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ENERGY BEHAVIOUR CHANGE BY COLOURED IN-HOME DISPLAY

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Abstract *It is estimated that by 2020 some 53 million, next-generation gas and electricity meters, commonly known as 'smart meters', will be installed in approximately 30 million homes and small businesses across the UK. A significant feature of the smart meter device will be the In-Home Display (IHD), promoted by the UK Department of Energy and Climate Change (DECC) as a means to help customers use energy more efficiently; aiming to improve the accuracy of household utility expenditure.*

As a precursor to the mass rollout scheme, this paper evaluates the effectiveness of an IHD device by monitoring potential changes in gas and electricity consumption behaviour within a residential context. The study involved monitoring 12 houses and 18 flats that had access to a coloured, real-time, smart IHD. The results were compared against a control group of 9 houses and 13 flats that did not have an IHD.

The paper reports on the initial six months of recorded energy data from a three year research project that investigated the impact of the IHD on energy-related behavioural change. In doing so, the study also involved understanding the occupants' perception of existing billing information, identifying changes to their energy use behaviour since the installation of the device and collecting occupant feedback on the usability and features contained within the IHD. The paper concludes by presenting evidence that demonstrates the IHD had a positive impact on energy consumption behaviour leading to an average reduction in gas consumption of 17% (houses) and 23% (flats), and an average electricity reduction of 10% (houses) and 2% (flats).

1. INTRODUCTION

Improvements and advancements in home energy efficiency (including more energy-efficient appliances) will go some way towards meeting the low carbon targets for new homes. However, action is still required to encourage occupants in the residential sector to modify their energy consumption patterns by means of behavioural change.

Since the 1970s, researchers have studied how feedback on electricity consumption impacts upon consumers understanding and subsequent behaviour. Indeed, studies involving informative billing and periodic feedback have produced energy savings of between 10% and 20% [1][2]. The key presumption used to explain such results is that in providing consumers with more detailed and/or frequent information about their consumption, they would have a greater understanding of their energy use patterns and subsequently be able to modify them more effectively [3][4][5][6][7].

In-Home Displays (IHDs) are intermediary devices that can collect, display and/or communicate household energy consumption, either by individual parameter (gas, electricity, water) or collectively. Within the context of behavioural change, IHDs (also known as energy monitors) can be integral in reducing domestic energy demand and lowering household carbon dioxide emissions by means of providing real-time feedback to the occupants.

This paper presents and discusses the key findings from a research project that examined the effect of behavioural change on energy consumption. This pre-normative project was one of the first studies to record energy consumption, energy use behaviours and the users' opinions of a coloured IHD displaying both electricity and gas consumption. The research was conducted at the onset of the smart meter roll-out scheme and the results were used to inform Scottish governmental policy on IHDs in new homes.

The paper evaluate the users' opinions of existing energy feedback mechanisms (energy bills) as well as the new IHD technology. In doing so, it was possible to identify the behavioural changes associated with variances in their energy consumption levels. The study involved providing a sample group (n=30) with access to a real-time, coloured, dual-fuel IHD. The consumption of gas and electricity within the intervention group was compared to that of a control sample that did not have access to such a device (n=22). The data for this paper was collected during the first 6 months of a 37 month research project which started in the autumn of 2010.

2. METHODS

The same member of the research team conducted a semi-structured interview in the participants home (those with access to the IHD). Each interview lasted between 15 and 60 minutes. In households with more than one adult, the semi-structured interviews were conducted with both adults present, with closed-ended questions answered after some deliberation between the two adults. The gender, age, income and employment information was collected based upon the profile of the person responsible for paying the energy bill. In the higher occupancy households, the dependent(s), often of late primary school or early secondary school age, were also present and participated in the interview.

The first of these interviews was conducted at the beginning of the study (September 2010). The participants were asked to comment on their current understanding of their energy bill as well as providing information on their energy consumption habits and routines. One month after the IHD was activated, the participants with the IHD were asked about their initial experience of interacting with the device. The last of the semi-structured interviews was conducted 6 months later at the end of this trial period. In this final interview, those with the IHD where asked to comment on their overall experience of the device, focusing on two main topics: 1. whether they continued to interact with the IHD, (how and why) and; 2. what specific features of the IHD were used (or not used).

