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Publication date:
2010

Citation for published version (APA):
Shanks, K., & MacPhaidin, A. (2010). Tailored energy-use behaviour intervention initiatives. Paper presented at IV Congresso Nazionale AIGE, Rome, United Kingdom.

Tailored energy-use behaviour intervention initiatives

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ABSTRACT

The recent adoption of behavioural change policy aims, public interest in green living products and the growing array of related public initiatives indicates an increasing acceptance of the role of behaviour in pursuing greater levels of energy efficiency. There are many different ways to approach influencing awareness and driving behavioural change at national levels across large populations. Where advertising campaigns have been reported to have little noticeable impact on large scale energy efficiency taking a tailored approach can prove effective at local level but cannot be readily extrapolated to the larger scale. This paper reports on two tailored intervention initiatives in Ireland, under the National Energy Efficiency Campaign 'Power of One' and a national television series. Whilst both initiatives generally addressed the same intervention actions and technical factors these were approached in different ways. This paper describes the framework of both initiatives reporting results and the technical techniques used to quantify changes in consumption from short term energy data. The experience of these interventions provides indications of key factors for scalability of behavioural change initiatives.

Background

Historically energy efficiency in the building sector has been mainly associated with the technical aspects of building design, i.e. the technical characteristics and performance of a buildings envelope or fabric and its energy consuming systems, such as heating; cooling; ventilation and lighting systems. While the majority of policy development and mainstream research and development focussed on the technical aspects of these elements, the diversity of implications due to human factors were not as well explored or addressed. The dynamics of human interactions with, and usage patterns of, buildings and their systems were historically treated in simplistic deterministic ways. Effectively, occupants were treated as having a limited number of linear responses and actions in the research and development of energy efficient building design techniques, strategies and the development of energy system technologies. However, from the 1970's onwards scientific investigation continued to show that there were very often large differences between how much energy a building was predicted to consume and how much it actually consumed in reality. Through these types of findings and although these differences are typically due to not only human factors but also other factors like, construction quality; variation in ambient conditions; etc., the idea that human factors could be more important than originally appreciated continued to grow. By the late 1990's professional bodies were beginning to accept that the differences between the theoretical amount of energy a building was predicted to consume at design stage and the amount it consumed in its operational life was an important issue. This shift in thinking can be illustrated by the series of Probe studies of advanced low energy buildings [1] conducted by the Usable Buildings Trust commissioned by the CIBSE Journal. In the majority of these scientific field studies, non-domestic buildings were shown to perform less well in reality than expected at the design stages where some of the reasons were due to human factors of usage and management. Similar work under various European Commission programmes also indicated a common difference between predicted and actual performance in housing.

From the late 1990's through to the mid-2000's as climate change concerns and energy security became increasingly important priorities for most countries, there was an increasing awareness of the role human interaction, i.e. behaviour, has on the energy performance and therefore efficiency of buildings. With this growing momentum of awareness and acceptance by industry experts and policy makers a significant milestone was reached in 2006 when, for the first time, the high level policy strategy of the European Commission on energy efficiency, Action Plan for Energy Efficiency [2], explicitly included a priority to address behavioural change. With this milestone, most Member Sates started to include priorities of addressing behaviour in their own national policies and developed actions targeting behavioural change in their work programmes for climate change and energy efficiency. As a result, research and development effort has only recently started to focus more on how we, as occupants, interact with our buildings and on ways to increase our awareness of the impacts as well as exploring different types of intervention techniques to try and drive behavioural change to increase energy efficiency. It is in this context that this paper reports on two tailored intervention initiatives that focussed on exploring behavioural change in a number of households in Ireland.

