Smart energy monitoring technology to reduce domestic electricity and gas consumption through behaviour change

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Abstract

If the UK is to address its energy reduction targets, it is vital to understand energy use behaviours and to devise technology that positively encourages domestic occupants to use less energy. This study is cross-over research that spans energy research, social science and socio-technology. The work presented in this dissertation reveals the domestic energy saving potential of the use of In-hone Displays (IHDs) by quantifying changes in actual energy consumption and then evaluating these changes using social science research techniques to document the psychological nature of the human interaction with a digital user interface (UI).

Many studies have investigated how IHDs for domestic electricity use change behaviour; the findings of this unique 37 month pre-normative study, the first of its kind in the UK, show that the coloured dual-fuel IHD had a positive effect on consumption behaviour and energy reduction. However, the exact difference in energy consumption between experimental groups is dependent on the type of normalisation condition applied to the recorded energy consumption.

After the first six months of monitoring, those with a coloured IHD reduced their gas consumption by an average of 20% compared to a control group; this was tested to be statistically significant ($p<.05$). This difference in consumption was similar for those living in flats and those living in houses. The quantitative figures are reinforced by the findings from questionnaire and the semi-structured interviews, which show that those with an IHD were significantly more likely to reduce their gas consumption and reported increased use of the controls and settings like thermostats for heat-related appliances. Thirty-one months later, this change in gas use behaviour persisted. Over the total 37 month monitoring period, the majority of participants continued to engage with the IHD on a daily basis and consumed 27% less gas than the control group. This difference reached statistical significance ($p=.05$). The questionnaires conducted 31 months after the initial findings found that those in the intervention group had statistically higher gas reducing behaviour change scores ($p<.05$).

The first six months of energy data show that the sample group with the IHD used 7% less electricity than the control group. The difference in group means was found to not be statistically significant (p>.05). The difference in electricity consumption was considerably higher in the sample living in houses than in the sample living in flats. Qualitative feedback from the participants suggests that the use of the IHD had a slight positive effect on users' consciousness of reducing electricity consumption. However, a larger portion of the occupants with no IHD were similarly confident in ingrained methods of regulating and reducing their electricity consumption. Thirty-one months later, the difference in electricity consumption was substantially higher than was measured for the first six months. Over the total 37 month monitoring period, the intervention group consumed 21% less electricity than the control group. This was not statistically significant (p>.05), the interviews found that those with an IHD did not directly attribute their reduced use of electricity to the IHD. Rather, they maintained low levels of electricity use because it was an ingrained habit long before they used the IHD and for fire and safety reasons.

Between the 6 month report and 31 month report, both experimental groups reduced the amount of electricity and gas they consumed. This was attributed to changes in weather patterns and occupants growing more accustomed to their new home. The properties with highest gas consumption reduced their consumption closer to that predicted by the Standard Assessment Procedure (SAP). The research found contrasting differences in how the two utilities where perceived and used. This was evident when the energy data was divided into groups based on occupancy. Larger savings in gas consumption was seen in the intervention group with lower occupancy: the intervention group consumed considerable more electricity than the control group in the lower occupancy dwellings, and consumed considerably less in the larger occupancy dwellings. Electricity was described as a luxury, used to maintain a certain quality of life. Those with younger dependents felt it necessary to provide them with as much electronic luxury as they could. Electricity was relatively freely accessed and used by all residents with little resistance if a justified reason was given for its use. However, space heating was perceived as a sacrificial commodity. Heat was described as being relatively easy to regulate with the use of blankets and extra clothing. Heating controls were perceived to be out of reach for many but one or two in the household. This tended to be in control of the person responsible for the majority of household tasks.

The users of Ewgeco IHD commented more on the device’s ability to promote new gas saving behaviour in order to reduce gas consumption. In contrast, the visual representation of real-time electricity consumption was used more as a safety feature, and appears to fail to produce significant electricity reduction. The participants used the electricity consumption information to reinforce their existing levels of electricity use awareness and it highlighted electrical appliances that had been left on to them. This was reported to be specifically useful at times when the occupants were retiring from the living spaces in the home.

These findings demonstrate that a simple ‘push-information’ style IHD may need to evolve further with greater smart home control functionality, internet capability and user interaction for this technology to be part of the low-carbon solution. However, it has also been demonstrated that, for particular household groups, IHDs can lead to longer term changes in energy consumption behaviour, specifically for heat.

Chapter 1

1 Introduction

1.1 Innovation of low energy homes

The concept of creating energy efficient homes has been at the forefront of the UK construction industry for some time. August 1986 marked the opening of the 'Energy World' exhibition in Milton Keynes, which featured homes built to energy efficient standards at least 30% better than was required by the 1985 Building Regulations (Horton 1987). Twenty years later, the BRE Innovation Park, launched on June 2005, featuring demonstration housing that showed modern methods of construction (MMC), near zero carbon homes and a variety of emerging technologies (Gaze 2008). Most notable of these is the Kingspan 'lighthouse', which was described and assessed as achieving 100% energy/carbon improvement compared to Part L of the English Building Regulations 2006.

These exhibitions attracted a great deal of interest from both the general public and the construction industry in the UK and overseas. However, Briggs (2008) argues that despite the apparent success of the 1986 Energy World Exhibition, there was little enthusiasm for change. This was partially due to the steady and constant flow of oil and gas, the development of nuclear power and the lack of any political, financial or economical drivers.

Twenty years after the '1985 Energy World' exhibition, the global situation appears very different. The contribution of CO_2 and the other five greenhouse gases to the effects of global warming have since been internationally investigated and the results published, and internal political action has been taken to mitigate the effects of greenhouse gases in an effort to prevent further damage by global warming.

The importance of using clean and sustainable energy from renewable sources will continue to increase as a result of global imperatives to tackle climate change and the need to ensure, secure and diversify energy supplies. The threat from climate change derived from energy production and consumption, coupled with concerns over energy security, are the main drivers for reducing the amount of energy used in homes. The UK government is supporting the drive towards promoting locally based small-scale electricity generation (micro-generation) and reduced energy in new home through design. Through a combination of regulations, grants and targets for reducing CO_2 emissions, the construction industry is challenged to deliver ‘zero carbon’ homes by 2016 (Theobald & Walker 2008).

1.2 Reducing energy consumption in homes

It is well recognised that the domestic sector constitutes 25-30% of the UK’s total carbon emissions. After cross-party pressure over several years, led by environmental groups, in 2008 the UK Climate Change Act became law. The Act puts in place a framework to achieve a mandatory 80% cut in the UK's carbon emissions by 2050 (compared to 1990 levels), with an intermediate target of 34% by 2020.

The fuel poverty agenda and the need to provide future fuel security have given the UK government substantial incentives to move towards a low/zero carbon sustainable community. This requirement directly impacts on the built environment, with the emphasis on more energy efficient homes (Jenkins 2010, Bros Williamson 2012).

Furthermore, the UK Green Building Council (UKGBC 2008) Zero Carbon Definition Task Group stated that, with the current trajectory of housing standards, over 10%-80% of homes in the UK will be unable to achieve zero carbon targets using the method of carbon compliance. Moreover, less than 1% of the UK's existing building stock is replaced every year, and it has been estimated that 85% of the current housing stock will still be operational and lived in by 2050 (Palmer et al. 2006). This means that the UK cannot meet its carbon reduction targets without a means by which to engage occupants, who are generating the demand. Changes in occupant energy consumption behaviour is a key issue in addressing the increase in electricity and gas demand, capping wastage and reducing reliance on fossil fuel operated power stations.

Against this backdrop, the UK construction industry now has to address changing and increasing regulations and standards to reduce carbon dioxide emission as promised in national, European and international pledges. The construction industry continues to be on the front line of energy efficiency requirements, with new housing and the refurbishment of existing housing the main vehicles for change, and the building regulations and government funding incentives the most convenient method for driving energy reductions.

Currently, zero carbon homes are perceived as achievable by a combination of:

- Ensuring an energy efficient approach to building design
- Reducing CO_2 emissions on-site through low and zero carbon technologies and connected heat networks.

Building regulation, coupled with voluntary eco-design standards like Eco-homes and Scottish Building Standards Section 7, can accomplish much in terms of reducing the energy requirements of new houses. A fabric first approach is often adopted for new build and retrofit construction projects in an attempt to reduce energy demands, specifically the demand for heating fuel. Much reported progress has been achieved in material innovation and expanding knowledge in the research field of retrofitting older dwellings to reduce the consumption of thermal energies (Currie et al. 2013, 2014). The solutions for reducing thermal energy consumption tend to be complex to install, to have a considerable expense and to be difficult to scale up to a national level. Challenges in understanding buildings' pathology and ventilation strategy tend to lead to issues with surface and interstitial condensation when the achievement of low thermal transmittance rates are the sole objective of the retrofit.

On-site low and zero carbon energy generation technologies are perceived as reasonable measures, but they have been met with opposition, with many uncertain about their role in mass produced housing. The addition of micro renewable technology for on-site generation is becoming more widespread, although the number of installations is linked to the funding mechanisms and financial incentives attached to the type of on-site generation.

The energy performance gap is a well-documented phenomena that describes the increase in energy consumption between the modelled energy requirement and actual energy demand. The performance gap is often attributed to discrepancies between the designed fabric efficiency and the as-built building envelope. This is addressed with modern off-site construction methods, increased onsite checks and post-occupancy building performance evaluation (Bros Williamson et al. 2014, 2015).

However, various factors influence the operation and energy performance of the dwelling when it is in use, and these are critical to research and report. Researching these factors will create deeper understanding of how energy is used in existing dwellings, and help to develop strategies for maintaining low levels of domestic energy use. One such factor that impacts significantly on the energy performance of the dwelling and contributes to a widening performance gap is occupant energy and building use behaviour.

Figure 1.1 illustrates the three fundamental components that contribute to and influence the achievability of low carbon homes. The components as described in Figure 1.1 are applicable in varying degrees to addressing energy use in existing housing stock, as well as showing an approach to addressing energy use in new builds.

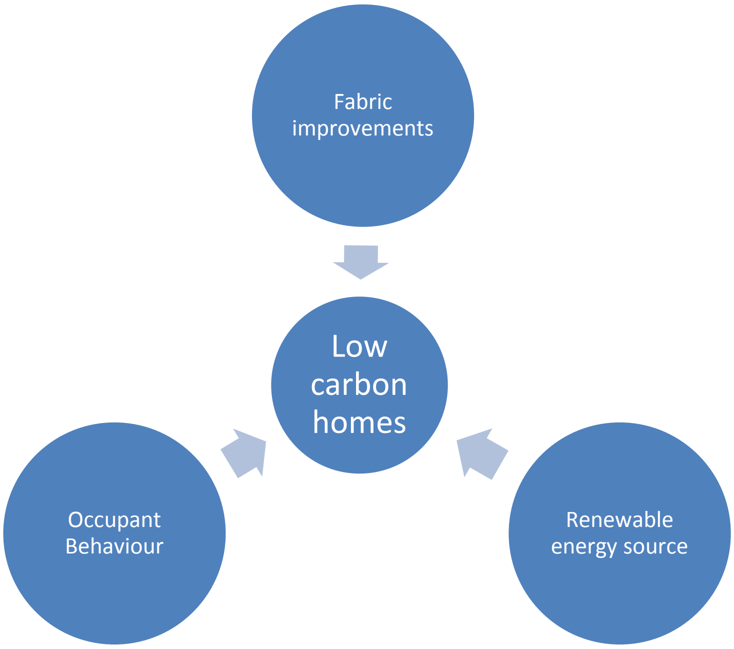


Figure 1.1: (F.O.R.) Fundamental components equating to the achievability of low carbon homes in Scotland

1.3 Smart energy technologies

In a 2012 policy announcement, the UK Department of Energy and Climate Change (DECC 2011a) stated that 53 million next generation gas and electricity meters, known as smart meters, will be installed in 30 million UK homes and small business. This is set to start in the second quarter of 2014, and scheduled to be completed by 2020. The rollout of smart meters will play an important role in Britain's transition to a low carbon economy, and help to meet some of the long-term challenges which will ensure an affordable, secure and sustainable energy supply.

The smart meter will possess a range of benefits to customers, with accurate billing being primary amongst them. However the real benefits to the occupant will take the form of being able to access their electricity and gas consumption visually and in real time, at any time throughout the day. However, the smart meter alone cannot provide the occupant with the ability to see their consumption in real-time. An in-home display (IHD) is required to help occupants to view and understand their energy use. These devices are commonly referred to as smart monitoring technology by utility companies and IHD suppliers.

Consumers with the new smart meter will be offered an IHD, which the EU (2010) and the DECC (2011b) believe give customers more control over their energy use and help them save energy and money. An IHD or smart energy monitor is an intermediary product that can log, manage and visualise the energy use of individual products or whole households. These devices have been previously utilised in past research for their role in electricity conservation and measuring their ability in provoking behaviour change in electricity use. Past research commonly used primitive forms of the IHDs. .

Increasing the energy efficiency of homes and reducing the domestic sector's operational energy demands are paramount. Understanding energy use behaviours and devising technology that positively encourages domestic occupants to use less energy is vital to these commitments. Furthermore, to optimise and reduce carbon emissions within a quota based system, it will be necessary for a household to observe, record and quantify their carbon emissions, then to forecast their future use. Optimisation is achieved through having the system cooperate with other users to recommend cooperative actions that will result in reduced emissions, as well as activities such as trading emissions.

