs. A cumulative, frequently updated, 'this event' display might be best, to prompt users to switch off as soon as possible and perhaps to show how long the appliance had been switched on for. There could be comparisons with other events, eg 'usage so far today' versus 'usage yesterday/ last day of use'
- c. high level of automation and several settings eg wet appliances. A permanent representation of the energy used with each setting might be best, and/or 'this event/ last event'...
- d. highly automated appliances with few settings eg cold appliances - energy information from these is probably best left to a central display.

It would be cumbersome (and expensive) for most people to have a plethora of separate feedback devices, but a realistic arrangement could include (c.) above, while concentrating on a form of display that gives real-time feedback (dramatising the impact of switching electrical appliances on and off), and also displays day-late and other 'historic' information to the user's specification, e.g. comparing days, weeks or months with those directly preceding them, or with comparable periods in the previous year.

Solid/liquid fuels

Solid and liquid fuels are bought in finite quantities. It is clear to the customer how much is left in the tank / pile / store; this constitutes feedback in itself.

Prepaid gas and electricity (Pay-As-You-Go)

The customer is aware of paying for finite amounts of energy – in this respect, PAYG resembles solid or liquid fuel – and the need to top-up the meter is a constant reminder of usage. The Northern Ireland Electricity displays for prepayment customers, which tell them how much credit they have left, have given a 1% saving over baseline (ie, when customers switched from credit to PAYG), while PAYG customers use roughly 5% less electricity than those on credit meters (Boyd, 2008); the Salt River Project M-power programme in Arizona, with similar meters, gave 13% savings for thousands of customers, compared with

previous usage (these of course included substantial savings on air-conditioning) (Pruitt, 2005; Stein and Enbar, 2006).

Electricity

This is normally paid for in arrears (with intermittent, poor feedback from bills, often estimated); and direct debit is the worst form of payment from a feedback point of view. The rapid growth in consumer electronics is counteracting the benefits from savings in lighting, cold and wet appliances: people typically buy a new appliance for the service that it can provide, with little thought of the consumption, and fast-changing consumer electronics are notoriously resistant to labelling. So the case for raising awareness is a strong one. Basic real-time displays (which may not be very accurate, reliable or well-designed) have been surprisingly effective in the hands of motivated users, although their shortcomings have left them unused or abandoned by others. Accuracy, reliability and design are all improving, and displays linked with smart meters now mean that the data available to the householder and the utility can be identical.

Gas

At present only a few trial households have displays showing hourly gas consumption, as part of the UK trials. Businesses have benefited from automated meter reading accompanied by next-day feedback on their consumption in the form of emails or web pages, as documented in the report of the Carbon Trust trials (2007). There are early indications from the UK trials that many customers are taking an interest in the gas data from their new smart meters, although the gas information is less prominent than the real-time electricity data with which it shares a display device.

There is a case for siting the display of gas data alongside the heating controls for a dwelling, or for combining the feedback device with the controls. In that way, the user can put the feedback information to use immediately by experimenting with the controls.

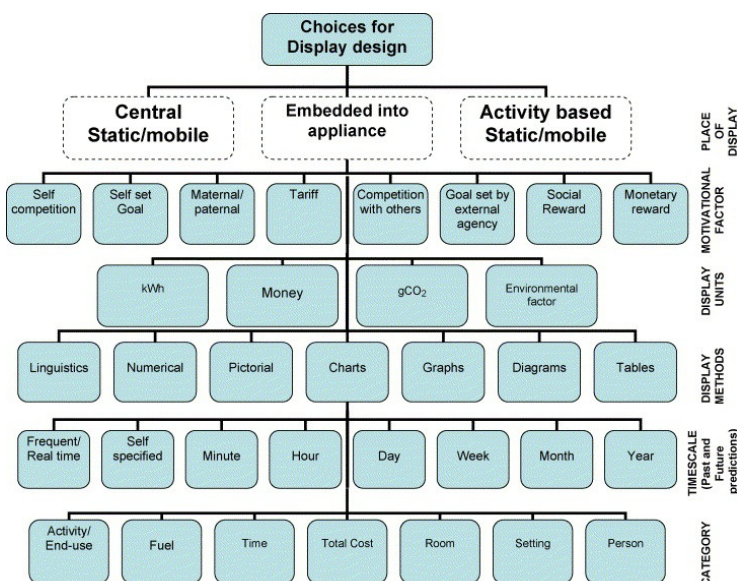
Multi-utility displays

There is a case for single, central displays that give the customer easily-accessible information on electricity, gas and water use at the same time, and a few have now been developed (e.g. the Landis & Gyr ecoMeter; USCL in California). Heat metering will also be a candidate for multi-utility displays, for those with community heating.