Differences between theoretical and operational energy consumption

Typical impacts of behavioural factors were found in some unexpected results of an energy performance survey of Irish housing in 2005. In this study 150 dwellings were surveyed, audited and householders interviewed on their general usage patterns and comfort expectations. The theoretical energy consumption of each house was calculated using the then industry standard tool, Home Energy Rating (HER), using surveyed physical dimensions and materials whilst the actual, i.e. operational, energy was determined from weather corrected fuel and electricity bill data averaged over the previous three years. The sample of dwellings was selected on the basis of a statistical representation of the national housing mix. As can be seen in Figure 1 below, whilst there was a general correlation between the theoretical and actual energy consumption of most dwellings there were a significant number of dwellings where theoretical and actual consumption was very different. The weak correlation for the whole sample, represented by the trend line, was caused by such anomalies that exhibited these large differences. Interestingly there were similar number of dwellings where actual consumption was much higher than theoretical as those where actual consumption was lower than theoretical. A key inference from these anomalous findings was that the dwellings that were designed to be highly energy efficient, i.e. had a low theoretical consumption, were the majority of dwellings where actual consumption was much higher than the theoretical consumption. Synthesising the energy data with householder interviews, the types of factors that were the potential cause of these large differences include:

- high levels of expected thermal comfort (reflected by long heating periods and high thermal amenity)
- higher than average quantity of appliances and devices
- fixed time control of domestic hot water

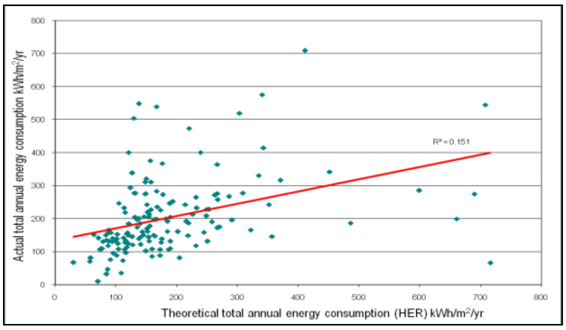


Figure 1 Actual against theoretical total annual energy consumption of 150 dwellings

With elements of EU and national priorities of increasing energy efficiency by targeting behavioural change most Member States started new initiatives and programmes. In Ireland a national energy efficiency campaign was developed and launched, i.e. Power of One, to both raise awareness of where energy in the home can be used more efficiently and supporting this through a high profile tailored intervention initiative, i.e. Power of One Street, as an element of the larger campaign. This involved intervention challenges and mass media profiling of the experiences of 12 households representing a range of socio-economic and geographic types. Similarly, at the same time, as the growing public awareness of climate change impacts and actions associated with energy consumption in homes was gaining mass media profile, the Irish national television network, RTE, commissioned a program series to address energy use behaviour in the home. The series, called 'My family aren't wasters...', was a reality based show framed around following the experiences of two typical households meeting the challenges of a tailored intervention initiative.

The framework for both these initiatives was a series of energy challenges based on the main domestic energy end uses. This was in contrast to the majority of mass media messaging in advertising campaigns and social networks that framed tips on energy saving around different rooms in a house. The rationale for this framing was that it provided a simpler framework for providing feedback on energy impacts and savings. The underlying aim of both intervention initiatives was to illustrate how behaviour and habits affect energy consumption and challenge individual households to reduce their consumption by giving feedback on each household's individual behaviour based on collected data and analysis. This type of tailored feedback was based on synthesis of collected energy data, regular reactive interviews with householders which investigated their level of awareness and specific habits during the specific periods in which energy data was collected, and guidance on what specific actions could be readily changed to provide savings.

Energy use behaviour

From a behavioural science perspective, behaviour is influenced by a combination of factors that relate to an individuals cultural; technical and socio-economic situation. In terms of energy use behaviour in a domestic situation these factors can be generally categorised for individual household members as:

- Attitudinal
  - general environmentalist predisposition
  - nonenvironmental attitudes (i.e. attitudes based on attributes of products and systems being used or available for use)

  - perceived costs and benefits of actions
- Capabilities within the personal sphere
  - knowledge and skills
  - status within the household
  - financial resources
- Contextual
  - material costs and rewards
  - rules and regulations
  - available technology
  - social peer group norms and expectations
  - supportive policies and mass media messaging

As behavioural habits, once formed, are difficult to influence and change due to the wide range of factors involved it is difficult to implement intervention initiatives that tackle all of the factors simultaneously. Whilst raising awareness, through advertising campaigns, can target creating changes in attitudes the variation of socio-economic and technical, e.g. main heating fuel type, situations across households requires an approach that responds directly to the specific situations in individual households. The two separate intervention initiatives reported here were developed and implemented to provide such a targeted approach tailored for a number of individual households. The foundation of both these intervention initiatives was the provision of feedback on the energy impact of behavioural actions, where the feedback was tailored to identify, drive and support changes in site specific energy use behaviour. The foundation element of both was the provision of responsive, site specific feedback.

