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Visualising energy use for smart homes and informed users

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Abstract

We evaluatethe changes to domestic electricity andgas consumptionwhentheoccupants havelocalaccess to a colouredreal time in-home display (IHD). We report the preliminary sixmonths findings of a three year researchproject involving 52 new build Scottishdwellings (flats andhouses). On average, whencomparedto households with no IHD(n=22) the households with the IHD (n=30) reduced their gas and electricity consumptionby 20% and 7% respectively. We foundthatthe IHDwas valued by the users for its ability to incite behaviour to reduce gas consumptionandreinforce existing electricity savingbehaviour.

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1. Introduction

Providing occupants with the means to view and comprehend their own energy consumption provides perhaps the greatest potentialto encourage households toreducetheir energyconsumption [1-3]. What is often disputed is the effectiveness of feedback to reduce domestic energyconsumption and maintain longtermbehaviour change. Some researchers report thatthespeedbywhich the user receives the energyuse feedbackis important [4-7], and others suggest that the user must be given this informationat as high a levelof specificity as possible [8]. Early researchin this field reportedthat'indirectenergyconsumption feedback', through clearer billing information, energy saving advice services and providing users with their monthly energy consumption, has the potentialto help users reduce their electricity and gas consumption by between 5% and 22% [3][9][14]. In general, the more the researchers interacted with the occupants to provide the indirect feedback, the higher the energy savings. This form of energy feedback shows considerable savings can be achieved, however, this method of energy feedback is considered intrusive and requires considerable amountoftime investmentby researchers andoccupants.

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More recently, the In-Home energymonitor and Display (IHD) has beenusedas a means to improve the speedand specificity of energy use feedback to users. Research involving IHD’s commonly use relatively simple devices, monitoring electricity consumption only, and displaying the data numerically or as a monochrome graph. Electricity savings are typically attributed to the IHD of 5% to 15% [2][9][10]. The research andresults relating to gas consumptionbehaviour change throughuse of IHD are limited. Research with gas consumption displaying IHD’s are more commonly conducted outside the UK, where ambient temperatures over different heating and cooling seasons tend to be very different.4% and 12% [9][11][12]. The UK’ Energy Demand Research Project (EDRP) [5] review showed that gas savings throughthe IHD’s were often limited to a connectionto a smart meter and savings were negligible. Many authors, including those in the EDRP, of past research using IHD’s to measure changes in energyuse behavior, concealed the name or designof the IHD.

This research used the UK’s first IHD to simultaneously monitor domes tic electricity and gas consumption and display consumption levels using a coloured traffic light graph that updates in at a rate of 2 seconds. The objective of this study was to explore the efficacy of a new IHD with a different formof visualengagement in newly constructed homes occupiedby people and families living in social housing. We examined self-reported behaviour and actual energy use in a sample of 52 households in Edinburgh and Fife, UK.

2. Methods

2.1. The sample

This paper reports on the first phase of a longitudinal study, conducted over sixmonths between September 2010 and March 2011 in Scotland, UK. 52 properties across two sites in the eastof Scotland were involved in the trial. The selectionof homes was made up of 31 (60%) flats in site A and 21 (40%) two-storey, semi-detached houses in site Blocated 56 kilometers apart. Theflats where occupied by 1 or 2 occupants and had an internal floor area of 58m² for smaller flats (n=16) and 73m² for the larger flats (n=15). The houses where occupied by 2 to 4 people the average internal floor area was 84m² (SD = 6.87m²). Only 28 of the 52 respondents provided information about their household’s annual income. Of these, 79% earned less than £20,000. The median annualhousehold income was £14,128 (SD = £8,347), the median annualhousehold income in the UK in 2011 was £23,200. 64% of occupants were retired, unemployedor medically unable to work. This definitionis referredto by the UK Departmentof Energy and Climate Change (DECC 2014a) as ‘most vulnerable’.

2.2. Materials: The In-Home Display

At the time of the research, the Ewgeco IHD, see in Fig 1, best representedthenext generationof visually representing energy consumptions to users. It was one of the first IHD’s to combine a tri-colour ‘traffic light’ display to denote levels of consumption with all the functionality of thebasic monochrome andnumerical energy monitors usedin previous trials. Importantly, the Ewgeco simultaneously displays electricity andgas consumptioninformationon one screen, withoutthe requirementof a smart gas meter, where previous IHDs displayed only one utility or requires the user to toggle between displaying the utility on the IHD. These levels are shown to theuser as green, amber andred bars, respectively. These are functions not observed in IHD’s usedin previous trials.