With the exhaustive efforts made to reduce domestic energy consumption through fabric and renewable innovations, there is a need to establish a more demand-focused feedback mechanism in order to link consumer behaviour to energy consumption. Encouraging consumers to use less grid electricity and gas is an essential element of sustainable living and longer term fuel security. With the implementation of smart metering technology, an additional factor, referred to as behaviour change, has been identified as having a key role in reducing carbon dioxide emissions in buildings.

The aim of this dissertation is to investigate the potential of smart energy monitoring and display technology to create and maintain reductions in domestic energy consumption behaviour. Research is conducted to identify the relationship between reduced energy consumption and feedback from instantaneous smart energy technology on social housing tenants in a control study.

1.4 Hypothesis and objectives

In a regulatory environment where household energy conservation can only be encouraged by voluntary actions, can a certain level of energy feedback be sufficient to produce a change in either the understanding or the behaviour of residential customers towards energy consumption?

This study spans the disciplines of energy research, social science and socio-technology. The work presented in this dissertation reveals the domestic energy saving potential of in-home displays (IHDs). Actual changes in energy consumption during the research period are captured, analysed and quantified using techniques common to engineering and energy research. The observed changes in energy consumption are then evaluated using social science research techniques to capture, analyse and document the psychological nature of the human interaction with the digital user interface (UI) of the IHD.

Before the experimental research and field testing, a study of the relevant literature was conducted to define and review methods of energy use feedback. This part of the research investigates and reviews the means by which residents of low income, newly built rented accommodation can be influenced to take an increased level of responsibility for the energy they consume. The next generation of real-time IHD is identified and applied to experimental field research.

By providing a sample of housing association tenants with the means to view their electricity and gas consumption in real time, it is predicted that the occupants of these homes will change their energy use behaviour to reduce excess gas and electricity use. It is proposed that this will happen as a result of creating a cognitive educational aspect to their energy consumption, and closing the link between energy use behaviour and fuel bills.

Through use of smart energy monitoring technology, the conditions by which the occupants typically view their consumption have been manipulated to provide instantaneous feedback, whereas a control sample has been recruited to continue to view their consumption levels by whatever means they had been previously accustomed.

The hypothesis being tested regards the effects of feedback through the IHD on electricity and gas consumption levels as shown by comparing those of the intervention group with those of a control group that received no instantaneous feedback. The null hypothesis (H0): the intervention sample and control sample will not differ in their energy consumption over the trial period. Alternative Hypothesis 1 (H1) (experimental hypothesis) directional (one tailed): the intervention group will consume less electricity and gas than the control sample.

To test the hypotheses, two locations with a number of almost identical rental housing association homes were needed. The village of Windygates in Fife, Scotland, provided the study with 21 newly built two storey semi-detached houses. A newly constructed annex to an existing estate in Edinburgh's North east quarter was suitable as it offered 31 newly built, low income flats. Of the 52 homes/families, 30 were assigned to the group that would receive energy monitors, and 22 to the control group.

The research installed the UK's first coloured in-home energy monitoring display (IHD) to record and present electricity and gas usage information to the users. The elected IHD is called that Ewgeco in-home display, which works with smart metering technology and can currently be integrated with existing electricity and gas meters. This real time energy monitor is designed to engage occupants to reduce wasted or unused energy consumption by providing them with the ability to view their energy use in real time. It is predicted – in line with the views of other authors studying domestic energy behaviours – that providing consumers with better information about their electricity use can result in lower levels of electricity consumption.

This unique pre-normative study, the first of its kind in the UK, sets out to measuring the changes to electricity and gas consumption through the use of the coloured IHD. It is possible that providing the occupants of these homes with this type of technology can create a new level of learning that will raise awareness and understanding of the benefits that come with seeing and controlling energy consumption, ultimately eliminating wastage and the effects this will have towards protecting the interests of the occupants and furthering the UK's low carbon agenda.

Chapters 4 and 5 discuss and examine the differences in energy consumption made through the inclusion of the Ewgeco dual-fuel IHD device in a domestic setting. The trial, which was undertaken over two sites in Scotland, and spanned over six months, starting in 2010 and ending in 2011, was funded by the Technology Strategy Board (TSB). A further follow up study was conducted with one of the original sites 31 months after the end of the initial study period. Alongside the energy consumption data, social surveys were conducted at strategic points over the course of the trial. These questionnaire/interviews provided information that helped to identify how occupants perceived and used the device and, in turn, how they related this information to their everyday lives and practices.

Chapter 6 presents and illustrates the observations and themes that appeared during the qualitative portion of the 6 month trial using the same two sites, and further observations on user energy use behaviour 31 months later for one site. The qualitative data was collected using semi-structured interviews with questionnaires. Each interview was conducted with as many of the family members who resided in the dwelling as possible. This chapter focuses on identifying any changes in energy use behaviour and routines during the course of the two study periods, and aligns occupant stated behaviour change with or without the use of the IHD. The chapter goes on to present and discuss the findings related to the occupants' interaction with and opinion of this IHD and their preferences and attitudes towards how it delivered its energy information.

The thesis concludes with a summary of the key findings and results from the three studies, and recommendations for future studies.

Chapter 2

2 Review of Relevant Literature and Past Work

2.1 In-home drivers

2.1.1 Addressing the energy crisis one house at a time

Directive 2010/31/EU of the European Parliament on the energy performance of buildings notes that reducing energy consumption is part of a building's design, commissioning and use. This performance-based approach adds owners, operators and developers to the list of reasonable groups (Janda 2011).

As discussed previously, reducing energy consumption in the domestic sector is a fundamental component of meeting national carbon reduction commitments. There are a number of ways to achieve this goal, each of which emphasises actions by a different set of stakeholders or actors. Much of the work in the new build sector follows a physical, technical and economic model of the built environment (Lutzenhiser 1993), which focuses on architects, engineers and similar professionals as major players who make technical improvements to existing buildings and design new ones to higher standards.

In the context of existing buildings, architects and designers have much less opportunity to change most fabric components. Improvement to the thermal performance of the existing envelope is typically the chosen prerequisite for energy conservation in buildings, focusing on improved thermal performance levels and reduced air filtration. However, aspects of significant building improvements and renovations that are required to reduce the energy consumption of the mature housing stock begin to arise when considering:

- Period homes
- Listed buildings
- Buildings within conservation areas

- Varieties of construction method
- Types of homes, i.e. flatted dwellings, houses

2.2 Occupant energy use

Energy use in buildings is considered a social rather than a technological problem (National Research Council 1980, Stern and Aronson 1984). Social scientists have investigated how individuals can be motivated to use or conserve energy for more than a century (Rosa et al. 1988). From this perspective, it can be argued that reducing energy use in buildings requires changes to the entire fabric of society, not just to the shape and nature of buildings. Domestic energy use is also determined by a complex array of factors – physical systems, infrastructure, social norms, comfort preferences and options for control (Darby 2010b, Mullaly 1999).

However, Weber (1997) describes barriers between the potential of energy conservation and the technically feasible measures which could be taken as an 'efficiency gap' or 'energy paradox'. Weber (1997) identifies behavioural barriers as limits to the technical and social aspects of energy conservation. Behavioural barriers focus on individuals’ attitudes towards energy conservation. Obstacles to energy conservation may occur as a result of a lack of attention to energy consumption or a lack of perceived control, or due to a missing link between attitude and action. Social norms and lifestyle patterns may also hinder individuals’ more efficient energy use.

2.2.1 Current behaviour

Technical and physical improvements in home design may not be enough to guarantee reduced energy consumption, so the tightening of domestic energy regulations has been and will continue to be on-going. Increasingly the construction industry is encouraged to adopt ‘higher than standard building regulations’ with the aim of incorporating micro renewable technologies and higher efficiency heating systems into the design of homes.

This shifts the focus onto understanding how occupants are using energy within these buildings. The argument is that "*one can construct an energy efficient home, however if the occupants are using energy inefficiently, then carbon emissions will continue to increase"*. Van Dam et al. (2010) quotes work from Ihde (1990) that states that equipment and appliances in the home, specifically new technology, operate in the background, either physically or in the back of our minds. These background relations with technology are described as an 'absent presence' in households. With an increasing number of these background appliances in existence, especially technical installations which function autonomously, it raises the question of whether we being removed or detached from our household equipment, and, more specifically, the questions of when we know how much energy is being used and what its impact will be on our energy bills.

Despite improvements in household appliance efficiency and awareness campaigns, domestic electricity consumption has risen year on year from 2008 to 2010. 2010 domestic electricity use is up 4.0% on 2009 figures, and is the highest annual domestic electricity consumption of the past ten years. Furthermore, gas consumption in the domestic sector has increased by 15.0% in 2010 compared to 2009, and increased by 29.7% between the fourth quarter of 2009 and the fourth quarter of 2010. Domestic gas consumption has risen 28.1% on 1990 figures, with 2010 consumption the third highest annual consumption level over the past decade (DECC 2009, 2010, 2011)

The 2011 Digest of United Kingdom Energy Statistics (DUKES) found that between 1970 and 2010 electricity consumption from consumer electronics increased by 567%, from wet appliances by 247% and from cold appliances by 195%. However, since 1990 electricity consumption from consumer electronics has increased by 74% and from wet appliances by 22%, whilst electricity consumption from cold appliances declined 16%. This in part can be attributed to the work done within the industry to vastly improve the energy performance of cold appliances, improving energy efficiency from 48% to 62% compared to 1990 figures. Energy consumption per household has increased by 1% and energy consumption per person by 9% (DECC 2011a).

Work carried out by Darby (2010a) and Wood and Newborough, (2007) also comments on the increasing numbers of appliances in each UK household. Indeed, these authors go further, saying that many are without any obvious power rating or energy label and that appliances are managed and operated in a range of different ways. There are not many signs that householders are confident about controlling and reducing their consumption in terms of purchasing equipment, maintaining it or in its day-to-day operation.

Van Dam et al. (2010) and Borgmann, (2000) comment on the potential dangers associated with new energy efficient appliances and equipment becoming more distant from the conscious mind of occupants. Increased the self-regulating capability of new electronics in ways that are imperceptible to users might result in electronics drifting further into the background over time. Most background products are intentionally designed to operate this way: they are designed deliberately to have little or no interaction with the end user, however they continue to consume electricity.

This effect has been described as disburdening, and also as 'disengaging technology'. As a negative side-effect, these background products significantly contribute to the energy consumption of households and the invisibility of energy flows in homes. More than half of households' carbon dioxide (CO_2) emissions are caused by background appliances and 'imperceptible' energy consumption like 'phantom' loads (Van Dam et al. 2010).

While the disburdening effect also brings important beneficial aspects to users, it tends to undermine the direct cause-and-effect relationship between users, their behaviour and energy consumption. This is where the energy monitor could have a mediating role by giving people a (visual) representation of their energy consumption to help them to interpret the actual energy (or monetary) figures mentally and to perceive the energy consumption of other products. Ihde (1990) calls this relationship between users and products a hermeneutic relationship.

Past studies have demonstrated that public awareness and knowledge of climate change has steadily increased over the last two decades (Hulme et al. 2002, Upham et al. 2009), with terminology like ‘climate change’ and ‘global warming’ becoming commonplace in the UK since the early 2000s (Lorenzoni & Pidgeon 2006, Whitmarsh 2011, Whitmarsh et al. 2011). Poortinga et al. 2011 conclude that an overwhelming majority of the British public believe that the world’s climate is changing and that they considered this one of the most pressing environmental threats. However, research suggests that scepticism and uncertainty about climate change has increased in both Europe and the US in the recent years (Eurobarometer 2008, Leiserowitz et al. 2010).

As public scepticism and uncertainty about the existence of anthropogenic climate change begins to increase, this may have an impact on how people understand the impacts of their energy consumption actions. It will become progressively more difficult to encourage the public to make sacrifices to their lifestyles and lower their household energy consumption to assist with the development of a more sustainable low carbon society (Berkhout 2002, Joireman et al. 2010) using the motivation of preventing climate change.

Dobbyn and Thomas (2005) find that the group they observed exhibited no instinctive awareness that domestic energy use had an impact on the environment by increasing CO_2 emissions. According to Dobbyn and Thomas, this came as a revelation to the householders, who were more likely to associate environmental issues with recycling or transport issues than domestic energy use.

In contrast, the results from a 2008 Logica study involving over 10,000 participants from 10 different European countries, including the UK, noted that European consumers are concerned about climate change (80%) and believe their personal actions to have an impact (75%). However, the report also concludes that a majority of the study participants claim to be taking action to reduce consumption (69% say they do a lot to reduce their energy consumption at home). There seems to be a gap between perceived and actual energy efficient behaviour: on average the participants in the study carried out less than 2 of the 6 energy saving actions. Finally, the report notes that a lack of information is one of the top four reasons why people do not take more action to reduce their energy consumption.

Environmental reasons may no longer be an effective reason for people to reduce their domestic energy consumption, and they become redundant if harsher winters increase the need for space heating or warmer summers require additional mechanical cooling to maintain comfortable living conditions.