Feedback characteristics
The main characteristics of feedback techniques [3] include:

- frequency
- duration
- content
- breakdown
- comparison
- additional information
- other instruments
- medium of presentation

Studies over the past 20 years consistently show that increased frequency of feedback is key to its effectiveness in driving user learning and motivating behavioural change. However, there are limitations to how frequent particular types of feedback can be provided. At one end of the frequency scale, feedback of instantaneous consumption, i.e. kWh at minute intervals, can be constant but this type of information can be difficult to understand and interpret for most non-expert users. At the other end of the scale, monthly or quarterly billing, e.g. kWh totals per month or per three months, can be useful but on its own will be too little detail to enable a householder to link any specific part of behaviour, e.g. use of a washing machine, with a level of consumption. Due to these issues the feedback used in the interventions was daily and monthly where the impacts of changes in use were extrapolated to equivalent annual values to illustrate and quantify annual savings.

The most common contents of feedback are costs, e.g. €, and energy, e.g. W or kWh's, with potential for also including environmental metrics such as tonnesCO_2. However, whilst costs and energy are understandable to most users the added value of environmental metrics is not yet well established. In the interventions cost, energy and CO2 emissions were provided. The CO_2 emissions were further supported by providing equivalent less abstract concepts of the amounts, for example the equivalent amount of coal and the number of garbage bins needed to contain the volume of the emissions. These proved to help raise householders understanding of the scale of impacts of their actions.

Feedback can be aggregated or broken down into smaller parts that represent individual or smaller groups of energy end-uses. Where aggregated values cannot reflect the smaller individual changes in behaviour, smaller end-uses require sub-metering and more extensive monitoring to provide directly associated feedback. Research indicates that feedback broken down to end-uses is most effective in supporting behavioural change [3]. In the Irish interventions feedback was broken down into the five main energy end-uses below. This enabled focus on types of energy and fuels to allow for effort to be prioritised to end-uses that consumed the most, see Figure 2 below for the typical composition of energy end-uses in Irish households.

Six main energy end-uses:

- space heating
- domestic hot water
- small power appliances and equipment
- lighting
- cooking

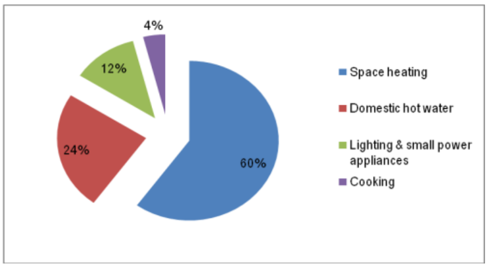


Figure 2 Typical composition of annual energy end-uses in Irish households

Many comparison approaches to date have been either comparison to historical patterns or comparison to similar generic benchmarks. Where the former has potential to indicate consumption changes due to changes in behaviour, amongst other factors, the latter can provide a compelling basis to investigate an individual's energy-use. However, neither have been found to consistently drive energy use reductions. As the aim of most comparison techniques is to compare consumption to some norm, finding one that is most relevant to an individual household situation has potential in being a key element of driving behavioural change. In the interventions reported here, consumption after changes in behaviour was compared to that before any changes were made. To provide this before and after framework each household was monitored for two weeks, before interventions started, to establish baseline energy consumption and temperatures.

Feedback that is accompanied by other information, i.e. tips on how to reduce energy consumption such as turning thermostats down 1°C will save 10% of heating fuel, does not always increase the effectiveness of feedback. In the current age of wide spread messaging and advice on energy behaviour available in the public sphere, additional information given in a tailored intervention can potentially confuse individuals resulting in lower engagement with the tailored feedback. However, although research is inconclusive on the added value of additional information [3], behavioural theory does point towards benefits when additional information is tailored to the specific behaviour of individual users. In the interventions here, additional information was only provided when requested by householders and each time was accompanied with extensive 'question & answer' driven explanations of how these relate to the particular technical and usage patterns of the individual householders. The key approach taken was to explore the underlying factors that created individuals behaviour and providing them with feedback on actual savings once they had made a change.