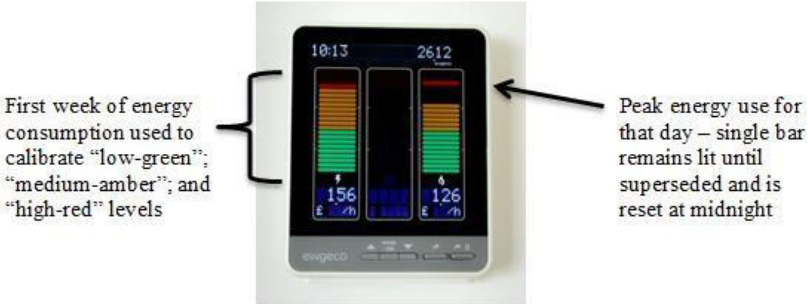

Fig 1. Ewgeco In-Home Display

2.3. Procedure

The Ewgeco IHD was installed into 30 (58%) homes (With IHD group), whilst 22 (42%) made up the comparison sample (Without IHD group). The IHD's were installed into all the properties after construction and before the occupants moved in. A series of independent t-testanalysingthebuilding andsample characteristics found nostatisticalsignificant difference betweenthe dwellings with and without the Ewgeco IHD[p>0.05].

Before occupancy the new occupants had an opportunity to opt-in to the research allowing the research team to contact the occupants, after occupancythe occupants had the opportunityto opt-out of the research andprovidesignedinformed consent. The IHD was installed as part of the Housing Associations buildingspecifications, the occupants were not askedto which group they wanted to be part of. The IHD was the only intervention used on the With IHD group. The Without IHD groups were given no energy feedbackof any kind fromthe researchteam. The research receivedethicalapprovalfromthe University.

The research teamvisited each participanttwice, once in September at the beginning of the project after the occupants moved in and again at the endof February, marking the endof this initialphase of monitoring. During eachvisit the energyloggers were downloadedandthe meter readings taken, duringeachvisit the occupants alsoparticipatedin a guided-interview.

During the two visits, theoccupants were asked to state on a Likert scale how often theyconducted 12 different energy saving activities relating to both electricity (n=7) and gas (n=5). The first questionnaire with the aim of creating a behaviour baseline asked participants to score themselves from1 to 4 howoften they conducted theenergy saving activity where 1 represents never and 4 represents always. During the second questionnaire occupants were asked to comment if they increased or decreased the frequency of conducting the same set of energy saving activities, where 1 represents 'much less' and 5 represents 'much more'. The responses were averagedand formed the Energy Efficiency Behaviour Scores (EEBS) for each occupant; the EEBS were then calculated for each group. Independent t-tests analysing the first EEBS before use of the IHD found no statistically significant difference between the occupants with or withoutaccess to the IHD.

The raw energy consumption data (kWh) for the groups were normalised using common building normalization factors. The coefficient of variation(CV) for each normalised dataset showedthatnormalising the actualgas consumptionbythe predictedgas demand for each dwelling provided the best statistical fit for this sample. Using the same analysis technique showed that by not normalising the electricityconsumptionprovided the beststatisticalfit for this sample.

3. Results

Results froma Shapiro-Wilk's test [p >0.05], skew values, kurtosis values andvisualinspectionof their histograms shows that the electricity and gas consumption data were approximately normally distributed for the group with IHD and without IHD for both groups living in flats andhouses.

3.1. Gas consumptionandusagebehaviour

All the properties with the Ewgeco IHD consumed 20% less gas over the first sixmonths compared with those without [M =1.36, SE = 0.08]: this difference was statistically significant[t(50) = 2.36, p = <0.05, with]. a medium-sized effect [Pearson's r= 0.32]. The houses with a Ewgeco IHD on display [M =1.26, SE = 0.11] have consumed 17% less gas, on average, comparedto thosein withthe WithoutIHDgroup [M=1.52,SE=0.09]. This differencewasalsosignificant [t(19)=-1.73; p=<0.05], and the data indicates a medium-sized effect [r= 0.37]. On average, the occupants living in flats with an Ewgeco IHD on display[M =0.98, SE = 0.09] had a normalised gas consumption score 22% lower than those living in flats without an IHD [M =1.25, SE = 0.12]. The difference between group means was statistically significant [t(29) = -1.78; p = <0.05]. The data indicates a medium-sized effect [r= 0.31]. The results show thaton average, the With IHD group consumedconsistently less gas than the without IHD group over the initial 6 month period (See Fig 1).