Design choices

Wood and Newborough (2003) summarise the range of choices open to a feedback display designer, as indicated in the figure below. It serves as a useful reference for anyone aiming to design new displays and/or test preferences (Figure A1).

Figure A1. Summary of the factors influencing the design of energy-information display system for use in an intelligent home. Copied from Wood and Newborough 2003



Feedback modes

Ambient

Ambient feedback is aimed at peripheral vision, not at supplying detail. Examples are the Energy Orb, which is used to signal time-of-use rates for electricity (Martinez and Geltz; Stein and Enbar, 2006); and the 'traffic light' in the ecoMeter which shows green for 'low' consumption (the threshold is pre-set); amber for medium, and red for high; or the type of feedback in the designs being developed by the Interactive Institute in Scandinavia. Ambient feedback gives the user a feel for what is going on, without requiring detailed attention, and they alert users to unusually high consumption. It can of course be given in combination with more detailed information on a display.

Analogue

Displays can illustrate the scale of consumption without numbers, though careful use of graphics. These can be actual graphs or charts, or can be different-sized shapes. The GEO displays give an example of combined analogue and digital feedback.

Digital

This has been the predominant mode to date, but as displays become more design-led it is likely to shrink in relative importance. However, clear digital information is obviously important for customers who want accurate, useful data and who are prepared to drill down into some detail.

Feedback types and metrics

All the options outlined below have been tested and have been shown to be effective, to varying degrees. It is beyond the scope of this brief review to go into detail about this, but all could be taken into consideration when the next stage of this project investigates preferences in focus groups.

Real-time feedback

This is the type of feedback associated with first-generation displays, for electricity consumption only. Most real-time displays to date show both cost and consumption, on the same screen or with a straightforward toggling between the two (Fischer, 2008). However, the 'cost' figure is typically a cost per hour, based on instantaneous consumption, and so this fluctuates wildly and is a lot less reliable than a figure based on cumulative consumption over a given period. The available evidence suggests that people are more interested in the size of figure on the screen (cost or kW) than on any figures for associated carbon emissions, if these are given.

The types that follow are all compatible with real-time feedback, as options on a display or a related website, and are therefore included in this review.

Historic feedback

Historic feedback gives cumulative usage / generation data, and can be used for comparisons, ideally with comparison periods chosen by the user, e.g. how much did I use last month compared with the same time the previous year? A more sophisticated variant can correct for weather (degree days).

Units of energy are likely to be more effective than units of cost, for historic feedback; they are less intelligible to the average person, but more reliable comparators. Changes in the unit cost of fuel or electricity over time can sabotage a customer's perception of how consumption patterns are changing. There is a risk that displaying cost savings could actually backfire for some customers, as it could show figures that are considered too trivial to matter.

Predictive display

A display can allow the customer to set targets or budgets for the future, and can indicate how successful s/he is being in relation to moving towards these targets. The prototype SenterNovem 'PowerPlayer' is an example.

Comparative / normative feedback

Comparative feedback gives comparisons with some reference group of individuals (e.g. neighbours in a postcode area; people with a comparably-sized home) or with a significant metric such as average carbon emissions per household for the country, or a 2020 target for average household emissions). This is an ambitious type of metric for a simple display, but as there is increased 'blurring' between different types of interface, all using the same or similar communication protocols and technologies – dedicated display, PC, mobile phone, personal organiser, etc – it is likely to become more feasible.

This type of feedback lends itself well to graphical display: valid scales and proportions will be at least as important as choice of units. Behavioural economists in the USA have recently been showing interest in normative feedback and have discovered a way of avoiding regression to the mean among low-consuming households (Schultz et al, 2008). However, exploratory research in the UK, by the CSE (Roberts et al, 2004) showed suspicion about the validity of comparators. It seems most likely, from the limited literature on the subject, that comparative feedback may be useful on occasion as a way of awakening interest or checking where a household stands in the broader scheme of things, but is not the most useful type on a regular basis.