Following behavioural theory, the use of other instruments, e.g. targets; financial rewards; etc., in combination with feedback should increase the effectiveness of feedback. Although this has historically only been shown in laboratory based studies [4] the context of mass media exposure and use of targets in the two intervention initiatives reported here does indicate their viable effectiveness.

The medium of presentation used to give feedback to users, directly influences their level of engagement and determines the scope in frequency, duration, content, etc. Feedback through computers creates a platform on which to provide a wide range of content and functionality that gives the user greater choice and control over the information they view. Whereas, billing based feedback has a much more limited capacity. The medium utilised in these intervention initiatives were the use of energy experts accompanied by graphical charts of consumption changes and data. This combination of expert interpretation reduced the amount of cognitive processing and technical knowledge needed by the householders. Other studies have shown that combinations of text, graphs and charts can be more useful than using a single type of presentation whilst sensory based techniques such as the use of colours and sounds are the foundation of emerging persuasive technologies [5].

Tailored intervention initiatives

Although the two intervention initiatives reported here were based on the same methodological techniques of whole house lumped parameter modelling of energy demand, energy data logging, appliance audits and extensive face-to-face 'question & answer' sessions to tailor feedback they differed in the characteristics listed in Table 1 below.

Intervention characteristic	Intervention A: Power of One Street	Intervention B: RTE series
Duration of intervention	6 months	4 weeks
Number of participant households	12	2
Framing of energy use	By end-use, i.e. heating, hot water, small power, lighting and cooking	By fuel type, i.e. electricity and non-electrical energy
Targets used	No specific targets used, participants encouraged to find out how far	Minimum targets used which would determine pass or fail.

	they can reduce by themselves driving self-directed learning.	Targets differed for each household as they were tailored to house design, construction, heating system and audit of appliances.
Frequency of feedback	Monthly	Every 2 days
Incentives	Media exposure of participants experience and successes plus implicit competition between households.	To pass the target and media exposure. Surprise rewards were given at the end of the overall programme.

Table 1 Key differences between intervention initiatives

These differences were driven primarily by the communication medium for which they were designed. Intervention A was designed to live online and in the mass media by generating real-life narratives of the relatively long time-span process of experiential learning of participants and harness this to engage the various interests of the public. Intervention B was designed to focus on the relatively fast process of householders identifying quickly what energy consuming behaviours they can do without and taking action and harness their trials and errors in this process to engage the prime time television watching public through pseudo-entertainment format.

Both interventions were highly successful in terms of public viewing, e.g. Intervention B recorded between 21% and 29% of viewers across the six evenings it was transmitted, and motivating the creation of similar styled initiatives within local social networks but the impact on national levels of energy efficiency is not clear [6]. This is partially because methods to evaluate the impact of behaviour intervention initiatives at the national scale are currently not well developed and as such have only recently become a development priority for national stakeholders internationally.

Intervention A: Power of One Street

This intervention initiative involved six energy challenges focussing on each of the five main domestic energy end-uses with a final challenge that covered all energy end-uses simultaneously. The aim of each challenge was to reduce energy consumption in a particular end-use by as much as possible over a one month period. Reductions had to come from changes in behaviour and usage patterns and participants were encouraged to ensure they maintained acceptable levels of thermal comfort and appliance amenity, these factors were monitored. The energy challenges ran in two groups of households, the first group started in the middle of winter, January 2007 and the second group in the middle of winter, February 2008.

Each household was surveyed physically to build an energy model using the standard Home Energy Rating tool which was combined with a full audit of all appliances and an initial interview with individuals to determine house specific usage patterns. This information was synthesised with energy monitoring taken over a two week period prior to the start of the energy challenges. Adjustments were made to the models where there were significant differences in characteristics between the standard options available in the modelling tool and the reality found on site such as living room temperatures; any special light fittings (e.g. external driveway floodlighting); and any use of non-metered fuel use (e.g. logs in an open fire). Using this data and information, specific tips where energy use could be reduced by changes in behaviour were defined for each household individually. These were included in a logbook prepared for each household.