Weber (1997) also highlights the apparent gap between people's energy reduction attitude and their actual behaviour. The attitude of wanting to reduce energy appears to be prevalent, yet the behaviour required to reduce energy consumption is lacking. The report by Logica (2008) emphasises the existence of an attitude-behaviour gap in the participants in the study. Logica (2008) concludes that the attitude-behaviour gap may be one of the greatest challenges facing the public climate change agenda. In this respect, technology may have an important role to play in closing the gap between the awareness that climate change is a problem and behavioural changes that reduce energy consumption.

Research suggests that learning by trial and error, observing how others behave and modelling our behaviour on what we see around us provide more effective and more promising avenues for changing behaviours than information and awareness campaigns (Jackson 2005). Although the past literature places the greatest emphasis on trial and error, arguing that we learn what to do (and what not to do) by experiencing positive (and negative) reinforcements (rewards or penalties) for our behaviours, a means of providing the positive and negative trial and error experience will need to be administered by a form of feedback, because it is through feedback mechanisms that actors learn about the effectiveness of their contribution (Van Raaij and Verhallen 1983).

The same issue has been highlighted in recent studies of domestic energy consumption. Gatersleben et al. (2002) and Jensen (2002) both demonstrate that pro-environmental intentions and behaviours do not necessarily correlate with reduced energy consumption in the household. Darby (2010a) concludes that there is evidence of a reverse correlation. Environmental attitudes are often reported as being higher in households in the higher socio-demographic classes. Past research has noted a positive correlation between household size and energy consumption.

The existence of an attitude-behaviour or cause-effect gap (sometimes called a value-action gap) has plagued attitude behaviour theory since at least 1934, when LaPiere published his work on attitudes versus actions. During a social literature review on consumer behaviour, Jackson (2005) argues that there are only a relatively limited number of quite specific avenues for behavioural change. Specifically, the literature suggests that humans learn new behaviours through trial and error, through `persuasion, or through various forms of modelling (social or cognitive learning).

The central assumption underpinning the majority of these studies is that the provision of feedback on energy consumption will raise awareness and thereby encourage individuals to make the rational decision to cut their energy consumption in order to reduce costs and/or carbon emissions. A solution to this energy 'information-deficit' model is expressed in the conclusions of Wilhite and Ling (1995): *"better energy feedback leads to a more energy-conscious consumer, one who is better equipped to make informed decisions about how to use energy in the home".* They are specifically referring to billing information from utility companies. They state that increased transparency and the disaggregation of household consumption by end use would lead to a change in energy reduction behaviour.

Furthermore, this cause-effect model is widespread in the pro- environmental behavioural change debate and is to an extent supported by the empirical evidence. However, more sociologically and anthropologically grounded research suggests that this model neglects important dynamics of household practices that are critical to whether, and how, feedback might be used (Gram-Hanssen 2011, Aune 2007, Lutzenhiser 1993, Shove et al. 1998). These studies suggest that, whilst feedback is both necessary and valuable, it might not be sufficient to bring about changes in behaviour because it fails to acknowledge broader social and cultural influences on household energy use (Hargreaves et al. 2010).

Arguably, this theory can be applied in the context of new digital technology. Increasing the speed of feedback through real-time in-home displays may have greater potential for increasing awareness or knowledge, in turn seeing quicker changes in energy-use behaviour and, as a result, a decrease in consumption.

2.2.2 Invisible energy, the consumer element

It has been noted that technical and physical improvements to existing homes and new housing design are not enough to guarantee reduced energy consumption. Consumption in identical homes, even those designed to be low energy dwellings, can differ depending on the behaviour and the occupants' level of energy understanding (Sonderegger 1978, Curtis 1992-93, Keesee 2005, Darby 2006).

Furthermore, UK figures published by DECC (2011a) reaffirm that domestic emissions continue to increase, to approximately 30% of the current UK energy footprint. Therefore it is becoming increasingly necessary to reduce domestic energy demand through some form of intervention that targets customers' demand for electricity and gas (Darby 2001, Fawcett et al. 2001).

Ihde (1990) suggests that the relationship between humans and technology is becoming distant; Boardman and Darby (2000) note that energy is understood as invisible to most consumers. Darby (2006) continues to describe how most people possess only a vague idea of how much energy they are using for different purposes, and do not comprehend the difference they could make by changing daily behaviour or investing in efficiency measures.

A common theme of the literature is that most energy consuming behaviours are part of inconspicuous routines and habits (Karjalainen 2011, Darby 2010b, Burgess & Nye 2008, Shove 2003, Sheldrick & MacGill 1988, Kempton & Layne

1994), therefore making it difficult for people to relate specific behaviours to the energy they consume. Burgess and Nye (2008) suggest that energy is ‘doubly invisible’ to householders: it is also an abstract force entering the household via sockets and often hidden wires.

Although conceptualised as a commodity, a social necessity or a strategic material, electricity in particular is an invisible entity. Furthermore, electricity and gas are usually limited only by the apparatus or appliances through which they flow. Once switched on, these continue to use gas or electricity until they are stopped by manual switching or automatic controls. This contrasts with the use and physical presence of solid or liquid fuels, which can be seen and weighed.

Gas and electricity may operate at the level of the subconscious within the home Dobbyn and Thomas (2005) comments that:

> *Energy and power are not terms within the natural language of mainstream householders. Whilst there does seem to be some latent cultural guilt about the notion of waste, with some householders reporting an impulse to turn off lights, TVs and radios (that was not seen in practice!) there appeared to be virtually no sense of being able to actively and significantly reduce energy consumption in the household. Indeed consumers appeared remarkably disempowered in this area with levels of consumption always being attributed to the inherent size and shape of the household. Switching suppliers was considered the most effective way to reduce bills.*

In this regard, attempts to change the patterns and consumption of domestic occupants have to take into account the interface between consumers and their surroundings. The challenge is to raise people’s awareness of the use of energy in the home from the subconscious to the conscious level, to inform them of ways in which energy consumption can be improved and to enable them to feel part of the solution. This is where consumption behaviour intervention enter the debate, in an attempt to bridge the energy gap or energy paradox.

2.3 Action taken to involve the end user

The European Directive 2006/32/EC on energy end use efficiency and energy services places considerable emphasis on improving the transparency of domestic energy consumption and giving the final user a reasonable amount of relevant information to enable them to make better informed decisions with regard to their individual energy consumption.

The directive goes further by commenting on the level and clarity of the information that should be given to the final energy user.

- Billing information provided to the final users should be based on actual prices and actual energy consumption.
- It should be presented in clear and understandable terms.
- Accurate billing should be conducted frequently enough to enable customers to regulate their own energy consumption.
- Information should be set out in clear and understandable terms by energy distributors.
- Comparisons of the final customer's current energy consumption should be made with consumption for the same period in the previous year, preferably in graphic form.
- Wherever possible and useful, comparisons should be made with an average normalised or benchmarked user of energy in the same user category.

The directive goes on to comment that

> *Member States shall ensure that, in so far as it practically possible, that final customers for electricity, natural gas, etc. are provided with competitively priced individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use.*

This brings a focus onto smart metering and advanced metering infrastructure, both of which are being reviewed and debated in the UK.

In light of the EU directive, the response to DTI/DEFRA billing and metering consultation 2007 (EnergyWatch 2007a, Defra 2008), which focused on changing customer behaviour, concluded that end users in the UK were currently experiencing:

- Bills not being based on actual energy use - one in three bills were estimates;
- No historical or comparative picture that could provide contextual meaning to current consumption;
- Information from the meters that is not easily accessible or understandable;
- Energy bills that are more a reflection of an accounting process than readily understandable to the consumer.

2.4 Types of feedback

There is considerable variety of literature surrounding the feedback mechanisms being employed to engage occupants in their recent or current energy consumption or energy patterns. From the early research in 1970s to the more recent work, common themes emerge which establish feedback as learning by doing, allowing energy users to teach themselves through experimentation.

Langenheld (2010), Darby (2010a, 2006), Owen and Ward (2010), ESMA (2010), Faruqui et al. (2009), Van Elburg (2008), Fischer (2007) and McCalley and Midden (2002) are among the authors who have extensively reviewed past research focusing on a range of consumer feedback methods and mechanisms. From these reviews, feedback has been categorised into five basic types, based on mix and degree factors, which Langenheld (2010) divides into three groups:

- Instantaneous and continuous immediacy of information.
- Type, quality and quantity of consumption data.
- Interaction and control by the energy consumer.

The five key types of feedback of energy consumption by which behaviour may be changed are:

1. Indirect feedback
2. Direct Feedback
3. Credit, or pre-paid feedback
4. Time sensitive/dynamic pricing (with or without load management)
5. Utility controlled feedback (load management)

These feedback mechanisms are described and discussed in more detail in the next sections.

2.5 Indirect feedback

The definition of indirect feedback extends to the raw data of the energy consumed by the household being estimated by the utility company and the consumption data is sent out to the customer in the form of a bill. The form of feedback can be described as ‘learning by reading and reflecting’.

Feedback in this manner can be enhanced by:

• More frequent bills.
• Frequent bills based on readings plus historical feedback.
• Frequent bills based on readings plus comparative/normative feedback.
• Frequent bills plus disaggregated feedback.
• Frequent bills plus detailed annual or quarterly energy reports.

Commenting on feedback as the primary form of energy behaviour intervention, many past authors have described the range of practices that take place when an intervention such as feedback is used and the process that follows towards achieving behaviour modification:

1. People take in information concerning their energy use.
2. They act and change their behaviour in some way.
3. They gain an understanding of what has happened by interpreting any feedback that is available.

These three elements do not always happen in a neat sequence, but all are involved when a person learns about energy use.

Meter readings reflect how much electricity, gas, fuel or water has been used by a particular household to measure the quantity owed to the utility provider. Meter readings, however, do not reveal which specific behaviours contributed most to total electricity, gas, fuel or water use. From an educational point of view this is problematic, because people generally do not know which and whose behaviours significantly affect resource use, and people cannot receive specific feedback on the results of their behavioural changes (Steg & Vlek 2009, Gatersleben et al. 2002).

Kempton and Layne (1994) argue that the analytical efforts of the end users are being restricted by the format in which they receive price and consumption data. Those who are less efficient often possess limited analytical abilities, further expanding the gulf between utility company feedback mechanisms and improved consumer knowledge of consumption. However, in the Oslo informative billing trials, Wilhite and Ling (1995) find that improved billing feedback can lead to more energy conscious consumers who are better equipped to make informed decisions about how to use energy in the home.

Studies conducted by Logica (2007) and EnergyWatch (2007b) find that consumers still have low levels of understanding of their energy bills and furthermore that around one-third of bills are likely to be based on estimates rather than readings. Despite the efforts of many householders to read their bills and meters, in the absence of more transparent cues the form and means by which consumers receive their utility bills best suit the efficient analytic abilities of the energy utility company and not those of the end user.

2.5.1 Indirect examples

One of the earliest studies which included both electricity and gas indirect feedback was conducted by Socolow (1977), who carried out field experiments with a set of nine newly built three bedroom town houses in New Jersey, USA. The study looked at energy conservation in the homes in the wake of the 1973 energy crisis. The project spanned over five years and documented electricity and gas consumption over the course of the study before presenting periodic feedback in the form of charts and graphs to the occupants. Using meter readings collected by the researchers and supplied to the residents on a daily basis, the residents reduced their summer electricity consumption by 10% to 15% and their winter gas consumption by up to 10%.

The research by Gaskell et al. (1982) provides further evidence of the impact of customers reading their own meters and receiving feedback. In Gaskell et al.'s study, some participants also had weekly visits, some were provided with information on energy reduction techniques, and some received a combination of these two approaches. For participants reading their own meters, they also kept an energy diary of consumption and activities, and recorded temperature readings. For electricity, participants with meter readings and feedback saved 9%, participants with feedback and energy information saved 11% and participants with information alone saved 8%. For gas consumption, participants with meter readings and feedback saved 5%, participants with feedback and energy information saved 22% and participants with information alone saved 9%.

This shows that a combination of feedback and energy saving information was most successful at reducing electricity and gas consumption. However, this was an intensive and arguably intrusive campaign, with researchers personally giving householders written advice, making weekly visits to read meters and checking any problems, as well as conducting interviews. Also, this study was conducted at a time when energy conservation was a relatively novel topic and the energy crisis of the 1970s was fresh in the memory, and hence it is difficult to apply the findings to the present time. There was no reported statistical analysis done in comparison to a control group.

Similarly, a study of gas consumption in Dutch homes by Van Houwelingen and Van Raaij (1989) found similar reductions in gas consumption under a range of interventions. The study had a 12 month pre-trial period followed by a 12 month post-intervention period, each of one year. Participants opted in, but the take-up rate was high (78%). One group (n=55) had monthly feedback about gas use, plus advice on energy saving and a target for savings. Consumption was significantly reduced by 12.3% against controls (n=55) and 4.6% against a group (n=55) receiving the advice and targets only. The latter group may be a better comparison because the control group was composed of households that had not agreed to the target. Savings relative to the control group declined to 0.3% over the year but were sustained at 3.4% against the advice plus targets group.

In the USA, Harrigan and Gregory (1995) and Gregory and Harrigan (1997) describe the Niagara Mohawk programme, which provided a service to low income households in gas-heated houses. They compare savings in gas consumption over a year between households offered assistance with insulation, with and without provision of energy-training and thermostats. The group that receiving training reduced consumption by 10% more than the group that did not (with relative savings sustained at 7% after three years). Across the two groups, those who accepted the insulation saved 5% more than those who did not, so this cannot account for the whole effect of training, but the training itself included more than just feedback.