2.1. The sample

A total of 52 newly built dwellings took part in the study, all of which were constructed in 2010. 31 of the sample were single level flats (apartments), whilst 21 were 2 storey houses. All participants agreed to provide energy consumption data and participate in the interviews. The dwellings in the sample contained either one (27%), two (65%) or three (8%) bedrooms. The average floor area of the flats was $64m^2$ and $84m^2$ for the houses.

58% of the lead respondents were female, and 42% were male. The occupants in the 2-adult household group were in heterosexual relationships (important to note when interpreting the results by gender). Of those households with 2 adults (24%), 63% identified the female occupant as being responsible for energy and payment of the energy bill. The number of occupants in each property ranged from 1 to 4: 1 (31%); 2 (40%); 3 (17%); 4 (12%). The flats had an average of 1.7 occupants whilst the houses had an average of 2.7 occupants; this difference was statistically significant ($p<.05$). The age of respondents ranged from 18 - 68 years (mean=39 years; SD=13.9 years). The average age of those living in the flats was 43 years old, whilst those living in the houses was 36 years old; this difference was not statistically significant ($p>.05$). 48% of all the participants had between 1 and 3 children (under the age of 16) resident in their home.

Only 28 of the 52 respondents provided information about their annual household income. From those that did respond, 79% earned less than £20,000 p.a., and 4% earned over £45,000 p.a. The mean annual household income for this group was £15,087 p.a. (SD=£8,347). At the time of the study, the UK national median disposable income was £23,200 p.a. The average disposable income for those living in the flats was £14,120 p.a. and £16,830 p.a. for those in the house group. This difference was not found to be statistically significant ($p>.05$).

The respondents' occupations were also varied. The largest single categories were: unemployed (31%); medically retired or disabled (21%); retired (12%); caring, leisure and other service occupations (14%); professional (4%); administrative and secretarial (6%) and other (12%). The employment categories used were taken from the 'major groups' as detailed by the Standard Occupational Classification 2010 [8]. 52% of those in houses were either temporarily or permanently unemployed. 87% of those living in the flats were employed, this difference was not statistically significant ($p=.07$).

2.2. Technology: The In-Home Display

The Ewgeco IHD (see Figure 1) was the only intervention mechanism used in this study. The IHD was installed in the hallway of the flatted accommodation. The houses were designed without a ground floor hall, so the IHD was installed in the living room. In both instances the installers were asked to locate the IHD in a prominent position between 1.2m and 1.4m above the finished floor level (i.e above a light switch, near the system thermostat or beside the front door). The IHD interface displayed the energy consumption levels at a refresh rate of 2 seconds.

The energy consumption data was collected by the logger installed beside the meters. At the time of the research, the Ewgeco IHD (manufactured by Tayeco Ltd) was the best example of a device that was capable of visually representing energy consumptions to users. The coloured, dual-fuel IHD was one of the first to combine a RAG (red-amber-green) coloured, traffic-light display to denote levels of high, medium and low consumption. In addition, the IHD possessed all the functionality of the basic monochrome and numerical electricity IHDs used by previous authors.

An important feature of the IHD was that it simultaneously displayed electricity and gas (space and water heating) consumption information on one screen. This was achieved without the requirement of a smart gas or electricity meter, nor did it require the user to toggle between screens. Such features were not observed in previous IHD trials.

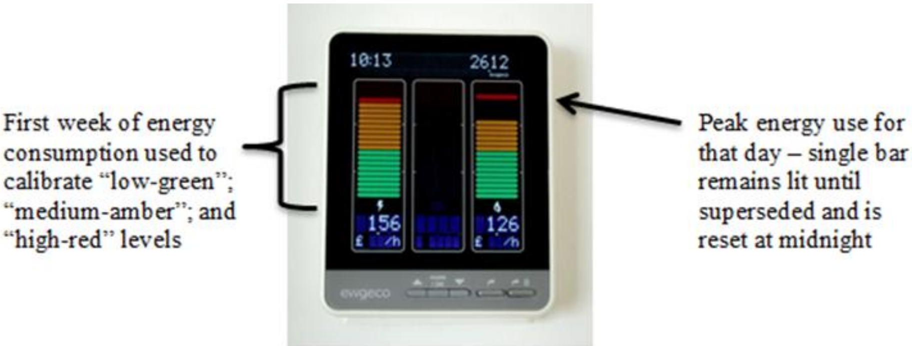

Figure 1. Ewgeco In-Home Display (IHD)