The logbooks also included a diary of electricity and fuel readings and a record of any notable changes, such as going on holiday or having guests staying, to be completed by participants every two or three days. Although an energy coach was in regular weekly contact with each household throughout the energy challenges, there was a poor response by participants in keeping regular diary records. However, energy and fuel was monitored using electricity data loggers and temperature sensors to help overcome any gaps not recorded by the participants. A key point was that the main heating fuels were not monitored separately by data loggers and it was therefore not possible to investigate the dynamics of heating energy use where participants did not keep a regular record. This mean's that in over 50% of the participant households feedback on heating fuel use could only be based on monthly fuel readings elaborated by heating systems timer settings and temperature data recorded at 10 minute intervals.

Although energy monitoring did not have a full resolution the synthesis of the available data, interviews and modelling enabled identification of significant behavioural patterns that could be changed to reduce consumption without causing hardship. For example, if rooms temperatures were found to be very high due to either heating system thermostat settings or prolonged periods of default heating system timed on periods these were targeted in the feedback. Figure 3 below shows the temperature reductions and thereby indicates the heating energy consumption reduced by one of the households. The 'baseline' graph is living room temperature before any of the energy challenges started and the 'challenge 1' graph is living room temperature after the thermostat setting has been reduced and heating switch on time was reset to be one hour later and the switch off time reset to be one hour earlier.

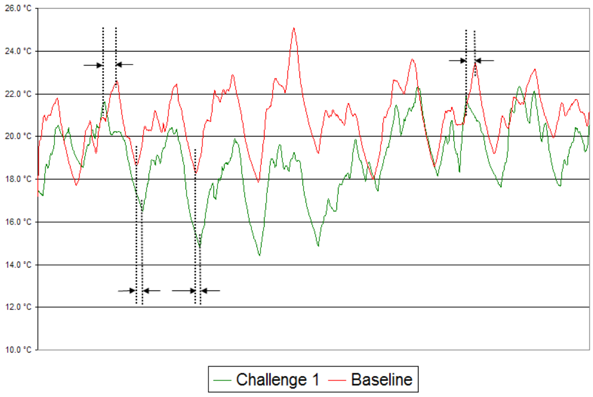


Figure 3 Sample living room temperature 'before and after' changes made in energy challenge

The overall amount of energy reductions achieved varied across the households, see Table 2 below. This was partly due to both technical factors, i.e. context, and individual household levels of engagement with the initiative, i.e. attitudinal. It was found that regular contact between the intervention organisers and participants is key to sustaining engagement and participation over a period of six months. However, as the intervention had a structure where focus on energy end-use changed on a monthly cycle the need for participants to re-engage with the initiative to learn about a new set of energy uses on a monthly basis was an effective driver in maintaining a minimum level of activity and learning.

Household	Annual saving (€/year)	Total CO_2 reduction (tonnes CO_2/year)	Total energy reduction (%/year)
1	793	3.2	21.2
2	282	1.3	18.8
3	832	3.6	17.6
4	394	1.9	25.2
5	389	1.9	21.4
6	763	3.68	18.8
7	352	1.82	20.2
8	424	1.9	20.5
9	543	3.92	22.4
10	493	2.67	16.2
11	328	1.78	14.4
12	920	3.24	26.7

Table 2 Equivalent annual energy reductions achieved over all six energy challenges

Intervention B: RTE television series

This intervention initiative involved two energy challenges framed on the two main different types of energy, i.e. electricity and non-electrical energy. The aim of each challenge was to reduce energy consumption by a pre-defined minimum target reduction within a one week period.

Reductions had to come from changes in behaviour and usage patterns and both households were monitored daily to ensure they maintained acceptable levels of thermal comfort, used appliances typically needed in daily life (e.g. washing machine, television, etc.) and maintained acceptable use of lighting. The energy challenges ran in consecutive weeks in winter, November. Each household was surveyed physically to build an energy model using the standard Home Energy Rating tool which was combined with a full audit of all appliances and in-depth interviews with individuals to determine both their awareness of energy consumption and their specific usage patterns. This information was synthesised with energy monitoring taken over a two week period prior to the start of the energy challenges. Each energy end-use and electrical sub-circuits were monitored separately and delivered to a bespoke online data management tool.