In 29 German homes, 19 trial properties and 10 controls over a 10-month trial period, meter readings combined with historic feedback have produced electricity savings relative to control groups of 4% and gas savings of 1% (Haakana et al. 1997).

The West Lothian Energy Advice Project used a method based on client meter readings to provide tailored advice to low-income households who contacted the local utility company because of difficulty paying their energy bills. The project covered over 1,000 customers over a four month period, and reported savings of 11%, which it is suggested resulted from behavioural change only. It has been documented that the motivations for reduced consumption are almost entirely financial and a large part of the savings come from better understanding of heating controls. The effectiveness of the programme depended to a great extent on the combination of trained advisers, in-home face-to-face advice and follow-up with feedback. Comments from the advisors estimate that the 12 week period gives sufficient time to establish behavioural change and that if someone were going to return to their old inefficient habitual ways, he or she would do so within three months. Conversely, if an individual has adopted a change in behaviour for over three months then this change will last for at least a year (Green et al. 1998, Darby 1999, Barr 2005, Darby 2006).

Brandon and Lewis (1999) investigate the effect of various forms of monthly feedback in UK homes (n=13 to 22 per group, compared with a control group of n=13 homes) in a nine-month study of total (electricity plus gas) energy use. This intensive intervention brought about statistically significant savings ranged from -3% to 12% relative to controls, but it was not possible to ascertain the influence of users being provided with data (which might have included reading their own meters).

Völlink and Meertens (1999) combined advice through text TV with weekly feedback and a self-set savings target (5, 10 or 15%) for people living in energy-efficient homes. Although the study was small (n=48 Dutch households in total), savings over a period of five months were significant, relative to a control group, at 23% for gas and 15% for electricity. It is not possible to say which of the interventions was responsible for the effect, and since participants were living in energy efficient homes, the results cannot easily be generalised to the general population.

More recently, combining customer meter readings with advice (without feedback) produced electricity savings relative to control groups of 3% and gas savings of 2-14% with Dutch households (UC Partners 2009).

The studies presented and discussed in this section highlight that energy consumption reduction can be achieved, but in these cases usually as a result of intensive studies which include researchers or advisers periodically visiting participants, so the results may have been influenced by the Hawthorne Effect. Other studies with less intensive interventions such as Hutton et al. (1986) in

Canada and Midden et al. (1983) in the Netherlands found that there were no significant effects of written advice alone on either electricity or gas consumption.

Many authors emphasise that putting improved billing techniques into practice rarely requires extensive training or major technical innovations from utility providers. The costs may be small in relation to the potential savings in terms of both energy and money and there are strong arguments for the adoption of more frequent billing for actual consumption, and for the provision of a graphical presentation of comparative consumption.

However, when considering how to make energy use more transparent and how to disaggregate each household's energy consumption by appliance – i.e., how to provide a breakdown of how much energy goes to space heating, water heating, appliances, lighting, etc. – it is often thought that an audit of each customer's home and a regular update of information would be required. Such measures could prove to be more difficult and expensive for utility providers to collect and present to the end users.

From the examples given, indirect feedback has shown the potential for helping to reduce domestic energy consumption, primarily by improving end user knowledge and inciting changes in occupants' energy usage patterns. However, this method appears to work better when the analytical process is completed by an external body, whether that be a utility company or a research team. Once the actual meter readings have been collected, analysed, presented and even explained to the occupants, the past literature suggests that savings can be achieved and behaviour can be changed. However, this progress is labour intensive for the party providing the service, and may not be easy to replicate across all households.

Furthermore, this method of feedback suffers from a significant time lag between meter reading collection and feedback. If individuals can experiment with energy in their homes and instantly see the consequences of their usage without the need to rely on the analytical abilities of others, then perhaps the reduction of energy consumption may be higher and longer lasting. This provides a rationale for how direct feedback could enter the debate.

2.6 Direct feedback

Direct feedback for energy consumption information takes the form of the instantaneous return of data directly at the point of use; this can be done independently of the utility company through the use of real-time energy monitoring technology with a graphical display. Alternatively, the introduction of smart meters deployed through the utility company and/or access to the utility company's website allow the occupant to log-in and view their consumption updated half hourly.

Criticisms from authors in the fields of indirect feedback point out that homeowners have no way of knowing what amounts of energy are being used. Energy bills are often not specific and come too late to make people aware of energy wasting types of behaviour, and, thus, have a limited feedback function. Van Houwelingen and Van Raaij (1989) suggest that more immediate feedback is needed to save in home energy.

It is assumed, based on theoretical and field research, that if residential consumers had more detailed and/or frequent information about their consumption, they would better understand their energy use patterns and be able to change them effectively (Allen & Janda 2006, Boardman & Darby 2000, Van Raaij & Verhallen 1983).

Faruqui et al. (2009) point out that direct feedback, such as the energy monitor, not only provides consumers with current energy use information, but also possesses the ability to turn a once opaque and static electric bill into a transparent, dynamic and controllable process.

Many other authors in this field agree that providing the occupant with the ability to view their home's energy use instantaneously is more likely to yield a higher energy reduction. However, Allen and Janda (2006) suggest that attributing these benefits exclusively to the use of feedback mechanisms is complicated by the heterogeneous nature of consumers, because individual socioeconomic factors play heavily in studies of this nature. This makes it difficult to rely on the specificity and frequency of any form of feedback to produce instantaneous energy reduction results.

2.6.1 Keypad meter

Keypad meters are similar to standard credit meters: they display consumption in a numerical and non-graphical manner, but they have the added function of allowing the user to access historic energy consumption data for weekly and monthly periods. Langenheld (2010) and Darby (2006) describes key meters as 'semi-smart' because they allow for the transfer of information such as tariff-changes and meter reading data 'to and from' the keycode at the payment point/shop and allow customers to access information on current and past usage on an annual, quarterly and monthly basis. The meter also shows credit remaining and maximum demand.

A study of prepayment tariffs for British householders (mostly from low-income households) shows that over 80% of electricity customers and 70% of gas users wished to continue with this method of payment, although most of them knew that it was more expensive than payment in arrears (Darby 2006).

When keypad meters were introduced as an option to low-income customers in Northern Ireland, they were reported to be extremely popular and have now been made available to all customers (Van Elburg 2008, Darby 2006). There is a 2% discount for electricity bought in this way. Furthermore, 30% of Northern Ireland's domestic electricity consumers now use a prepayment keypad meter. Electricity savings to date for all keypad customers are estimated at 3% (Owen & Ward 2006).

The Keypad Powershift trial was undertaken with 200 customers from October 2003 to September 2004. 100 customers (the “Price Message Group” PMG) were given the Keypad time of day time bands and tariffs (four time bands, three rates) and compared to a control group of 100 customers who had a flat-rate tariff (as per normal keypad customers). The results suggest that many prepayment users actually benefited from ‘time of use’ (TOU) tariffs without having to change their behaviour. The TOU tariffs achieved some load-shifting, but no overall electricity demand reduction. Powershift consumers saved money but not energy (Owen & Ward 2007).

A review of literature presented by Darby (2006) indicates that savings from pre-paid feedback range from 3% to 20%. Savings of 10 to 20% are quoted for North American systems. Figures from earlier small-scale studies in Europe show savings of around 3%. The differences are due in part to the sample size, the objectives of the utility providers and the way in which the information had been displayed to the final users.

In the case of the Northern Irish and European trials, the primary focus was on reducing costs for the utility provider, by reducing expenditure for meter reading and the cost of billing and improved security and reducing fraudulent behaviour. In trials in which reducing the costs for the utility company was the primary aim, very little or no significant behaviour change was documented.

This brings the discussion back to the topic of maintaining long term energy reduction through behaviour change. The energy savings experienced in the keypad or prepaid meter trials may in part be due to the introduction of a new metering system. The increased attention to energy use may be due to a desire or need to learn about a new or different type of payment technology. Whether these savings are maintained without the presence of an energy monitor remains to be seen.

2.6.2 In-home displays

The ‘rolling out’ of both electricity and gas smart meters into all GB homes by the end of 2020 was announced by DECC in December 2009 and is set to streamline the way energy consumption information is transferred and handled. This strategy will see the replacement of some 47 million gas and electricity meters along with the introduction of a stand-alone display to accompany each of the new smart meters.

The decision to include a stand-alone display was announced by the government in their consultation response ‘Impact assessment of a GB-wide smart meter roll out for the domestic sector’ (DECC 2009).Since then the language used to describe the accompanying display has changed. The list below presents a non-exhaustive list of the most common terms used to refer to the technology that displays domestic energy consumption. These are generic terms and do not include the commercial brand names applied to the device.

- Stand-alone Display
- Home Energy Monitor (HEM)
- Home Energy Management System (HEMS)
- Home Energy Display (HED)
- Real Time Display (RTD)
- Smart energy monitor
- In-Home Display (IHD)
- In Premise Display (IPD)

More recently, with increased media and social attention on the energy sector, coupled with the pending introduction and macro roll out of smart meters, the in-home energy monitor has occasionally been incorrectly referred to as a smart meter in journals, articles, reports and within the industry. The two are essentially different devices that can be used independently or in tandem, but one does not rely on the other to perform its task. The energy monitor, as the name suggests, monitors the energy used within the home and relays that information via a numerical or ambient display to the building occupant. In contrast, the smart meter is a technologically improved version of a ‘standard’ electricity or gas meter the initial function of which is to communicate with the utility provider by transmitting regular meter readings to give end users utility bills that are more accurate to the meter reading. The smart meter will most likely be installed in a similar location to the existing electricity and gas meters that it intends to replace. The replacement program has led to existing meters being labelled ‘dumb’ meters (more on smart meters in section 2.7).

The context in which the terms above are used is relatively academic: Ofgem favours the term real time display, whereas the Energy Saving Trust use the term in-home display, emphasising its ability to provide near real time consumption information. The term real time display was previously reserved for monitors with a quick data transfer time, i.e. 2-3 seconds from meter to display. In the wake of the 2009 DECC announcement, however, the Energy Saving Trust recommended (ESTR) in the consultation draft of January 2011 that a six second transmission rate be sufficient, while still allowing for the maximum battery life and lower energy consumption by mains operated devices.

The ESTR consultation notes the transmission rate for 12 commercially available home energy monitors, all of which range from between 2 seconds to 60 seconds. The modal score for the group is 6 seconds, and a mean (average) is 11 seconds. Since that consultation, there has been no definitive specification for data transmission time, and therefore the majority of those energy monitoring displays provide energy consumption data at 6+ seconds per transmission. As a result the industry appears to have adopted the terminology ‘in-home display’ to describe technology that provides near real time consumption data.

Each of the other names appears to be synonymous with every other, and they are used as such throughout literature of the past 20 years. Past research which looked at energy monitors and their effects on domestic energy consumption has not commented on the transmission rate of the monitors used in the various trials, and therefore conclusions cannot be drawn on the effectiveness of the energy monitor based on how quickly an end user receives the information.

The term smart energy monitors appears to be more prevalent in the language of utility companies and that of manufacturers and suppliers of the device. The word smart as a prefix to their supplied technology positions the device in the current media and popular vocabulary, granting it equivalent social significance to smart phones, smart TVs, etc.

An explanation for ‘smart’ in this appellation relates to its improvement over its predecessor and on newly introduced internet connectivity that enhances communication. Figure 2.1 shows examples of the most common and commercially widespread IHDs that were prevalent at the time of writing.

Figure 2.1: Examples of the most common IHD’s in UK and EU market (2011)

2.6.2.1Electricity consumption trials

Unlike the prepaid or prepayment meters, an energy monitor provides the occupant with a standalone display, which is connected, often wirelessly, to a transponder which collects consumption data via a current clamp-on clip to the wires travelling to the existing ‘dumb’ or standard electricity meters. These devices report on whole house electricity usage and perform bill-related calculations. Other smaller plug-in devices exist which record and report on individual appliance usage and costs. These are utilised by connecting them to an appliance and to a power socket. These devices have not been reviewed because whole house energy consumption is the focus of this thesis.

A variation of the whole house energy monitors are typically the device used in previous research literature, although the end display varies considerable in size, information displayed, graphical content, mobility, additional features and the types of display. Some displays can also set an alarm to go off when the load rises above a level chosen by the user, but at the very least the energy monitors in past trials present the occupant with current and historical information on their energy consumption.

Past research exploring the effectiveness of domestic energy monitors commonly follow a similar methodology; a certain number of householders can observe the display or displays for instantaneous information. The energy consumption over the set trial period is compared to control properties or to historic energy consumption spanning a comparable time period.

For research involving relatively simple displays, monitoring electricity only, and displaying numerical consumption data or non-coloured graphical data, savings are typically of the order of 5% to 15% (Hargreaves et al. 2010, Boice 2009, Mountain 2006, Dobson & Griffin 1992, McClelland & Cook 1979).

Over the past decade, authors including Langenheld (2010), Darby (2010, 2006), Owen & Ward (2010), ESMA (2009), Faruqui et al. (2009), Van Elburg (2008) & Fischer (2007) are among the few who have collated and reviewed extensively past research over a period of 30 years which has used electronic feedback mechanisms as a means of reducing domestic electricity consumption. These reviews are far reaching in terms of global projects, and document research over the past 30 years. Some form part of the wider reporting which has been presented to national and international stakeholders and governing bodies. The key findings from these reviews of past work support the common consensus that there may be a 5% to 15% savings range achieved by the use of an energy monitor that displays electricity consumption to occupants.