3. INDIRECT FEEDBACK MECHANISMS

The interview results found widespread concerns about the cost of household energy. A significant proportion of the sample were on relatively low incomes and therefore energy bills represented a significant financial burden on household expenditure. 53% of respondents agreed, or strongly agreed, that they were paying too much for the energy they used. A slight trend was detected where, on average, a higher proportion of the younger respondents (those under 29 years old) agreed that they were paying too much for their energy bill compared to the older group (60 to 74). This correlation was tested to be statistically significant ($R = -0.3$) ($p<.05$). When asked what constituted a ‘fair price’ for energy, many respondents used their neighbours’ utility bills as a benchmark, whilst others rationalised the cost of energy bills against other household bills such as communication bills (telephone and internet) and grocery bills.

In the first series of interviews, 60% of the respondents indicated that they did not understand their energy bills and commented that the wording and format of the bills was confusing and difficult to interpret. The responses were tested for differences based on gender, age, employment status, property type and disposable income of the respondents. The differences were not found to be statistically significant ($p>.05$).

51% of those within the sample were paying their energy bill by standing order (direct debit). Most had chosen this type of payment method out of convenience and in response to receiving a financial incentive from the energy company for choosing this method.

A common theme from this group was a sense that they felt detached from their bills. 65% of the interviewees said they did not know (or were not entirely sure) what they paid for their energy (i.e. the tariff used to calculate the cost of their energy consumption). Despite this, most participants (77%) indicated that it was important for them to understand their energy bill, whilst only 15% felt that this issue was unimportant. A large majority of the respondents (77%) said that they liked to know how much energy they used; an even higher proportion (89%) said they liked to know how much money they spent on energy. 33% said they didn't think 'too much' about the energy they used. 82% of the respondents said they tried to reduce their energy consumption because they believed it would save them money. 51% respondents said they tried to reduce their energy consumption because it was good for the environment. Differences in responses based on age, gender, employment status and income were found not to be statistically significant ($p>.05$).

4. USER EXPERIENCE OF THE IHD

Those with the IHD (n=30) were asked to describe and rate their experience of using the device. The results showed that 87% of the respondents had interacted with the coloured dual-fuel IHD over the course of the study period. In addition, 84% said that they viewed the display either several times a week or more than once a day. Only 9% of respondents' stated that they were not interested in using the IHD. The interviews provided the following critical insights:

- Participants who reported that they did not use the coloured dual-fuel IHD device were more likely to state that that they did not think too much about the energy they consumed ($t=2.12$, $df=28$, $p<.05$).
- Between the second and third interviews, the occupants interacted less often with the IHD ($z=-4.57$, $p=.001$, $r=-.58$). Given the reduction in electricity and gas consumption by those in the intervention group with the IHD (See Section 5) this finding may be attributed to energy consumption behavioural change having already occurred during the period of the study.
- Most of the occupants (81%) reported finding the IHD easy to use in the first interview (2010). This figure was slightly increased in the follow-up interview (83%). Interviewees also commented that their attitudes towards the IHD had changed over the course of the

trial. For the majority of the IHD users, the visual features of the monitor stood out as its most engaging component with the main screen communicating the real-time energy consumption levels. This feature was sufficient to prevent a number of the households from interacting any further features contained within the device.

- A small number of households with the IHD requested a tutorial on how to use the device. This was despite having previously received a user manual and instructional DVD. To these users, the IHD was not sufficiently intuitive enough to be easily understood or operated.

4.1. Household experience of the IHD

Several interviewees commented on the IHDs ability to communicate with younger members of the family. The vivid coloured bars which formed the ‘traffic light’ graphic were easily understood by the children from their experience of common situations where the colour red has a ‘warning’ connotation.

However, two conflicting comments were made by the occupants of 3 and 4 person dwellings that were supplied with the IHD. These families all had children, aged between late primary school and early secondary school. Some of these participants commented that the children became a catalyst for the household to engage with the IHD and that the parents were motivated to use the monitor to teach their children about energy conservation and reinforce what they had learnt at school about energy accountancy. Conversely, other families with young children stated that other roles and responsibilities in their family life had left them with less time to devote to monitoring their energy usage and act upon the information provided by the IHD.