Adjustments were made to the models where there were significant differences in characteristics between the standard options available in the modelling tool and the reality found on site such as living room temperatures; any special light fittings (e.g. external driveway floodlighting); use of non-metered fuel (e.g. logs in an open fire) and special appliances including hot-tub and swimming pool plant. Using this data and information, specific targets were set that were achievable but would require major changes in behaviour, see Table 3 below.

Energy Challenge	Household 1	Household 2
Electricity	60%	70%
Non-electric energy	25%	40%

Table 3 Energy reduction targets

The differences in the targets are due to significant differences between the households in terms of technical characteristics, amount and type of appliances and usage patterns. For example, Household 1 preferred to maintain lower room temperatures compared to Household 2 although the house was better insulated. This was evidenced through the temperature monitoring in a baseline period two weeks before the start of the challenges. The impact of this was that Household 1 had less scope, than Household 2, for reducing heating system energy consumption and therefore the reduction target for the 'Non-electric energy challenge' was lower. Similarly, Household 2 had many more electrical appliances and devices, e.g. multiple televisions; multiple clothes dryers and electronic games machines, than Household 1 therefore there was more scope to reduce their electricity consumption and the reduction target was higher than Household 1.

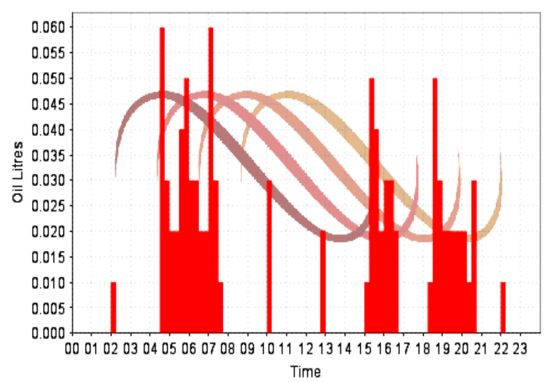
Each challenge had a mid-point review after three days where an energy coach gave them an update on the equivalent annual reductions they had made due to any changes in behaviour. This required the development of a rigorous analysis of energy consumption quantities and patterns in terms of how this short term period of three days related to annual consumption. This was acheived by development of an adapted degree day equation combined with annual run-hour estimations of all appliances. The adapted degree day equation enabled adjustment due to outdoor ambient temperature; a proxy value for solar gain variation between the short three day period and annual average and a proxy value for internal heat gain from people and electrical equipment (e.g. lights; refrigerator; etc.). This enabled extrapolation of the actual monitored energy consumption to an equivalent annual value. The difference between this amount and that from the whole house energy model built from the baseline data and information was the energy reduction amount achieved and could be compared directly to the reduction target. The reductions achieved are shown in Table 4 below.

Energy Challenge	Household 1	Household 2
Electricity	64%	72%
Non-electric energy	30%	44%

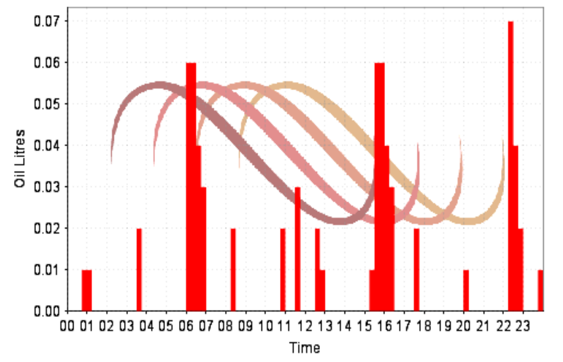
Table 4 Equivalent annual energy reductions achieved in energy challenges

These reductions were achieved in different ways, following are some examples. The examples are provided as descriptions of specific behavioural changes made by individual households associated with the consumption changes illustrated by paired daily consumption profile charts as recorded by the energy data monitoring system before and after the energy challenges. It should be noted that equivalent annual reductions are not a simple division of consumption after and before. Quantification of equivalent annual reductions required the use of daily totals in the adapted degree day calculation described above. This was required to ensure climate correction in terms of both external temperature and a proxy representing a qualification of differences in available solar radiation due to the extent of clear skies. As this lumped parameter calculation technique had limited resolution of solar radiation and that the before and after periods occurred within one month of each other there was no adjustment included due to account for changes in solar geometry.