When the trials involved questionnaires and interviews similar to those executed by Hargreaves et al. (2010), Boice (2009) and Allen and Janda (2006), the energy monitors were very well received by the participants, with a higher portion of the trial participants stating that they would like to have such a display permanently. Furthermore, many of the participants did not want to lose the increased energy use awareness that they gained from having the monitor in their homes. In the 2006 Allen and Janda trials, all the homeowners predicted that they would not be able to retain their newfound awareness over time if the energy monitors were to be removed.

The Allen and Janda (2006) study into the effectiveness of a simplistic electricity domestic energy monitor in Oberlin, USA (n=10 homes) over a three month period concluded that the monitors have a greater effect on energy consciousness than on conservation behaviour in both high-income and low-income homes, and the monitor became an interesting information source for these households. However, no significant energy savings were realised over the first three months of the monitor’s installation. Indeed, some homeowners did not change their habits at all during the study.

A more recent 15-month pilot study was conducted by Van Dam et al. (2010) using an energy monitor referred to as the Home Energy Monitoring System (HEMS) in the Netherlands. The study explored the extent to which participants manage to sustain their initial electricity savings over time. After four months, the results showed savings in electricity consumption of 7.8%, although the study found that savings could not be sustained in the medium to long-term.

2.6.2.2 Gas consumption trials

Most of the published trials involve standalone energy monitors connected to standard meters; as a result, most studies have involved electricity consumption, not gas. Few trials exist which used an energy monitor to display household gas consumption, although there are examples from North America, the Netherlands and Australia. Hutton et al. (1986) and Van Houwelingen and Van Raaij (1989) were pioneers in using in-home displays to provide daily feedback on residential gas consumption.

Hutton et al. (1986) developed a simplistic numerical in-home display called the Energy Cost Indicator (ECI). ECI displayed current, next hour, rolling day, monthly and previous day costs to 280 homes in California, Quebec and British Columbia. The rollout of the ECI was combined with provision for extensive written feedback and guidance, with which a further 263 homes were supplied; 241 properties acted as the control sites. The report concluded that there was a significant 5.1% electricity saving for the homes in Quebec. Incidentally these were electricity only properties, had the highest energy knowledge and were in the coldest of the three trial regions. Gas savings were significant at 5% in British Columbia, compared to a group who had energy efficiency information (if an outlier was excluded), and in California for income quartile Q3 (middle class, educated). A comparison group of 263 homes (75 using gas in addition to electricity) received advice only and did not make significant savings in either gas or electricity relative to the 241 control homes. None of the effects were persistent. However, the properties given an ECI were also given additional learning material, so it is impossible to distinguish which intervention yielded the results.

Around the same time as the ECI trials in North America, in the Netherlands Van Houwelingen and Van Raaij (1989) investigated a range of interventions aimed at influencing conservation behaviour, one of which was an energy monitor similar to the ECI used by Hutton et al. (1986), referred to as the ‘Indicator’, which displayed household gas consumption. The Indicator showed two bar graphs, one depicting actual gas use and one displaying the reference normative value, normalised using external air temperature. The participants were 285 renting households who volunteered for the trial. With daily feedback through the energy monitor, a 12.3% reduction in natural gas use was achieved, more than the stated 10% conservation goal.

Ueno et al. (2006) constructed and used an on-line Energy Consumption Information System, called the ECOIS II, which they used 10 households in Kyoto Japan. The ECOIS II gave the occupants a detailed breakdown and array of information on city-gas, electricity consumption and room temperature. The consumption data was collected from the 10 households in Kyoto, Japan and the data was transferred to and analysed in a laboratory-based computer before being sent to an information terminal (a B5 sized laptop computer) in each house by e-mail. Although the ECOIS II is not technically typical of the standalone in-home energy monitor as used by the other researchers discussed here, it is pertinent to include Ueno et al.'s (2006) findings, because they conducted one of the few modern trials that included giving feedback to occupants concerning their gas consumption.

Comparisons of energy consumption before the installation of ECOIS II (period 1) and after the installation (period 2) revealed that the power consumption of many appliances and energy consumption of the whole house was reduced. Total power consumption decreased by 18% and the total city-gas consumption decreased by 9%, averaged over the 10 houses, with the ECOIS II. However, the 9 control homes without the feedback laptop experienced a total electricity consumption decrease of 5% and the total city-gas consumption increased by 0.4%. Ueno et al. (2006) conclude that the installation of ECOIS II had a certain influence on the energy-saving awareness of the residents.

A smaller study by SenterNovem (UC Partners 2009) involved interviewing 18 volunteer Dutch households, providing them with energy advice and asking them to make weekly meter readings for three months in winter. These households reduced their electricity usage by 3% and gas by 2% (statistical significance was not tested). A further 18 households received the same intervention but also volunteered to set themselves a target for energy savings and accept a new design of energy monitor on trial (showing current, highest, lowest, monthly and yearly electricity and gas consumption and cost, plus the conservation target and savings). This group reduced electricity usage by 6% and gas by 12%. However, either the savings target or the energy monitor or the combination of the two might have been responsible. The report suggests that those with a real time display will deliver superior energy saving results compared with the other methods.

Black et al. (2009) used an energy monitor in a study of student properties in New South Wales, Australia. There were 18 intervention cottages and 14 control cottages, each with 8 students per cottage. An energy consumption monitor was used in phase one of a three phase electricity and gas consumption intervention project. The phases spanned 7, 8 and 11 weeks respectively and occurred at different times of the year. The results for the use of an energy monitor showed overall electricity savings of 24% compared to the 14 control cottages, but those cottages with more electrical appliances experienced only 4% savings. The figures for gas consumption increased by 10% in the energy monitor group. In phases two and three (when an energy monitor was accompanied by social marketing on energy reduction), savings improved to 13% and 19% reductions in gas consumption respectively for the display groups.

Black et al. (2009) suggest that this may be attributed to problems with the smart meters' communication protocols. Further technical issues experienced during the trial resulted in a variable number of cottages providing useable data: those with energy monitor electricity data n=9, gas data n=7, controls with electricity data n=14, gas data n=12. Black et al. (2009) conclude that providing separate tools for real-time feedback display and social marketing support strategies has a significant influence on energy consumption behaviours, and enhances intrinsic motivations.

Trials like the one conducted by SenterNovem (UC Partners 2009) serve to support the current academic thinking that households will produce greater savings when they use an energy monitor rather than indirect methods of energy awareness. However, Black et al. (2009) supports the view that an energy monitor's ability to reduce domestic energy consumption is increased when it is accompanied by written awareness documentation.

2.6.2.3 Behaviour component

In an attempt to understand occupant behavioural patterns, Valocchi et al. (2007), who have used two differentiators (household income and personal initiative) to divide the residential customers into four main consumer categories.

1. *Passive Ratepayers – Consumers who are relatively uninvolved with decisions related to energy usage and uninterested in taking (or unable to take) responsibility for these decisions*
2. *Frugal Goal Seekers – Consumers who are willing to take modest action to address specific goals or needs related to energy usage, but are constrained in what they are able to do because disposable income is limited*
3. *Energy Epicures – High-usage consumers who have little or no desire for conservation or active involvement in energy control; these consumers are more likely to own a large number of high-consumption devices for gaming, computing or entertainment*
4. *Energy Stalwarts – Consumers who have specific goals or needs related to energy usage and have both the income and desire to act on those goals.*

Valocchi et al. (2007).

The challenge is to shift people in the direction of becoming 'energy stalwarts'.

Whereas previous research into feedback mechanisms has typically associated direct feedback with motivational and behavioural impact measures, other studies have illustrated the potential for learning or knowledge to affect feedback, which is the necessary prerequisite for behaviour in many situations.

The more recent in-home energy monitors are designed with more functionality and are typically equipped with a digital speedometer which now shows current electricity consumption. The introduction of a graphical style display to the energy monitor design was supported by the findings from the 2009 Anderson and White focus group report, in which five groups commonly preferred an energy monitor to have a simplistic graphical display to provide an ‘at a glance’ level of current consumption. However, the numerical values are also important for conveying more accurate information.

The conclusions from the semi-structured interviews conducted by Hargreaves et al. (2010) involved three types of energy monitors with a graphical display, which ranged in complexity:

(1) A simplistic monochrome grey speedometer display.
(2) A coloured speedometer which did not differentiate the intensity of consumption by use of colours – i.e., it was not a traffic light system.
(3) A complex graphical user interface, similar to the design of smart phones and tablet computers.

Only the more complex model provided feedback on the home heat source, but this was not representative of real time energy consumption because the monitor displayed a percentage amount for the length of time the boiler had been in operation, updating in 15 minute increments

Because all the participants of the trial where volunteers, Hargreaves et al. (2010) noted that motivations for acquiring an energy monitor varied and expectations of the device varied accordingly. Participant motivations where broken down into:

- Financial
- Environmental
- Information curiosity
- Early technology adopters

Those who were motivated by saving money expressed a sense of disappointment when they had not saved the money they expected, and further frustration that rising fuel tariff prices would further hinder their attempts to turn reduced energy consumption into tangible financial savings. Those primarily motivated by the environmental impact of their energy use were also the only ones who reported that their behaviour ‘spilled-over’ into other areas of their lives, i.e. recycling and travel. A third group, motivated primarily by the desire to see information pertaining to their own energy usage, voiced frustration with the simpler energy monitor, and would have preferred more complex interactive displays with wider capabilities so they could analyse and present consumption data in different ways. The final group appeared to be interested in the technology and the design of the display. Feedback from this group praised the appearance and simple colour graphics of the two simpler models, whereas the complex model was criticised for its complexity and appearance.

Similar to the work of Allen and Janda (2006), the implication of these motivational types seems to suggest that there is no single way of encouraging households to use an energy monitor or to focus that use on energy savings. The match between the way the device is presented to potential users and the main motivation of the target group may be a critical factor in the success of interventions (Darby 2010b). When extrapolating these findings into the wider national rollout arena, in this context it may be prudent for installers to have a set of options with which to present the device to different households.

Hargreaves et al. (2010), UC Partners (2009), Anderson and White (2009) and Kidd and Williams (2008) concur that the energy monitor devices in their trials received praise from their respective participants and comment on users’ ability to understand the device easily. Users in past studies have held discussions in the household to explain energy consumption to children. Users found that the energy monitor motivated them to apply known conservation strategies by showing their effects. This is supported by Van Houwelingen and Van Raaij (1989), who report that the main use of the energy monitor they tested was to monitor the effects of efforts to reduce consumption. The important implication is that the energy monitor can be more effective in maintaining conservation behaviour than initiating it.

The science of behavioural change crosses the boundaries of psychology, sociology, ergonomics and economics; it also relates to engineering and product design (Darby 2010b, Darnton 2008). However, many researchers in this field comment on the dangers associated when a 'fit and forget' attitude to interventions such as the provision of an in-home display, because such an attitude will tend to lead to savings only for people who already have the motivation and understanding to make use of interventions. Others will need additional support and/or exceptionally good design to make the display or site immediately engaging and self-explanatory. Once no-cost energy-saving responses are exhausted, many householders need guidance on how to access any available resources to invest in energy efficiency (Darby 2010b).

It has been found that individualised energy use information in the form of better bills, periodic feedback and continuous feedback can lead to reductions in energy use. Overall, the literature demonstrates that clear feedback is a necessary part of learning how to control fuel use more effectively over a long period of time and that instantaneous direct feedback, in combination with frequent, accurate billing (a form of indirect feedback), is needed as a basis for sustained demand reduction. Thus feedback is useful on its own, as a self-teaching tool. It is also clear that it improves the effectiveness of other information and advice in achieving better understanding and control of energy use, which addresses one of the key points attributed to the behavioural barriers noted by Weber (1997) and Logica (2008).

This conclusion depends heavily on research from outside the UK, with little of it from temperate climates, so relative expected percentage savings in the UK are difficult to estimate. However, a base level effect of energy monitors alone could be less than 3% electricity savings, whereas supplementary interventions that increase engagement could double or triple the benefit. Far fewer studies have tested effects on gas consumption. They have generally shown a benefit; while it is not feasible to quantify it, savings tend to be of a similar order to those for electricity. As noted in previous sections, informative billing alone does not easily allow users to learn or improve their energy conservation habits through trial and error. The inherent time lag involved in billing somewhat hinders end users from identifying which behaviour or appliance contributes most to their energy consumption.

2.6.3 Ambient displays

Ambient displays rely on displaying and attracting the attention if the end user through the use of colours. Darby (2006) and Martinez and Geltz (2005) refer to this as the ‘pre-attentive’ processing of presenting information. These types of monitors are not always accompanied by numerical or text display, but primarily rely on changing colour to alert the householder to the fact that something relevant to their electricity consumption or supply has changed or is about to do so.

Some direct displays can be programmed to sound an alarm when the load has exceeded a given level (a more user-friendly version of the load-limiting trip switch). A flashing light was used to alert a sample of American householders that the outdoor temperature had dropped below 68°F and it was time to turn off the air-conditioning and open windows for cooling instead. This gave savings of 16% over a three-week period, whereas the group without it achieved only 7% savings (Seligman et al. 1978). In a similar study, Van Houwelingen and Van Raaij (1989) used an energy monitor that included a signal light simply to show when the gas heating was on; the energy monitor increased savings by 12.3%, but there is no evidence that this specific function of the energy monitor was responsible for the savings.