Disaggregated or appliance-specific

Appliance-specific feedback is becoming available, and could clearly be useful in terms of 'visibility', but there is no clear evidence as yet as to how far this process needs to go, and how far it may be desirable to leave room for householders to work out for themselves the significance of different end-uses by paying attention to their real-time information and behaviour patterns. The cost of supplying the feedback will rise with complexity, and there will be some optimum level, e.g. separating out appliance groups such as cold, wet, lighting, water heating, and ICT. As mentioned above, separating space heating from other end-uses is highly desirable. Newborough and Wood (2007) discuss the issues. Intuitively, it seems likely that there is something to be gained by leaving room for users to work out for themselves something of what has happened to explain their consumption patterns, rather than being shown every last detail for each individual appliance.

Different metrics may be best suited to different end-uses: there is potential for confusion here. One obvious source of confusion is that between the kW and the kWh. How far should a display be able to function on its own, as a learning tool, and how far should we expect a rollout of displays to be accompanied by public education campaigns? The question of metrics is likely to be dealt with most effectively through graphic design, allowing the householder to make valid assessments and comparisons.

Variable pricing feedback

There is very little time-of-day tariffing for residential customers in the UK, apart from 'Economy 7'. Northern Ireland Electricity have pioneered a 'Powershift' tariff (Boyd, 2008). But variable tariffs are frequently promoted to utilities as a potential benefit of introducing smart metering, and could become significant in the UK. The 'Tempo' tariff in France is used in conjunction with a display that warns customers whether they are about to have a 'blue' day (lowest unit price), a 'white' day (medium), or a 'red' day (critical peak pricing for the coldest/hottest days of the year).

Shared (group) feedback is an option that can be used to promote a sense of citizenship and common purpose. An example is the website that was set up during the California energy crisis by the Lawrence Berkeley National Laboratory, giving a load curve for each day for the entire state in real time and showing how close customers were to reaching the limit of supplies and facing blackouts. This site received up to two million hits a day during the crisis, and is still available, for California and several other states (see <http://currentenergy.lbl.gov/ca/index.php>). Another example is substation metering and feedback, under way for three villages as part of the UKDRP trials.

Own-generation feedback

There is some evidence of a conservation impact when a household is aware of the existence, extent and timing of any electricity that is generated on the premises (Keirstead, 2006; Dobbyn and Thomas, 2005). In any event, part of the rationale for smart metering is that it can record both imports and exports of electricity and is necessary for smart grids that can optimise the balance between load and supply.

Example of how a display can inform actions and choices

This online review of a 'Power Cost Monitor' acts as an illustration of how an American family worked out how to act, using the feedback available:

We are family of 5 (kids 9, 7, and 3) that lives in Vermont where it can be quite cold and dark in the winter.

Our electric bills started climbing to about \$200-\$250 a month. We heat the playroom in the basement with electric heat but use it seldom, I had a new plasma TV and related equipment, we leave a pole-light on out front every night (efficiency bulb) - - we had no idea which - if any - of these items was the culprit.

... whenever we pass [the monitor] and it's high (say \$.60 or higher), we look around the house to determine the cause. Thru some time and some testing, we've determined that a few inefficient appliances are the main cause of our high bills. Our dishwasher in particular is VERY costly, although it was Energy-Star rated, it was done (we discovered) with all the options and features turned off. When you turn on the hot rinse, hot dry, etc - the cost skyrockets....

The ... monitor made our efficiency efforts realtime, ...we can try things and trial/error on a minute-to-minute basis if we care to, we don't need to wait for our once a month bill to see if our attempts bore fruit.

I also realized that at night, while everyone's in bed and everything's off, we were drawing \$.08 per hr or \$60 month! So many items in the house just suck power whenever they are plugged in while they're powered on or not...just making you aware of your usage is worth the price [approx CA\$100] alone. (see http://www.powercostmonitor.com/p3982/power_cost_monitor.php)

From the UK, an in-depth study of ten users of a digital display device in the village of Talybont in Wales gives many examples of how people reacted to their feedback (Kidd and Williams, 2008). The 'nudge' effect was very important. So was the device as a focus of attention and a point of reference for discussion within the household.