Household 1 reduced their non-electrical energy consumption beyond the target. This included reducing the boiler thermostat from 80°C to 70°C. As indicated by the paired daily consumption profile in Figure 7 below, the timed periods of operation were also changed. It was noted from the temperature data that room temperatures fell to average 16°C to 18°C in the main living areas. This was on the edge of being impractical.



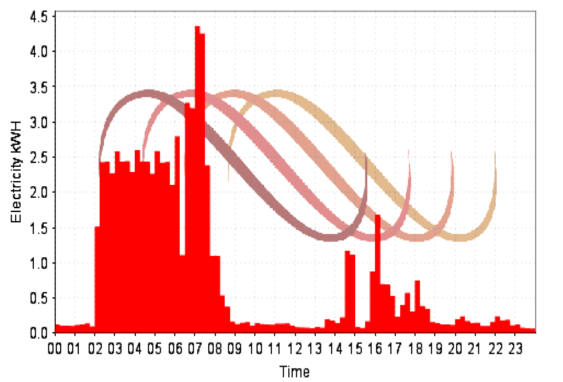
Before Non-electric Energy Challenge



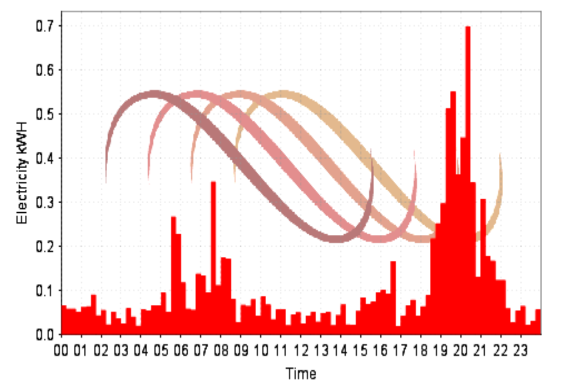
After Non-electric Energy Challenge

Figure 7 Household 1: Paired before-after daily oil consumption profile

Household 1 also reduced their electrical energy consumption beyond the target. The main element of this was the turning off of electric storage heaters in the kitchen/dining room and entrance hall. The 'Before' chart, see Figure 8 below, shows the high electricity consumption from 02:00 to 06:00 of these electric storage heaters, whereas the 'After' chart shows this is no longer consuming electricity once they had been turned off in response to the challenge. The scale of consumption, i.e. y-axis, shows the extent to which electricity consumption has been reduced post challenge.



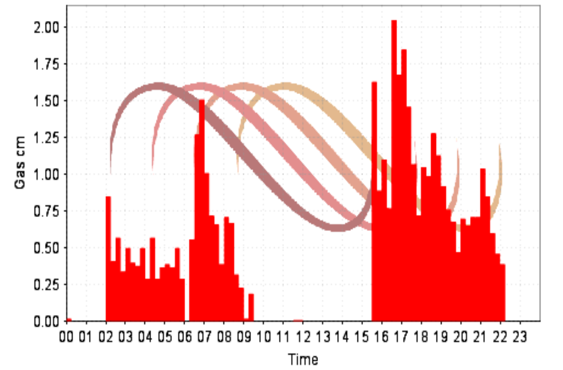
Before Electric Energy Challenge



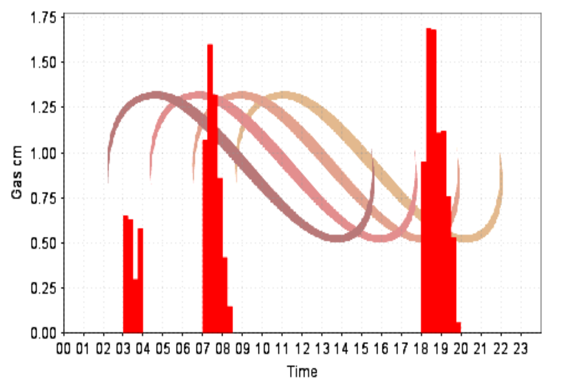
After Electric Energy Challenge

Figure 8 Household 1: Paired before-after daily mains electricity consumption profile