Martinez and Geltz (2005) describe the testing of an ‘energy orb’ which changed colour according to the time-of-use tariff in operation. The orb flashed during the two hours before a ‘critical peak’ with high unit costs, and users who tried it out tended to reduce consumption well in advance of the peak and to continue with the reduction for some time afterwards. As a consequence, there was some overall saving as well as load-shifting.

In their study of ecoMeter use by university students, Black et al. (2009) note that “often power was reduced because the unit displayed red”. The SenterNovem ‘PowerPlayer’ trial participants appreciated the green and red signals on their displays which indicated whether they were meeting their target consumption for the day. Hargreaves et al. (2010) used three GEO energy models, two of which had a coloured display; the more complex version (similar to a tablet computer) provided the user with a variety of pages on which to view their energy, one of which showed a cartoon character who change colour in a traffic light fashion depending on the level of electricity consumption. However, the effectiveness of this particular function was not discussed by Hargreaves et al. (2010). Feedback from the users indicated that the coloured display was more appealing and eye catching and was easier for young children to engage with. Early findings show a mostly positive response to ‘traffic light’ coloured utility monitors.

There are other commercially available products that use changing colours to indicate consumption level. Versions in the USA typically utilise the traffic light colour code to indicate the change in time of day tariff structure and not the intensity of energy consumption. The Wattson energy monitor in the UK uses colour to indicate consumption intensity: it uses blue, purple and red, not the more common green, amber and red system, to indicate consumption level. Little is known of its effect on energy consumption or behaviour because it has not yet appeared in academic study. Although this monitor utilises colour to attract the attention of the end user, its functions and numerical display are limited compared to other energy monitors. With no option to insert personal tariffs, the monetary consumption level is displayed as an extrapolated yearly figure using a pre-set tariff. Furthermore, the device relies on its downloadable function and accompanying software to provide users with consumption data that most other monitors provide directly on the display such as daily consumption, historic consumption and carbon dioxide emissions.

When designing their own energy monitor, the focus groups that took part in the Anderson and White (2009) study commented favourably on an energy monitor that possessed the ability to change colour in order to attract users’ attention to an increase in energy consumption. It is notable that the groups who designed a coloured visual display later changed their design from a single light to a coloured moving bar design. This preference was also found amongst the other three groups. One group, which initially favoured just a digital display, abandoned it in favour of a similar moving coloured ‘speedometer’ design. Although the groups valued the accuracy provided by digital figures, every one of the final designs included a graphic indicator of the current rate of electricity consumption.

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, the same means should be used for gas as for electricity. When analysing the effectiveness and design of home energy monitors, Van Dam et al. (2010) noted that the use of colour in an energy monitor can be make the interface understandable to users.

There is some research that supports the use of ‘ambient’ signals to customers. However, similar to other studies using energy monitors in consumer trials, not much research has been done into the measuring and displaying of household gas consumption, especially in the UK climate.

The work carried out by Van Dam et al. (2010) concludes that certain groups of people seem more receptive to energy-saving interventions than others. These participants quickly develop new habits and exhibit larger savings than other participants. They warn that a ‘one-size-fits all’ approach to home energy monitors cannot be justified. For energy monitors to be effective, a deeper understanding is needed that embraces social science, contextual factors, usability and interaction design research.

2.6.4 Summary of monitors used in previous trials

Table 2.1 tabularises the relevant data from a list of energy monitors that have been utilised by past academic authors. The list is a selection of trials using only independent energy monitors (not requiring a home computer), providing information on both electricity and gas consumption. Three of the more recent trials using electricity only monitors have been added to provide chronological context. Table 2.2 shows examples of the various energy monitor displays that have been used in trials as listed in Table 2.1.

Author	Monitor name	Country	Year	Duration	Monitored utilities	Number of occupants with energy monitor	Trial type	Coloured Display	Results
1. Deremer	PowerCost monitor	California, USA	2007	12 months before and 12 months after install	Electricity	300	Compared to previous year's consumption (pairwise sample)	No	13% reduction
2.Allen and Janda	The Energy Detective (TED)	Ohio, USA	2006	30 months	Electricity	10	Compared to 50 control properties	Flashing LED	13.6% reduction
3.Van Dam	Home Energy Management Systems (HEMS),	Utrecht, Netherlands	2010	15 months	Electricity	93	Compared to 189 controls	No	7.8% reduction not sustained after 4 months
4.Hutton	Energy Cost Indicator (ECI).+ literature to reduce energy consumption	British Columbia	1986	12 months before install and 12 months after	Electricity and gas	93	Compared to previous year's consumption (pairwise sample)	No	2.7% increase to for gas. 5.1% reduction in electricity consumption
5.Van Houwelingen and Van Raaij	Indicator based on the Energy Cost Indicator (ECI)	Utrecht, Netherlands	1989	36 months	Gas	50	Compared to 55 control properties	No	12.3% reduction
6.Senter UC partners	Power player	Amsterdam,	2009	3 months	Electricity and gas	18	Compared to 55 control properties	Yes	4% electricity and 13% gas reduction
7.Black	EcoMeter	New South Wales, Australia	2009	24 months	Electricity and gas	9	Compared to 14 controls	Yes	4-24% for electricity, and 10% increase for gas*

*Original author suspected that equipment malfunction was responsible

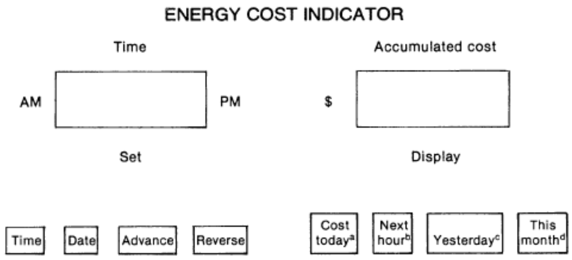
Table 2.1: Previous Studies including Energy Monitors

1.

2.

3.

4 & 5.



6.

7.

Table 2.2: Energy monitors in-home displays used in the trials listed in Table 2.1

1. The PowerCost monitor

2. The Energy Detective

3. No descriptive evidence exists about the HEMS used by Van Dam (2010), although the literature review stage of the report makes reference to the common HEMS having a display like that presented above.

4 & 5. The energy cost indicator, as described. No images of the indicator and energy cost indicator exist. This technology was described as a specific energy display device developed for the research project. The authors describe the

feedback information and the physical properties of the ECI were developed as a result of information provided from literature reviews, focus group interviews with consumers, personal interviews with manufacturers and retailers and laboratory testing at the National Bureau of Standards
6. powerplayer
7. Ecometer

There are no graphical displays or coloured speedometers on the TED energy monitor, except for the consistently flashing green LED, which is not an indicator of consumption intensity or levels but rather an indicator that the monitor is operating. The users in the trial spoke of the monitor's ability to attract attention with the blinking LED (Allen & Janda 2006).

Not included in Table 2.1 because it was a qualitative study, but still relevant, are the various coloured IHDs utilised by Hargreaves et al. (2010). This is one of the few studies that involves an energy monitor with a graphical display. The only IHD in the trial that displayed consumption in a coloured range received mixed reviews, many of which spoke negatively of its complexity but nonetheless believed that colour was a good way of alerting users to occasions of high consumption.

Similarly, qualitative results from a study in Australia (Black et al. 2009) involved the use of coloured lights presented in four squares below the bars charts in the main portion of the display. The lights were set so that the one lit square (green) indicated current use was below 1 kW; two lit squares (both green) indicated use of between 1 and 2 kW; three lit squares (two green, third yellow) indicated use of between 2 kW and 4 kW; and all four lights (the fourth being red) illuminated when 4 kW or more was being used.

The pre-set levels of kilowatts to colours may serve to disillusion large family households, who could rarely stay below 3 kW, resulting in the monitor becoming ignored and rendered meaningless. Otherwise, the conclusions from the Black et al. trials indicate that conservation behaviour may have been modified because the monitor displayed red when consumption levels where high.

The monitor used in the trials reported on by SenterNovem and the monitor's manufacturers, Nuon, also resembled that of a tablet computer, providing the user with a dedicated 'webpage'-like screen to further scrutinise their energy consumption using an array of charts and graphs. Although the monitor does utilise green and red to indicate when the household is inside or outside a user-set consumption target, these colours are displayed so that the user can analyse a cumulative figure. Interestingly, the study did not address the user's perception of this particular coloured functionality of the Nuon.

After a review of the past and commercially available IHDs, the Ewgeco IHD was selected for this research, and is reviewed here. The Ewgeco shares various qualities with other energy monitors, but the key difference between Ewgeco and other currently commercially available monitors is its ability to monitor and display domestic gas consumption in colour, in real-time and alongside electricity consumption.

The Ewgeco monitor has a simple screen, and again it shares many properties with the monitors used in past academic trials. However, a number of differences remain between Ewgeco and those monitors tested by the author, as is shown in Table 2.1, and chief among them is the way in which Ewgeco presents consumption information to the user. A large portion of the display is dedicated to conveying consumption levels in the easier to understand context of identifiable colours, and furthermore the Ewgeco monitor also has a numerical display that reinforces the information presented by the coloured speedometer.

In addition, there are more functions available, as listed at the start of this section. Similar to the more modern monitors, the Ewgeco is always on, so in order to see different information, users must invest time in learning how to operate the various buttons that enable them to use additional features and to view consumption in different units.

In essence, the Ewgeco monitor improves the informational features of early electricity and gas monitors without adding the scope for charting and presenting data graphically. In this it is similar to the monitors made available from the newly emerging generation of computerised tablet-style energy monitoring. This study (covered in chapters 5 and 6) investigates whether a clearer real-time coloured feedback display for gas and electricity such as Ewgeco is effective in helping residents to understand and change their energy use, and how this effect is related to household characteristics and attitudes.

2.7 Potential of smart meters for different actors

The current fluent nature of the UK energy market, with large targets that must be met in relevantly tight timelines, should be considered. The Ofgem consultation in 2005 on the regulatory implications of domestic-scale micro generation is relevant: increasingly, householders are becoming generators as well as consumers of energy, and the introduction of a smart grid may allow for improved control, given the involvement of micro-renewable electricity generation, and address the intermittency issues attributed to this form of generation.

Darby (2010b) argues that the placement of smart metering within the parameters of the UK's metering infrastructure to create a smart grid or advanced metering infrastructure (AMI) is a promising way of developing the UK energy market and contributing to social, environmental and security of supply objectives. The Smart Metering Working Group estimated that meters offering more information to consumers could help to reduce household consumption of gas and electricity, in addition to other potential benefits (SMWG 2001). However the European Directive (EU Directive 2009/72/EC) requires a substantial improvement in the information given to energy consumers and there has been a considerable debate on the future of metering in the UK.

Authors addressing the implementation of smart meters as part of the UK energy infrastructure seem to suggest that AMI will lead to reductions in both the demand and the cost to serve customers through improved communication, but little evidence exists to show an overall reduction in demand.

Darby (2010a), reviewing smart metering for the UK under the scope of affordances, concluded that the advanced metering infrastructure, encompassing smart meters, will possess different benefits for different groups as part of the overall energy chain.

Throughout most of the last century, the electricity or gas meter has been an essential but very modest element of energy infrastructures. The introduction of smart metering or advanced metering infrastructure (AMI) is changing that. Smart metering is heavily promoted as an essential part of the transition to lower impact energy systems and as a means of customer engagement. For electricity, where most attention is concentrated (correctly), it is also seen as a step on the road to the smart grid – a highly complex, self-balancing system (Darby 2010a):

- From an international stand point, recent research has indicated that smart metering may bring about carbon emissions reductions and better supply management.
- At a national level, there is the prospect of improved customer relations, with the smart meter acting as a communications hub.
- At local level, smart metering increases the frequency of information for householders, leading to demand and cost reduction, at the same time affording the possibility of electrical load micro-management to the utility.

When all energy use is monitored by smart meters, grid companies will receive a much more accurate overview of energy consumption in their region. This means that they can examine suspicious areas where energy use is higher than expected, and thus smart metering will give grid operators the ability to detect fraud. In times of electricity shortage, the grid operator has the option to limit electricity use.

Gathering all data, the grid operator will be able to predict electricity use more accurately and use this knowledge in network and maintenance planning. The automation of the data collection process, with a higher frequency of more recent data, will put higher requirements on systems (Van Gerwen 2006).

The benefits from a roll out of smart meters with a visual display accrue to a number of actors:

- To consumers in terms of accurate bills.
- Accurate and real time information to enable them to manage energy consumption and potentially receive new services.
- To suppliers in terms of more frequent and improved accurate information.
- Reduced costs to servers and to society in terms of reduced carbon emissions.

There are also potential benefits for network companies from the use, subject to appropriate controls, of data collected through smart metering to better manage the electricity network.

When looking through the scope of assessing the effectiveness of smart metering for customer engagement, the answers depend on how, and for whom, the smart metering is designed. Darby (2010a) and Langenhald (2010) agree that more work is still needed to establish the forms of interface, feedback and support that will be most useful in reaching diverse populations. In particular, there is a need to ensure that disadvantaged groups do not suffer as a consequence of developments in metering and tariffing

Demand response by domestic energy users is not yet a common practice, but would be enabled by smart metering. Smart meters are capable of limiting or even cutting off the energy use when triggered by market developments. Van Gerwen, (2006) suggests that when all households in a country are able to adapt their energy use during a period of high prices or diminished availability the reliability of supply would be improved and energy market transactions, energy savings, energy awareness and energy efficiency would be enhanced. These long term advantages of smart meters may well contribute to the energy policy goals of governmental bodies.