4. The display: powering, durability, accessibility

The display device itself gives a message to users that may boost or detract from its credibility. Every detail of the design matters, from ability to go through a letter-box to user-friendly installation and commissioning. Allen and Janda (2006) give a detailed account of some of the difficulties encountered by a small group of householders who were given a new digital display without any assistance in setting it up or using it, and no guidance from the 'home screen' as to how to proceed. This lack of guidance was enough to prevent half the recipients of the monitor from touching it in order to explore what it had to offer.

In the UK trials and elsewhere, there have been criticisms of 'clip-on' displays because they were difficult to programme, used too much power, or had batteries that soon gave out, leading to relegation to a drawer or to landfill. If a display is to inspire confidence (whether it be a 'clip-on' or supplied with a smart meter), it has to show consistency with its purpose, to save energy, and it has to be demonstrably useful over long periods of time.

The UK trials have shown that there are householders who already use energy frugally, do not think that a display is going to tell them anything new or help them to identify any further areas for savings, and resent the extra embodied and in-use energy that a display requires. Imposing displays on such people may well be counter-productive.

Most of the electricity consumption of a display is accounted for by transmission of information from the meter or meter wire to the display; this can be met by 'power harvesting' from the mains supply, with extremely low (barely detectable) annual consumption.

However, if the display is to be moveable, it will require batteries in order to receive data, and there is a compelling argument for an electricity display to be moveable so that it can be taken around the home

while the user switches different items on and off and notes the impact. Alternatives are fixed displays that are powered directly from the mains, or moveable displays with a base such as a wall bracket, to which they can be returned for charging.

If displays are based in a well-lit, well-frequented part of the house, they are more likely to be used as a shared point of reference. This should be an advantage (given that energy consumption in most households is the product of the actions of a small social unit, not an individual), as long as they do not lead to so many disputes about energy usage that they are abandoned.

Given the rationale behind displays, there is a need to ensure that people with limited vision, or none, are able to access useful information about their energy use. Consultation with the RNIB would be a good place to start.

5. Gaps in the research

The most obvious gaps in the published research are those dealing with fairly detailed 'quality' questions, something which this project is designed to begin to address. A great deal of research has now been carried out on this in the process of designing and developing specific feedback displays, but it is commercially confidential.

More specifically, there are gaps in our knowledge about how display devices may be used over time. We know that some people lose interest in a real-time display quite rapidly but little, so far, about how interest may be maintained and developed. Little is known as yet about the uses of displays for predictive feedback / feed-forward, and how they could help people to budget. There is also room for more research into combining feedback with controls in single or related displays.

A second area for research centres around developing feedback arrangements that allow multiple pathways through which people can teach themselves at their own pace, avoiding information overload, inappropriate information, misleading metrics etc. This is essentially educational research and there is almost certainly a role for learning technologists here.

6. Summary: pointers to minimum requirements

Some pointers emerge from this review about likely minimum requirements for real-time (or near-real-time) displays.

Their effectiveness stems from

- ability to make energy usage visible and intelligible
- complementing what the user knows about their home, routines and practices
- providing actionable information, linking usage levels with specific actions, end-uses or processes. Combining displays with controls is an important area for research, particularly where heating is concerned.
- ability to maintain user interest by giving useful information and allowing for interactivity and learning
- suitability for use at a number of levels, from ambient signals to detailed interrogation by the user

Displays should be consistent in design and manufacture with their purpose, ie, they should be low-impact in terms of material and in-use consumption.

Location of the display will have an impact on how well it is used, and will also have implications for the amount and type of power it uses. A base from which the display can be recharged (but which allows for it to be moved around the home) would seem to be a good arrangement.

Research to date, including early findings from the UK Demand Reduction trials, tends to show that the importance of very basic 'ambient' signals is probably underestimated. Engineers and energy specialists

tend to forget that the average householder is not familiar with energy units, not very interested in energy for its own sake, and may be alienated by an over-numerical display.

Certain features of consumption are likely to attract particular interest, e.g. the scale of baseload or overnight usage, which can be startling; or the maximum and minimum levels of consumption in a given period.