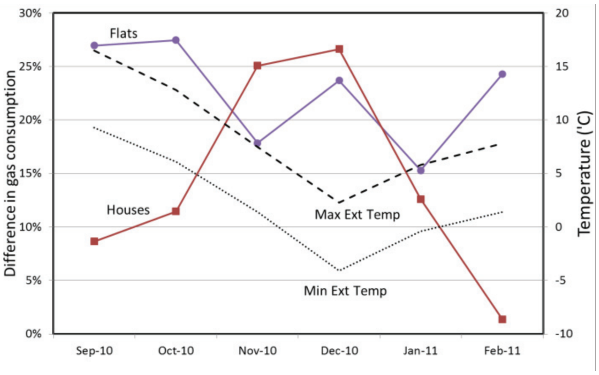

Fig 1: Difference in normalised gas consumption score per property type plotted monthly with monthly external temperature

At the beginning of the study (2010 interviews), the majority of the interviewes in the 'with' and 'without' IHD groups stated that they controlled the use of gas for space heating in the same way. The with IHD group had a similar gas reduction behaviour score [M = 2.52; SE = 0.11] as the without IHD group [M = 2.63; SE = 0.15]. There was no statistically significant difference between the mean scores of the two groups, [t(47)= -0.60; p > .05].

Many in the with IHD group referred to using thermostatic radiator valves (TRV) to isolate rooms that were rarely occupied, and using the system thermostat to reduce the temperature so it could be kept on for longer but at lower more 'tolerable temperatures'. Fewer referred to using thetimer on the boiler, stating that the interface was complex, non -intuitive andtheywere concerned that theymight disrupt the heating configuration, which may result in being left without any heating. On average, the 2011 interviews foundthat those in the With IHD group hada higher (better) mean (average) scorefor increasingthefrequencyof conducting energy saving activates for gas use [M= 3.50; SE = 0.07] than those in the without IHDgroup [M = 3.22; SE= 0.08]. This difference was statistically significant [t(47)= -2.43; p < .05], this was a medium-sized effect [r= 0.34].

3.2. Electricityconsumptionandusagebehavior

The results froma one-tailed independent t-test showthat thehouses with a Ewgeco energy monitor on display [M =1658, SE = 149] consumed 10% less electricity on average (mean), compared to those withoutthe IHD [M =1849, SE = 195], although this difference was notsignificant [t(19) = -0.793; p<>.05], and the data indicates only a small-sized effect [r = 0.18]. For thoseliving in flatted accommodation, the With IHD group [M =1194, SE = 105] had an average electricity consumption level 2% less than the without IHDgroup [M =1222, SE = 137]. The t-test results reveala non-significantdifference in theconsumptionlevels [t(29) = -0.170; p > .05], and the data shows a very small-sized effect [r = 0.03]. Overall, there was a 7% differences in electricity use between properties with a Ewgeco[M =1379, SE = 95] and those without, [M =1479, SE = 123] this differencewas not statistically significant.

For the first two months those in the with IHDgroup in both property types consumed much less than the without IHDgroup. This different drops in the following months to a point where those in the with IHD group consumes the same or more than the electricity than the without IHD group (See Fig 2).