2.7.1.1 Smart meter energy monitor

With the understanding that smart metering was developed initially to address the need for electrical load control by suppliers, the development of advanced metering infrastructure has gone some way towards revolutionising how energy is generated, distributed, used and purchased. Many authors commenting on the achievable objects of smart metering argue that demand reduction will not necessarily flow naturally from an improvement in information brought about by smart metering (Darby 2010a). Rather, smart metering and the smart grid are merely the instruments and vessels that will be used to improve the consistency, accuracy and speed of information pertaining to the generation and use of electricity and the use of gas. Essentially, the end result will be determined by how the information is utilised by different actors in the energy chain – only then will possible reductions in carbon emissions be made tangible.

Langenheld (2010) and Wissner (2011) argue that, despite several years of claims for smart metering, its actual implementation at the household level is in its infancy and there is little hard evidence yet about what AMI can actually achieve. A sceptical approach to smart metering is presented by Darby (2010a), who suggests that smart metering alone cannot incite customers to engage with their own energy appliances. However, this means of automating the collection of domestic consumption data may in turn allow for improved and more informative billing, which has been demonstrated to provoke energy conservation. Nevertheless, energy consumption behaviour may begin to be modified only after in-home energy monitors that provide instantaneous feedback are included.

Currently there is much to be learned about householder engagement from experience with consumption feedback in the absence of smart meters: how customers interpret and use feedback information; what they wish to see in the future; and how feedback may be combined with effective advice and other support. The literature shows an interest in, and even an enthusiasm for, simple and direct messages about energy costs over time and for relevant, trustworthy comparisons. Smart metering might facilitate these, but further work in real life situations is needed to validate these claims.

A smart meter is still a meter, and it can only take, store and transmit measurements at frequent intervals. In other ways, however, they are highly complex. A vast range of possibilities are opened up by the addition of communications technologies to metering, and these are exploited in different ways in different contexts.

Using the energy monitor as a tool to increase the amount of understanding and learning in the hope of encouraging end users to manage their energy consumption is a core part of provoking and possibly maintaining reductions in domestic energy demand. This IHD technology provides a mechanism for occupants to explore and define the most suitable techniques for expanding their knowledge of energy conservation and having a positive effect on their utility bills.

2.8 Conclusion

In the implementation of domestic energy and environmental rating schemes for homes, a fabric first approach is often adopted for new build and retrofit construction projects in an attempt to reduce energy demand, in particular with regard to reducing demand for heating. The addition of micro renewable technology for on-site generation is becoming more widespread, although the number of installations is linked to the funding mechanism, performance requirements and financial incentives attached to the type of on-site generation. With the implementation of smart metering technology, this third factor has a key role in reducing carbon dioxide emissions. However, encouraging consumer behaviour via energy display information is potentially of more significance than utility smart metering. This chapter has discussed the variations in impact and effectiveness of previous studies into home energy displays (IHDs). It has also reviewed the role of feedback information through historical diverse trials on consumer information.

The next chapter will discuss the methodologies used in this research and projects to gain a greater understanding of one of the most recent innovations in in-home displays and its influence on occupant energy use behaviours for electricity and gas.

Chapter 3

3 Methodology and Research Techniques

3.1 Introduction

This research focuses on measuring the effects of the introduction of an in-home energy display (IHD) into socially rented housing association properties. This is achieved by logging the changes in the social houses' energy consumption and concurrently observing any changes in occupants' energy use behaviour.

It is expected that providing a sample of housing association tenants with the means to view their electricity and gas consumption in real time will generate an energy learning experience. This learning experience could serve to further demystify the relationship between domestic energy consumption, rising fuel costs and carbon dioxide emissions to the occupant.

Investigating the relationship between domestic energy consumption and the presence of real time IHDs has become more important in the wake of the DECC's decision to include IHDs in its roll out of smart meters.

3.2 Methodology for energy monitor research

This work specifically focuses on domestic energy consumers, who represent 27% of UK energy usage. It explores the impact of smart energy monitoring technology on domestic electricity and gas demand. Through the use of semi-structured interviews, the relationship between information provided by smart energy monitors and the occupants' behaviour relating to their demand for and use of energy is investigated.

The work sets out to assess how domestic residents interact with energy (both electricity and gas) display monitoring technology, and how this behaviour affects carbon reduction, energy saving and fuel poverty.

The strategies used in this study reflect those of previous trials, and utilised a stand-alone in-home energy monitor (IHD) to display and record household energy consumption. Details of the IHD and the installation methods are presented later in this chapter. The impact of the feedback provided by the monitor is documented through a series of questionnaires and interviews.

In order to capture the energy consumption pattern from domestic dwellings, and to potentially influence domestic habitual behaviour concerning electricity and gas consumption, a device is required which will record and store the hourly consumption levels of both utilities and also display this information to the occupants. A device known as Ewgeco, an acronym for Electricity, Water, Gas, ECOlogical, was selected for this task. Further information on semantic terms for this product along with more detail on its genesis and early use in research is discussed in section 2.6.2 of Chapter 2.

The electricity, water and gas ecological energy monitor (hereafter referred to as Ewgeco™ IHD) is a standalone, in-home energy monitor designed by Tayeco Ltd in Perth, Scotland. A multi award winning device, the Ewgeco IHD came to market in 2007 and boasts of being the world’s first energy monitor to present the consumption levels of three diverse utilities simultaneously (electricity, water and gas). For this trial only the dual utility function is employed for electricity and gas).

The Ewgeco system serves two functions. Firstly, the Ewgeco logger collects and recorded the dwellings’ electricity and gas consumption, and secondly the Ewgeco displays this information in a range of formats to the occupants.

The Ewgeco IHD coloured dual fuel smart energy monitor was chosen for the trial because it combines all the basic numerical display functionality, as used in previous trials, with a coloured display and is the first UK IHD to display gas consumption alongside electricity consumption with near real-time data streaming from meter to display.

The research reports the findings from two points over this longitudinal research project. The end of the TSB funded project in February 2011 provided energy consumption and user feedback data for a six month period and marked the end of that phase of the project. The data for Phase 1 corresponds to two housing association sites, a total of 52 properties, 21 houses from one housing association site and 31 flats from the other.

Further funding via the Low Carbon Building Technology Gateway (LCBTG) was acquired in Q4 2013, allowing for a return visit to one of the original housing association sites, providing 20 data sets for the flatted accommodation. This monitoring period is referred to as Phase 2. The quantitative and qualitative data captured in October 2013 provides important information relating to the long-term relationships between occupants and their energy consumption pattern in relation to the IHD. Phase 2 provides an additional 31 months of data for 20 of the housing association tenants living in flats who were involved in the earlier 2010-2011 study.

3.2.1 Hypothesis and objectives

The data from the intervention group is compared to that of a control group. A Ewgeco energy logger was installed in all participating households. However, those properties elected to be part of the control group had no visual access to the Ewgeco IHD and were given no other form energy feedback or advice from the project team.

Through the use of the IHD, the conditions by which the occupants typically view their consumption has been designed to provide instantaneous feedback, whereas the control sample continue to view their consumption levels by whatever means they were previously accustomed to. The presence of the Ewgeco IHD was the only variable introduced by the research project. The project team did not affect or control other forms of energy saving advice to either group during the full project duration. Each group was free to receive or explore other forms of energy saving information that they would otherwise have received in non-experimental conditions such as in the post, on TV or from the utility company.

For the Phase 1 data, the following hypotheses were tested regarding the effects of feedback through the Ewgeco (IHD) on electricity and gas consumption levels and energy use behaviour:

- The null hypothesis (H0): the energy consumption difference between the intervention group and the control group will not differ significantly over the trial period.

- Alternative Hypothesis 1 (H1) (experimental hypothesis) directional (one tailed): the intervention group living in houses will consume less gas than the control group.

- Alternative Hypothesis 2 (H2) (experimental hypothesis) directional (one tailed): the intervention group living in houses will consume less electricity than the control group.

- Alternative Hypothesis 3 (H3) (experimental hypothesis) directional (one tailed): the intervention group living in flats will consume less gas than the control group.

- Alternative Hypothesis 4 (H4) (experimental hypothesis) directional (one tailed): the intervention group living in flats will consume less electricity than the control group.

Phase 2 of the research focused on measuring the longer term trends in electricity and gas consumption and energy use behaviour for the two research groups after the first short monitoring period. Phase 1 had a six month monitoring period, by the end of which most of the occupants had only been in residence for eight to nine months. During this time each household was visited and interviewed three times by the author.

Phase 2 was designed to allow the occupants of the properties to develop and settle their energy consumption routines and to give the occupants time to develop their own relationship with the IHD. Phase 2 sought to evaluate the effects of the IHD on energy consumption patterns and energy behaviour after the first six months of interaction with the device. It also sought to assess the relevance and priority of the IHD 31 months after the author disengaged with the sample population.

For this part of the research, the hypotheses relate to the energy consumption and usage behaviour of each participant, measured against themselves over time. The hypotheses are as follows:

- The null hypothesis 2 (H02): the energy consumption difference between the intervention group and control group will not differ significantly by the end of Phase 2.

- Alternative Hypothesis 5 (H5) (experimental hypothesis) directional (one tailed): the intervention group living in flats will have continued to consume less gas than the control group by the end of Phase 2.

- Alternative Hypothesis 6 (H6) (experimental hypothesis) directional (one tailed): the intervention group living in flats will have continued to consume less electricity than those in the control group by the end of Phase 2.

The objectives are divided into two main themes, over two time frames. A dual fuel IHD was used to engage a sample of the social housing population; therefore, the themes of the objectives, like the hypotheses, are divided into two groups: (1) changes in electricity consumption and (2) changes in gas consumption. It is expected that any changes in gas consumption that are a result of the IHD may not be directly linked to changes in electricity consumption by the same participants. This is sub-divided again by the apparent links between changes in consumption patterns and the occupants' energy use behaviour.

- Quantify the change in electricity consumption from each participant with a dual fuel IHD over time, and compare it to similar control properties.
- Analyse the change in the 'self-reported' use of electricity appliances and equipment, over time, and compare it to similar control properties; cross reference questionnaire responses with actual recorded energy consumption.
- Quantify the change in gas consumption from each participant with a smart dual fuel energy display over time and compare it to similar control properties.
- Analyse the change in 'self-reported' use of heating and hot water systems, over time, and compare it to similar control properties; cross reference the questionnaire responses with actual recorded energy consumption.
- Define the attitudes of the user towards the energy monitor and their perception of the purpose of the device and its overall functionality.

The objectives above are the same for the two monitoring phases. The overarching aim for the results from Phase 2 is to:

- Evaluate the ability of the coloured dual fuel IHD to maintain longer term behaviour change.
- Evaluate the role of the coloured dual fuel IHD in the daily routine and lifestyle of the users.

3.3 The test sample

The selected test group combines 52 newly built properties across two locations in the East of Scotland. Two locations are utilised in the study with a good number of almost identical rental housing association houses and flats. The village of

Windygates in Fife provides the study with 21 newly built two storey semi-detached houses. A newly constructed annex to an existing estate in Edinburgh's North East quarter was also chosen because it offers 31 newly built flats. Both sites are supplied with mains electricity and gas (for space and water heating), and furthermore control properties are present on both sites. These are the focus of the analysis and discussed later in Chapters 4, 5 and 6.

The test group is sub-divided into 'properties with' and 'properties without' energy monitoring IHD technology. Those properties without an IHD energy monitor on display are referred to as 'control' properties. 31 (60% of the total 52 participating properties) flats and 21 (40% of the total 52 participating properties) two storey semi-detached houses were selected. This is further broke down into 12 (23%) houses and 18 (35%) flats with the IHD energy monitor on display and 9 (17%) houses and 13 (25%) flats without access to an IHD energy monitor. Both sets of properties were constructed as part of separate housing association low income housing developments in Summer/Autumn 2010. The Ewgeco IHD was preinstalled before residency. Initially the same number of IHDs were allocated to each group – the final figures for each site were dictated by participants dropping out of the study. The total number of control properties in the study was 22 (42%) and the total number of intervention properties was 30 (58%).

The study was repeated in October 2013. Access was made available to one of the housing association sites in which 31 social housing tenants living in flats had provided 6 months of energy consumption data and responded to interviews in 2010 and 2011. During the 2013 study, 20 of the same participants provided energy data and completed interviews. The data analysed for the 31 months following the initial 6 month data set is referred two as Phase 2. For this phase, 13 (62%) flats provided the data for the intervention group (the sample with the Ewgeco IHD on display) and 8 (38%) flats provided data for the control group (the sample without access to the Ewgeco IHD). The remaining 10 properties on this site, who contributed during the 2010-2011 study, were removed from the 2013 data collected because of the following reasons:

- Participants had moved out of their respective properties, n=8

- The Ewgeco logger had malfunctioned, losing significant amounts of data, n=1.
- Participant no longer wanted to take part in the study, n=1.