Other, similarly conflictive behaviour was also noted over the course of the interviews. Among families, it was often noted that one partner might exhibit energy saving behaviour, whilst the other partner often saw less value in engaging with the IHD or pursuing energy saving routines. In these instances, a few interviewees described situations where engaging with the IHD had been the source of disagreements. However, the propensity for occupants to hold varying opinions and exhibit energy-efficient behaviour did not correlate to gender.

In acknowledging the often complex household dynamics that emerge from contrasting social norms and lifestyle patterns, the effectiveness of the IHD can be somewhat limited in regard to its effectiveness within a family unit, or indeed a home with multiple occupants.

4.2. User preference of IHD components

In the second round of interviews, 90% of respondents agreed or strongly agreed that the coloured RAG display was a very useful means of communicating energy consumption. The results from the third round of interviews found that 90% of respondents had maintained this preference for using the non-numerical graphic to view their energy consumption.

The participants were asked how they associated the coloured information from the IHD with the monetary value expressed by the display, as displayed in pounds (£) and/or pounds (£) per day. 63% of the participants agreed or strongly agreed that seeing their consumption in monetary value was very useful. This figure dropped slightly to 60% during the third round of interviews held in 2011.

Many of the participants who used the IHD described how they began to better understand the costs associated with running household electricity appliances, the central heating and hot water. Additionally, many of the respondents suggested that it would be beneficial to view the individual energy consumption of all household appliances.

Overall, less than half the respondents (39%) said that they had used most of the IHD functions during the second round of interviews, whilst even fewer (17%) having done so by the time of the third round of interviews at the end of the six month trial. Those that did explore the IHD found the following functions useful or very useful: the audible alarm (4% in 2010 and 4% in 2011), viewing historical energy consumption (14% in 2010 and 7% in 2011), and viewing carbon dioxide emissions (10% in 2010 and 0% in 2011).

This lack of engagement with the additional functions of the IHD and the downward trend in how the occupants rated its usefulness, may be due to a well-documented interaction with new devices where, over prolonged periods of time, the occupants will focus on only specific functions that they find easy to use or which they find most useful. In the case of the IHD device, this scenario is likely due to the fact that the additional functions were only accessible by pressing buttons in combination, which were described as difficult to understand and was perceived as complicating the device. Furthermore, when further enquiry was made about the users' lack of engagement or willingness to engage more fully with the IHD many elaborated by stating that they were not confident in doing so and/or did not possess the required level of knowledge to properly operate the IHD.

5. ENERGY REDUCTION WITH IHD

The results from the third round of interviews showed that most respondents stated that the IHD had made them more aware of how much energy they were using (77%) and of how much money they were spending on energy (77%). 68% of participants felt that the coloured, dual-fuel IHD had made them reduce the amount of energy they consumed, whilst only 7% reported that the device had not changed the way they used energy. A Likert scale (using a scale of 1 to 5) was used to measure the respondents' energy efficiency behaviour score (EEBS). The EEBS was developed as a bespoke methodology for the purpose of evaluating energy-related behaviour change [9]. It is a measure of how often people undertake common and well-documented activities to reduce their energy consumption, (i.e. lowering the temperature by adjusting heating controls and switching of lights when leaving an empty room, etc.).

5.1. Gas Consumption

The results from the third (final) round of interviews found that neither the intervention group (those with the IHD) nor those in the control group, felt that they had consumed excessive amounts of gas over the winter period. However, a larger proportion of the intervention group stated that during this period they had started using the various heating controls around the home more frequently in order to control the heating. In contrast, a significant majority of the participants in the control group stated that they had not changed their behaviour during the same period.

On average, the results from the third round of interviews found that those in the intervention group had a higher mean energy efficiency behaviour score (EEBS) for increasing the frequency with which they undertook energy saving activities relating to gas usage (M= 3.50, SE=0.07) compared with those in the control group (M=3.22, SE=0.08). This difference was found to be statistically significant (t(47)=-2.43, p<.05) and represented a medium-sized effect (r=0.34). For this numerical analysis, a mean score closer to 5 would represent that the group increased undertaking energy saving activities ‘much more’. A mean score closer to 1 means the group carried out the energy saving activities ‘much less’ than in 2010.

Once normalised using the modelled energy requirement figures [7], the initial 6 month monitoring period across the 52 properties in the trial found that the houses with the IHD consumed 17% less gas whilst the flats with an IHD consumed 23% less gas than the respective control groups (the figures were normalised in both instances). These reductions were found to be statistically significant (*p*<.05) and was observed for both dwelling types (flats and houses). In addition, the results revealed that properties with 2 occupants (both flats and houses) had on average achieved the largest reduction in energy consumption (23%) compared with other household sizes.