Overall outcomes from a feedback programme are the product of the impact per household and the proportion of households who use the feedback. There may be a tradeoff between the two, but the ideal is to have feedback that is accessible, engaging and that almost everyone can benefit from to some extent. There are householders who are already frugal with their energy, and feel that a display will add nothing useful to their knowledge or ability to save energy, and will only add to their electricity consumption. They may be right, and this needs to be recognised: there is nothing to be gained by foisting new technologies on unwilling recipients.

There are practical design issues for those with visual disabilities, and for those still unfamiliar with ICT.

A display device does not necessarily have to show everything that a householder might need in the way of information; consideration needs to be given to what is best shown on a display and what is best shown on a website, which is likely to have more possibilities for interactive learning. As time passes, the distinction between the two is likely to blur, however.

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Appendix 4. Design of domestic energy meters - a psychological perspective

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Introduction

From an ergonomic standpoint, design of data displays must consider both the 'what' and the 'how' of information presented to users. Design of a display has to begin with questions about what the user is trying to do and what effect the designer wishes to have on the user's awareness and subsequent behaviour. In the context of domestic energy metering there are potentially both short- and long-term goals. The short-term goal might be to provide a prompt for immediate actions (turn off lights, lower the thermostat), and also to help establish longer-term habits.

Research in economic psychology has clearly shown that consumer behaviour cannot be explained in terms of the most obvious rational principle of maximising the utility of outcome. There is no guarantee that providing users with the information needed to make a rational choice will actually increase the likelihood of that choice being made. Rather, some thought must be given to the broader strategic principles that identify what kind of information is most likely to produce the desired behavioural change.

Although these aspects are fundamental to the success of the broader enterprise, the primary focus of this study is on equipment design. Consequently the first section of this document highlights design principles that have emerged from sixty years of empirical research. One point to emphasise here is that there are no 'off-the-shelf' design solutions; firstly, because display design must always be viewed in the context of specific task and user characteristics; and secondly, because advances in technology are constantly generating new possibilities. Perhaps the most important development is the advent of screen-based digital displays that are no longer subject to the constraints imposed by electromechanical technologies.

The examples shown here are intended to illustrate some of the ways in which display formats have been designed to fit particular tasks and applications. With few constraints on screen-based displays, the emphasis in areas such as avionics has been on making information displays consistent with users' intuitions. This is a principle that is particularly appropriate for export to a sphere in which users have little or no training, and are therefore dependent on intuitive understanding.

Designing visual displays

Historically, ergonomics research was initially driven by avionics and process control. Applications initially focus on expert (and highly motivated) users performing complex control tasks. Critical behaviour characteristics tend to be speed and accuracy (avoidance of error). In this context, user goals and criteria for task efficiency are generally well defined. These characteristics do not apply in the case of domestic behaviours where at a broad level individuals may have different goals (implicit in weightings and values of perceived costs and benefits).

Avionics displays, though complex, represent the state of the art in ergonomic design of display formats. In this domain the objective is to create displays that are consistent with users' intuitions (reduces the likelihood of error), and provide clear, task-appropriate representations of information. These principles are also appropriate for the design of domestic meters designed to support energy-efficient user behaviour.

Ergonomic approach to display design

Preliminary considerations concern the purpose of the display, in terms of the type of message it is designed to convey and its relation to user behaviour?

In terms of information, displays may be designed to:

- provide quantitative information about a device or some aspect of the environment (temperature in degrees centigrade, electrical current in amps, etc.)
- present qualitative assessments – normatively-based evaluations (cold, warm, hot), or comparisons that relate current values to preset targets (high, low)

In terms of time scale, displays may present instantaneous values, histories, projected future values, or any combination of these.

In terms of user behaviour, displays may be used:

- in combination with controls that allow users to set system values or maintain a steady state in changing conditions
- to enable the user to predict or anticipate future states
- to alert users to conditions that require active intervention

Display design should be appropriate for conveying the information that users will actually use. Issues include:

Digital or analogue displays of quantitative information? Digital displays produce fewer errors and faster reading times (Murrell and Kingston, 1966; Zeff, 1965). However, although the information conveyed may be quantitative (e.g. speed of a vehicle, present electricity consumption), the important *message* may be qualitative. It may be harder to read the exact value represented in by analogue display, but it can directly convey the difference between current and target values ('check reading') in a direct and readily interpretable manner. In a system that is under user control, it is this mismatch that provides a cue for action, and also conveys information about the importance and/or urgency of that response.