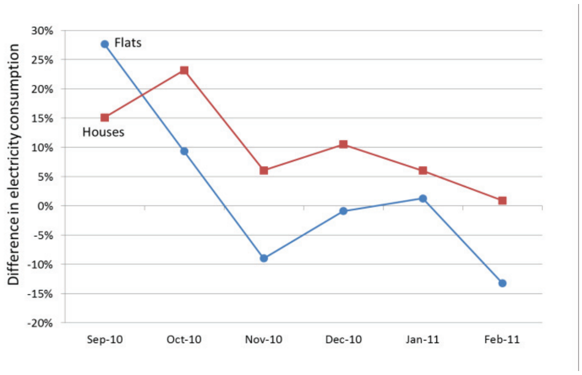

Fig 2: Difference in electricity consumption plotted monthly

The results of the first questionnaire show that the majority of those in both those with the IHD [M = 3.03; SE = 0.11] and without [M =2.91; SE= 0.14] reported 'sometimes' or 'always' conductingthe majority of electricity savingactivities listed during the interview. An independent t-test shows no statistically significant difference between the two group means [t(47) = 0.65; p >0.05]. The majority of those interviewedwith and withoutthe IHD give examples of how diligentand frugaltheywere in reducing the amount of electricity, this was a strong theme in the first interview. Participants with and without IHD group statedthat it was the concern of electricalfire and/or electrocutionthatmotivated their electricity saving habits. On average, both groups p rovided very stronganecdotalevidence that they were confident andcapable of maintain low levels of electricity consumption to balance household needs and low electricity bills. Interviewees from both experimental groups described the effect of electricity saving advert campaigns becomingroutedinto their habits of savingelectricity.

During the second interviewat the end of the 6 month study(March 2011), those in the properties with the Ewgeco IHDhad, on average a higher electricity saving score [M = 3.46; SE = 0.08], than the mean score for those without the IHD, [M = 2.99; SE = 0.08]. This difference was statistically significant[t(43.9) = -4.09; p < 0.05] and the effect size was large [r=0.50]. Very few in the without IHD group stated that their electricity saving behaviour increased, but the majority still adamantly stated how they were diligent in turning off appliances for fear of electricity fires and electrocution.

Overall, the coloured traffic light display was the preferred medium by which many of the users chose to engage with the monitor, with 90% of users stating that this was the most useful aspect of the device. 60% of users stated that the numerically features, showing energy use in terms of money were seen as being 'useful' or 'very useful'. For most of the users, the IHD's additionalfunctions, like showing CO2 levels and energyuse alarmsystem, were perceivedas beinguninformative. Users felt that these features overcomplicated the device and users were unable to see the relevance of these additional features in their da ily routine.

4.5. Discussion and conclusions

The electricity consumption comparison shows that, on average, during the initial 6 month period, the With IHD group consumed 7% less electricity than the without IHD group, and that this difference was not statistically significant. When monthly averages were analysed, it was seen that the With IHDgroups often consumed more electricity thanthe without IHDgroups. The 7% difference is in keeping with the 5% to 15% 'electricity savings' offeredby IHD's quotedbyother authors [2][9][10]. What is seen in this study is that 'savings' obtainedthrough the use of the IHD were limited as it was evident through the interviews that both groups hadalready adapted andmaintained long termelectricity savinghabits. In this respect, the monitor appeared to have become an instrument to reinforce peoples existing levels of electricity consumption. The device tended not to be associatedwith introducing newelectricityreducingbehaviours. When normalised, the With IHDgroup had a gas consumptionscore 20% lower than the without IHDgroup. This difference was evident throughouttheyear and more sofor December. For gas consumption, the Ewgeco IHD was notedfor its ability to incite newgas savingbehaviours throughincreasedinteractionwith temperature controls already existing in the home.

Results fromthe interviews foundthat when energyconsumptionis consideredwithin thehouseholdcontext, it is inappropriate to consider the occupants as a homogeneous group. As individuals within the household often have particular consumption characteristics, it is important to considerthat the IHDmust engage with allmembers of the household and has the ability incite behaviour change with whoeverhas access to energyuse in the home.

The results from this study shows that this IHD, which relies on simply 'pushing' information at users was still effective at helping occupants to maintain lower levels of gas and electricity consumption compared to a without IHD group. In this respect the IHD has achievedits goal. Whenconsideringtheresults fromsimilar past research, the 'push' IHD method of energy reduction through behaviour does not provide consistent results. Without the display and analysis of the effects on gas consumption, this research would have widelyconcurredwith the conclusion ofIHDs made bypast authors. It may have beentheprovokingpresence of the gas information on the Ewgeco IHD that encouraged the user to maintain visual engagement with the electricity display portion of the IHD.

This paper reports on the first 6 months of engagementwith the Ewgeco IHD, workis being undertakenby the authors to report on the behvaiour andenergychange after a further 31 months of interactionwith the Ewgeco IHD.

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