5.2. Electricity Consumption

During the third interview, those in the properties with the IHD had, on average, a higher EEBS for electricity consumption behaviour (M=3.46, SE=0.08), than the EEBS for the control properties (M=2.99, SE=0.08). This difference was found to be statistically significant (t(43.9)=-4.09, *p*<.05) and found to have a large effect (r=.50). Comparing the responses from the control group and intervention group revealed that both groups shared a similar level of confidence in maintaining low electricity consumption levels. Very few in the control group stated that their electricity saving behaviour had improved, with the majority commenting on their diligence in turning off appliances for fear of electrical fires and electrocution.

Many participants felt that they were already using the least amount of electricity necessary to maintain a reasonable quality of life. However, the IHD was identified as a device that could be used to encourage other members of the household to maintain low levels of electricity use.

The properties with multiple occupants considered the £/day feature of the IHD as an effective method of promoting energy saving behaviour for those in the home who were less conscious of using excessive and unnecessary amounts of electricity.

On average, during the initial 6 month monitoring period there was a 10% reduction in electricity consumption for the houses with the IHD and a 2% reduction in the flats with the IHD. These differences were not found to be statistically significant.

6. CONCLUSION

The interviews established that the participants were often unable to identify the cause and effect relationship between their energy use behaviour and their energy consumption. Indeed, prior to the installation of the IHD, the participants often found it difficult to distinguish which of their activities were most costly. The existing paper billing mechanism experienced by the sample did not appear to be sufficient in supporting a cognitive learning environment, nor was it conducive to promoting pro-conservational behaviour or the control of costs.

The introduction of the coloured, dual-fuel, IHD became an influential presence and valuable feedback mechanism and source for behavioural change. Those that interacted with the IHD were resistant to the device being removed at the end of the study as they felt that it was responsible for their reduced energy consumption. Similarly, many of the occupants felt it would be more challenging to retain their new-found awareness of energy consumption if the IHD were removed. Therefore, the IHD is clearly valued as an educational and learning tool and it influenced the sample in this trial to enhance their energy reduction behaviour. The use of the IHD in this study led to reductions in their energy consumption and improvements in their energy saving patterns.

The results from this research are from the 1st phase of a 2 phase research project, the results from the longer 37 month monitoring period will be published by the authors in due course.

The next step on the evolutionary track for this technology is to further develop the user interface. This will include incorporating game theory to enhance the user experience and provide a reward element (other than reduced energy bills) to promote a long-term relationship between the user and the technology. However, the opportunity for the IHD to be the centre of the so-called ‘smart-home’ has proven to be unattainable due to the incompatibility of domestic appliances to communicate synchronously to a metering device. However, one research path being explored by the authors is the development of the IHD into an emotional companion device.

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REFERENCES

[1] H. Wilhite and R. Ling, “Measured energy savings from a more informative energy bill,” *Energy Build.,* no. 22, pp. 145–155, 1995.

[2] B. Boardman and S. Darby, “Effective advice: Energy efficiency and the disadvantaged,” 2000.

[3] C. Boice, “Home energy display market test. Demand side plan technical appendix, Book 4 of 9.,” 2009.

[4] S. S. Van Dam, C. A. Bakker, and J. D. M. Van Hal, “Home energy monitors: impact over the medium-term,” *Build. Res. Inf.,* vol. 38, no. 5, pp. 458–469, 2010.

[5] K. Ehrhardt-Martinez, "ehrhardt martinez_2011 changing_habits_lifestyles_and_choices_the_behaviours_that_drive_feedback_induced _energy_savings_," 2011.

[6] T. Hargreaves, M. Nye, and J. Burgess, "Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term," *Energy Policy*, no. 52, pp. 126–134, 2013.

[7] J. Stinson, A. Willis, J. Bros-Williamson, J. Currie, and R. S. Smith, "Visualising energy use for smart homes and informed users," *Energy Procedia*, no. 78, pp. 579–584, 2015.

[8] ONS, "Standard Occupational Classification 2010, SOC2010," 2010.

[9] J. Stinson, "Smart energy monitoring technology to reduce domestic electricity and gas consumption through behaviour change," Edinburgh Napier University, 2015.