Analogue displays can also be more effective in conveying information about future states – e.g. gaining a sense of how long it will take to complete a process such as filling a tank or heating a system to operating temperature.

In general, the question whether digital is better than analogue thus depends not only on the type of information to be displayed, but also on the nature of the task being carried out (Green, 1988). In complex real-world environments, the need for check readings, evaluation of future states and other factors related to 'situation awareness' can override simple considerations of speed and accuracy of quantitative readout. For example, there is evidence that analogue cockpit displays are better than digital displays for novice pilots, when assessed in terms of cognitive workload and development of flying skills (Koonce et al, 1988).

Also related to situation awareness is the capacity of analogue displays to convey several types of information simultaneously in a direct and intuitive manner. Colour coding of a dial face can represent a maximum possible value (full tank, engine overspeed), an ideal or target value (green zone below this, red above). The pointer reading then conveys not also the current value, but also how this relates to preset benchmarks (e.g. air supply gauge, Fig A4.1).

Formats for analogue displays include dials, column gauges and also dynamic displays such as 'barber pole' displays, which can be effective as flow rate indicators. Fig A4.2 illustrates a number of display formats in an integrated avionics instrument panel. In this case, different formats are used for different types of information.

Fig A4.1. Dial-type diving gauges includes preset marker and colour-coded status zones, as well as indication of current reading



Fig A4.2: Avionics panel with various display formats

Speed (dial display with colour-codes that convey qualitative evaluation)

Altitude (clock display with two dial pointers)

Rate of climb/descent (use of horizontal for zero position means that pointer indicates up/down in an intuitive manner)

Rate of climb/descent (use of horizontal for zero position means that pointer indicates up/down in an intuitive manner)

Fuel flow (hybrid analogue/digital display enhances situation awareness)

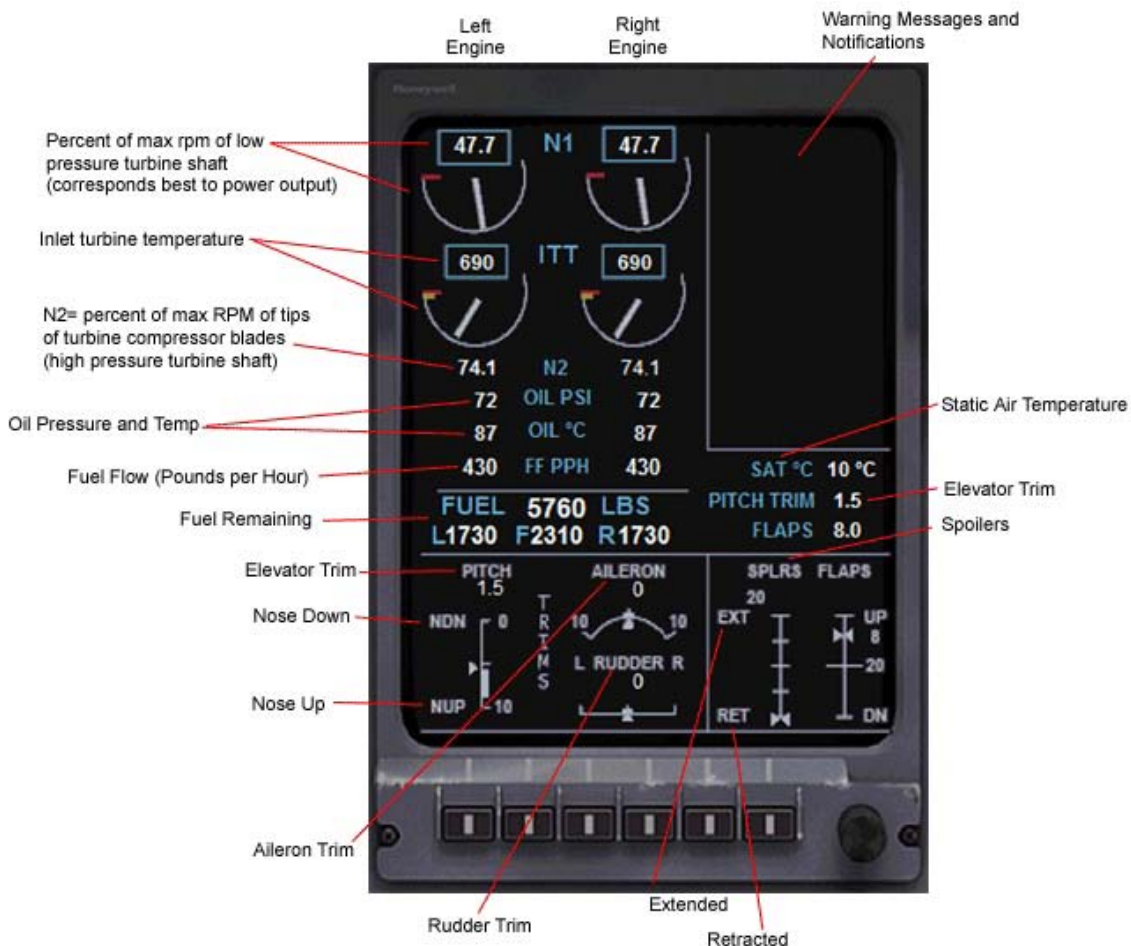
Fuel level (analogue bar-type display represents present level relative to full tank and warning level)