Household 2 achieved large reductions in their gas consumption for heating and cooking as shown by the before and after charts in Figure 9 below. The charts show that this was achieved by large reductions in the timed periods of the heating system being on. Before the challenge the gas fired heating system was on from 02:00 to 06:00; 06:30 to 09:00 and 15:30 to 22:30 every day, whereas after the challenge this was reduced to 03:00 to 04:00; 07:00 to 08:30 and 18:00 to 20:00. Temperature data showed that some room temperatures fell to 16°C to 18°C but significantly these were in rooms that were not in use very often and therefore did not affect indiviuals thermal comfort.



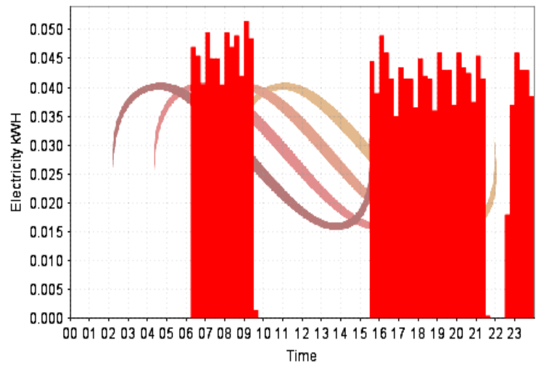
Before Non-electric Energy Challenge



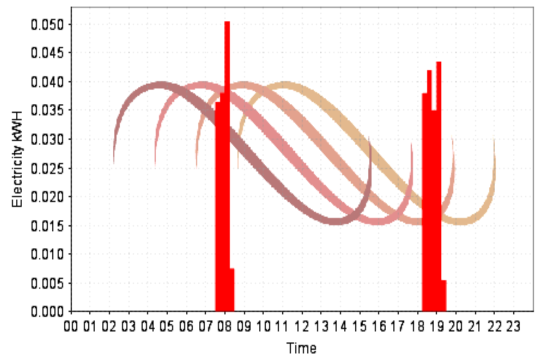
After Non-electric Energy Challenge

Figure 9 Household 2: Paired before-after daily gas consumption profile

Household 2 also achieved significant reductions in their electricity consumption by making small changes across all their electrical end-uses. This included changing how they controlled the hot water circulating pump that maintained hot water for showers, baths and sinks. Before the challenge the hot water pump was operating from 06:30 to 09:30 and 15:30 throughout the end of the day, every day. This pump circulated water from the gas boiler to a hot water cylinder. However, as hot water was not needed for most of this time and that the hot water cylinder was highly insulated they changed the timer settings on the pump to make some energy savings. This change in timer settings and resultant energy savings can be seen by the paired charts in Figure 10 below.



Before Non-electric Energy Challenge



After Non-electric Energy Challenge

Figure 10 Household 2: Paired before-after daily hot water circulating pump consumption profile

Conclusion

There was a high level of engagement by all participants with the energy challenges in the intervention initiatives described here. The experiences of participants, their successes, errors and struggles to make changes all provided compelling story lines for the mass media and were well reported indicating the level of public interest they generated. However, the type of feedback used to drive participants to see where they could make changes and the resultant impact of these individual changes required significant computation and synthesis of both measurable technical characteristics and assessment of the types of qualitative characteristics which drive behaviour including:

- attitudinal
- capabilities within the personal sphere
- contextual

Feedback was found to be effective in increasing the rate of learning and changes taken. Whilst national scale intervention programmes can only expect to achieve raising levels of awareness the success of tailored feedback in the interventions reported here, show an obvious value in developing intuitive intelligent feedback technologies to drive and support behavioural change for greater energy efficiency.

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