Qualitative displays As noted above, information conveyed by analogue displays such as dials and column gauges may functionally be both quantitative and qualitative. Other display options include warning/indication lights (with traffic-light colour coding) or verbal messages/alerts.

Pictorial displays These can be an important element of displays that represent systems of any degree of complexity. They are frequently encountered as map or flowchart displays (e.g. rail network, process control, respectively). One key design principle here is that representation should wherever contain analogue representations (e.g. depiction of flow by barber pole element should directly represent rate of flow).

Hybrid displays There is an increasing tendency for system information to be presented by means of 'soft' LCD displays. These have the advantages that they are reconfigurable by the user to meet particular task demands, and also allow information to be presented in both analogue and digital formats. Hybrid displays have the potential to combine the advantages of both systems, and are frequently used in avionics for applications such as engine displays where there is a need to maintain situation awareness (supported by an analogue component) while affording access to precise quantitative data (presented in digital format). A typical format is that used for engine controls in top left section of the cockpit display shown in fig A4.3. The effectiveness of this format has resulted in its near-universal adoption in avionics applications.

Fig A4.3: Note hybrid format for engine control display



Decision making – heuristics and biases

The immediate purpose of a display is to convey information to a user, and the effectiveness of its design might therefore be evaluated in terms of the extent to which this is achieved. However, when displays are viewed as components in a control system, effectiveness must be assessed in terms of the extent to which it supports users' decision making. Real-world situations often require people to make potentially complex decisions based on the costs and benefits of a number of available alternatives. A simple and rational model of decision-making might suppose that in these circumstances people will select the option with the most favourable net outcome; a utilitarian view that underpins traditional economic theory.

If applied at the individual level, the utilitarian model implies that we can increase the likelihood of an optimal decision by providing as much information about costs and benefits as possible. However, psychological research by Kahneman and colleagues (e.g. Kahneman, 2003; Kahneman, Slovic & Tversky, 1982) has conclusively demonstrated that everyday decisions are rarely reached in this fashion. People tend to make intuitive judgements, and when faced with alternatives find that preferences come to mind quickly and effortlessly. Such judgements can in principle be overridden by deliberations that follow the utilitarian logic, but this process is effortful and seldom completely successful.

Intuitive judgements are made possible by the use of heuristics – mental shortcuts - that select and simplify the available data, and by biases that distort the interpretation of numerically based information. 'Behavioural economics' and modern marketing practices are largely based on an analysis of these cognitive strategies. In the context of domestic energy displays, the implication is that in order to influence consumer behaviour it is necessary to understand what drives consumer decisions. Effective displays must not only communicate information in a clear and effective manner, but also deliver information that engages with users' decision making strategies.

The following summary highlights some of the more relevant findings in this area. A fuller discussion can be found in a review paper by Wilson & Dowlatabadi (2007).

Behavioural economics – utility-based models

The microeconomic decision model of consumer choice, based on maximising utility as defined by a fixed set of options and preferences (values), essentially assumes that consumers make rational choices, guided by their evaluation of outcomes. Decisions are essentially instrumental and self-interested, but 'utility' can be derived from sources other than money (may include social values, environmental concerns).

When applied to consumer choices, this model can be used to assess individual's willingness to exchange present cost for future savings; i.e. spending more up front to achieve lower running costs (discount rates). Discount rates are influenced by a variety of factors, including perceived risk, framing (i.e. how the alternatives are presented) and social arrangements.

The utility approach effectively models behaviour at population level, despite variability in individual preferences – individuals may not in fact be utility maximisers, but when considered in aggregate, behave as if they are. The problem is that evidence shows that individuals don't make consistently rational decisions, as defined by utility of outcomes, but employ heuristics that reduce processing demands, e.g.:

- 'satisficing': sequential search through alternatives until a utility threshold is reached
- recognition heuristics favour familiar responses and increase the likelihood of choosing a previously selected alternative
- elimination heuristics apply a filter that narrows down alternatives on the basis of a single characteristic; e.g. ruling out the most expensive options (even if affordable)
- availability heuristics excessively weight decision criteria that are readily available or salient

Implications for interventions that aim to change behaviour

If people made rational decisions based on outcome utility, the best strategy for intervention would be to improve net benefits of the desired behaviour, and to ensure that accurate information about cost/benefit

relations is readily available. However, behavioural economic research reveals shortcomings in this approach - individual preferences are not well-defined, fixed or consistent, and decision making is not always deliberative or optimal (a fact well known to, and exploited by, advertisers and marketing specialists).

Deviation from rational consumer choice behaviour arises for a number of reasons, of which the more important are:

- *anchoring*: the addition of inferior products to a range (e.g. supermarket “value” options) increases consumers’ preference for more expensive alternatives
- *loss aversion*: when faced with choices that involve withdrawal of existing benefits, consumers tend to overvalue this potential loss (important in the context of energy efficiency, where curtailment of usage may be viewed in this way)
- *habit*: a good deal of everyday consumer consumption is based on habitual cognitive or affective responses, rather than rational deliberation

The general implication is that, in order to support consumer decision making, the ideal formulation of classical utility theory must be combined with psychological insights of behavioural economics. Hence to achieve behaviour modification, it is important to target those factors that influence decision heuristics; such as:

- seeking to establish and consolidate appropriate habits, task procedures, mental associations and emotional reactions that are consistent with the desired behaviour
- emphasising a single salient or particularly desirable attribute may be more effective than providing information about all attributes
- supporting consumer choice by developing decision-structuring tools that:
 - present information in a clear and appropriate manner
 - identify and counteract potential biases
 - help individuals to prioritise their own interests and values

Technology adoption and attitude-based decision models

The diffusion of innovation model (Rogers, 2003) seeks to account for the adoption of novel ideas, practices and technologies. It describes a social communication process via person-to-person and media channels that governs decisions about the adoption of new technologies.

Key assumptions include:

- decisions can be viewed as a structured process that begins with a change in knowledge and ends with a change in behaviour
- the decision process is triggered by a set of circumstances that include perceived needs and social norms
- the translation of knowledge into object-specific attitudes is determined both by adopter characteristics and the attributes of the innovation
- feedback from later to earlier stages of the process can be both internal (psychological) and external (social, communicative)

There are five innovation attributes in the diffusion of innovation model that account for most of the variance in adoption rates. These are summarised in Table A4.1.

Table A4.1 Attributes of innovation within the diffusion of innovation model and examples in a residential energy context

Attribute	Example of attribute in a residential energy context
Relative advantage over the incumbent technology or practice (e.g., more convenient, flexible, cheap)	Cost savings, personal comfort, and family health from measures such as weatherization
Compatibility with existing needs or problems, prevailing social norms, and behaviour	Energy efficiency is unattractive if framed as a major deviation from behavioural norms
Complexity, i.e., the skills, capacity, and effort required to adopt an innovation	A perceived barrier to new and unfamiliar technologies – e.g. solar photovoltaic adoption
Trialability - whether innovations can be tested prior to adoption	Peer experience or social feedback is important to reduce uncertainty about irreversible weatherization measures; reversible changes such as use of clock thermostats can be tested in situ
Observability, e.g., whether innovations are highly visible (to potential adopters)	Solar technologies have greater normative appeal than less visible measures such as home insulation

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