3.4 Sample occupancy and building characteristics

Participants' experience with energy saving devices and knowledge of their utility provider may create systematic variations which cannot be dissociated from the effect of the experimental manipulation. Therefore, to reduce this eventuality, the participants from the different occupancy levels within each of the property types were randomly allocated to each condition.

Forming part of the prelude to the analysis conducted in Chapters 4 and 5, a number of independent T-tests were carried out to identify any statistical differences which may have skewed the results between the properties with and without the Ewgeco IHD. The profiling information collected during the first visits to the participants was used to categorise the properties and their occupants.

The first of the T-tests focused on differences between the occupants. The results showed that there was no statistically significant difference ($p=>0.05$) in any of the parameters tested below in either of the divided sub-sample groups (i.e. dwelling types, flats and houses):

- Income
- Age
- Occupation
- Number of adults
- Number of dependents
- Whether they were a support tenant
- Number of appliances
- Types of equipment

Additionally, based on a list of figures calculated through the Standard Assessment Method (SAP), a T-test was used to identify any difference between the dwellings based on the building characteristics:

- Number of bedrooms
- Orientation
- Property size
- Total heat losses
- Total heat gains
- Predicted space heating requirements
- Predicted water heating requirements
- Predicted electricity requirements (lights, fans and pumps)
- Primary energy requirements for the dwelling

The T-tests revealed no significant difference ($p=<0.05$) between any of the parameters listed above for either Phase 1 ($n=52$) or Phase 2 ($n=20$) of the data analysis.

Furthermore, during the first interviews, the two groups in each of the dwelling types were asked to respond to a series of questions which sought to test the difference between the intervention group and the control group. The questions were broken into three main sections:

- Understanding of the energy bills
- Electricity and gas consumption habits
- Opinions about the energy performance of their new homes

No significant difference was detected between the intervention group and the control group for either of the dwelling types for either Phase 1 or Phase 2 ($p=>0.05$). This result demonstrated that both groups shared similar views and opinions on their knowledge of their energy bills, had similar energy consumption behaviour and similar views on the energy performance of their dwelling the beginning of the study. These results evidenced a close sample group; therefore the factors tested above are very unlikely to have influenced the energy consumption of the properties in the trial.

The opinions and views relating to energy use and the Ewgeco energy display device were collected using questionnaires, which formed part of a typically one-hour long interviewing process. The qualitative results from the trial are further detailed in Chapter 5, but a number of quotes from end users are pertinent to this chapter because they reinforce certain aspects of the findings.

Phase 1

All the participants who provided energy consumption data also took part in the interviews. The participant characteristics of the occupants involved were as follows:

- A total of 52 properties took part in the study.
- Properties contained one (27%), two (65%) or three (8%) bedrooms.
- The number of occupants in each property ranged from 1 to 4: 1 (31%); 2 (40%); 3 (17%); 4 (12%).
- The age of respondents ranged from 18 - 68 years (mean=39 years; SD=13.9 years).
- Only 28 of the 52 respondents provided information about their household's annual income. Of these, 79% earned less than £20,000, and 4% earned over £45,000 per year. The mean annual household income for this group was £15,087 (SD=£8,347).
- The respondents' occupations were 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%). The categories for defining a respondent's occupation are derived from the 'major groups' as detailed by the Standard Occupational Classification 2010 (ONS 2010)
- 64% of occupants were 'key groups' such as retired, unemployed or medically unable to work. The term key group is used here to define those whose financial situation is fairly fixed and who have a limited expendable income. They are perhaps the most susceptible to rising fuel bills and most likely to be in fuel poverty. This definition is an interpretation on what the DECC (2014a) refer to as 'most vulnerable'. The definition here of 'key group' does not

explicitly include children and does not differentiate between those classified as retired, unemployed or medically unable to work who do or do not have young dependents. 48% of the participants had between 1 and 3 children (under the age of 16) living full time in their home.

Phase 2

During the 2013 revisit, 20 of the same tenants were again recruited to provide an additional 31 months of energy data, and the interviewing process was also repeated with these occupants. The participant characteristics of the occupants involved were as follows:

- A total of 20 properties took part in the study.
- Properties contained one (38%) or two (62%) bedrooms.
- The number of occupants in each property ranged from 1 to 3: 1 (43%); 2 (43%); 3 (16%). The breakdown of occupants in each flat had changed from 2011 to 2013. Three of the flats that had two occupants during 2010-2011 and had three during the 2013 survey. Additional persons included the additional of a live-in care worker for one and new born child for the other two.
- The age of respondents ranged from 26-70 years (mean=48 years; SD=13.4 years).
- Only 13 of the 20 respondents provided information about their household's annual income. Of these, 92% earned less than £20,000 and 8% earned over £45,000 per year. The mean annual household income for this group was £13,533 (SD=£10,987).
- The respondents' occupation remained unchanged by the time the 2013 interview was conducted. The responses were as varied for Phase 2 as for Phase 1. Unemployed remained the largest single category with (33%), followed by medically retired or disabled (24%); retired (14%); caring, leisure and other service occupations (10%); and process, plant and machine operatives (10%).
- 71% of occupants were 'key groups' such as retired, unemployed or medically unable to work.

3.5 Apparatus installation and limitations

The Ewgeco system comprises a fully portable visual display powered by a detachable cradle, sensors and a transmitter. The two sensors are connected to or near the respective utility meters. The sensors are wired to a transmitter, which in turn sends information (wirelessly) to the display. Figure 3.1 simplistically illustrates how the Ewgeco system collects and sends consumption information to the display.

Electricity use is collected via a current clip attached to the electricity cable, which connects the meter to the consumer unit. The gas usage is measured using a pulse block, which is attached to the pulsed output portion at the front of the gas meter. When the data reaches the Ewgeco IHD, it is recorded and displayed in a number of formats.

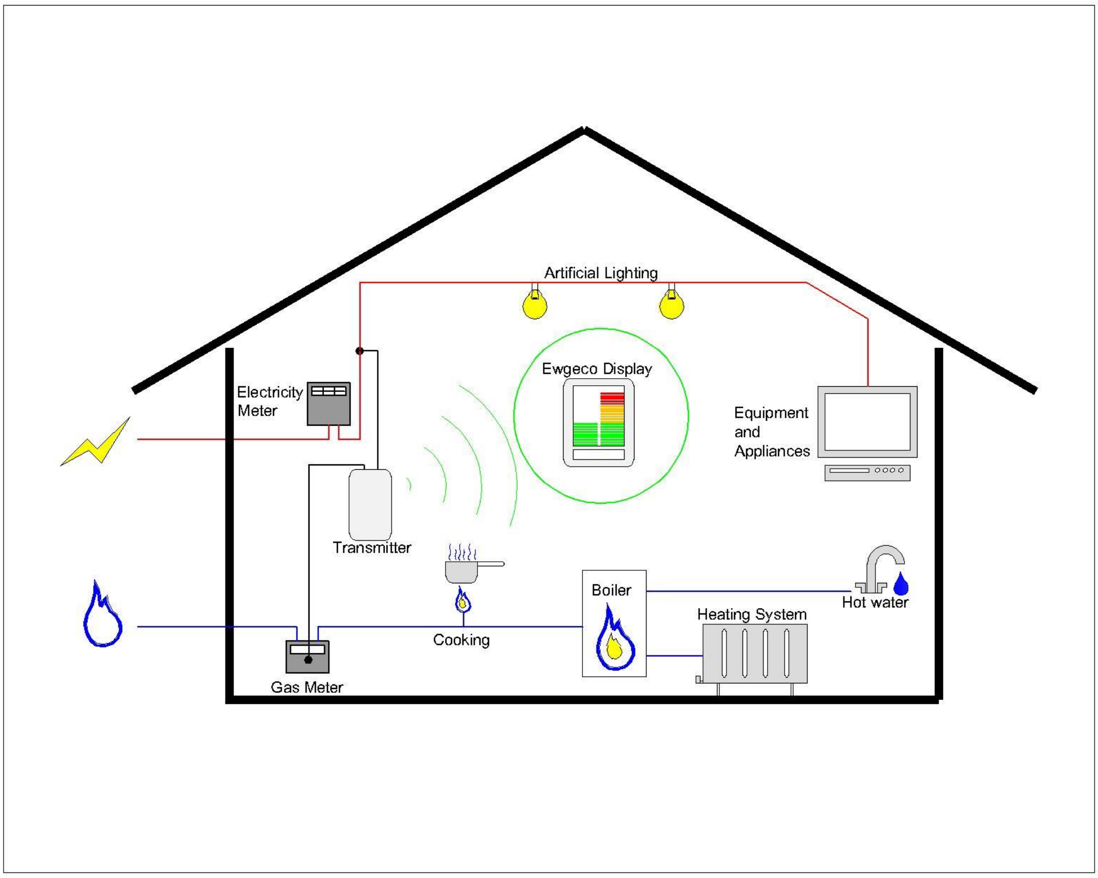


Figure 3.1: Schematic of Ewgeco's Insertion into the Home

As discussed earlier in this chapter, the Ewgeco system was installed in both the intervention dwellings (see Figure 3.2) and in the control dwellings (see Figure 3.3). These pictures are typical of the installation set for the Ewgeco system used in all properties related to this project. All the key components of the system are highlighted in green. For the intervention group, the display of the Ewgeco system was typically installed prominently in the dwelling, depending on its layout and design; locations typically varied. The flats and terraced houses had the Ewgeco IHD displayed in the hallway, whereas the semi-detached houses had the Ewgeco IHD installed in the living room. This was done because the semi-detached houses did not have a clearly defined hallway comparable to that of the other properties.

Figure 3.2: Photo of Ewgeco system installation

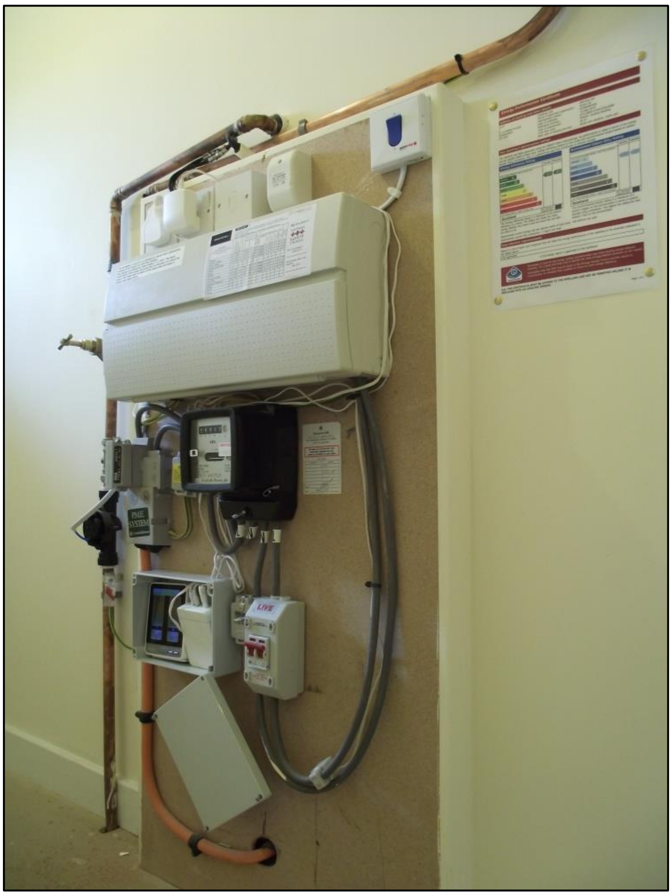


Figure 3.3: Photo of concealed Ewgeco used in control properties

The Ewgeco IHD (pictured in Figure 3.4) was chosen for the trial because it combines a coloured display with all the functionality of the basic energy monitors that featured a numerical display as used in previous trials. Ewgeco simultaneously displays electricity and gas consumption information through the use of coloured bars in a traffic light presentation. The IHD displays the green coloured bars at the bottom of each column to represent low levels of consumption. As consumption levels increase, so do the number of lit bars. Amber and red bars become lit to indicate high and very high levels of energy use.

Figure 3.4: Photograph of Ewgeco energy monitor in-home display

A key feature of the Ewgeco display allows current electricity and gas consumption to be compared side by side using the same units of measurement, both in a traffic light coloured speedometer format. The electricity consumption is displayed in the left hand column, marked by a lightning bolt. The gas consumption is display in the right hand column, marked by a flame. The colours or numbers of lit bars are not pre-set to represent any particular level of consumption. The system monitors the household consumption pattern for one week, then calibrates the colour range specifically to each home.

The electricity and gas consumption data are also represented as various numerical figures as follows:

- Current consumption in kilowatts and pounds (£).
- Total daily consumption in kilowatts and pounds (£).
- Carbon dioxide emissions (kg/day).
- Ewgeco units (which is an accumulation of the figures above).

The monitor contains additional features (illustrated in figure 3.5) which include:

- **Individual appliance monitor function**, which allows the user to view how much energy any individual appliance is using. This can be displayed in kilowatts or pounds (£) without the need to turn off other products in operation.
- **Alarm function** gives off an audible alert, attracting the users' attention when a pre-set level of daily consumption has been reached.
- **History review function** provides the user with the total consumption of the past days.
- **Peak consumption bar**, a single coloured bar which remains lit throughout the day and serves to indicate the peak energy use for that day. The bar will remain lit until it is superseded and replaced by another bar higher up the display, and will reset at the start of each day.

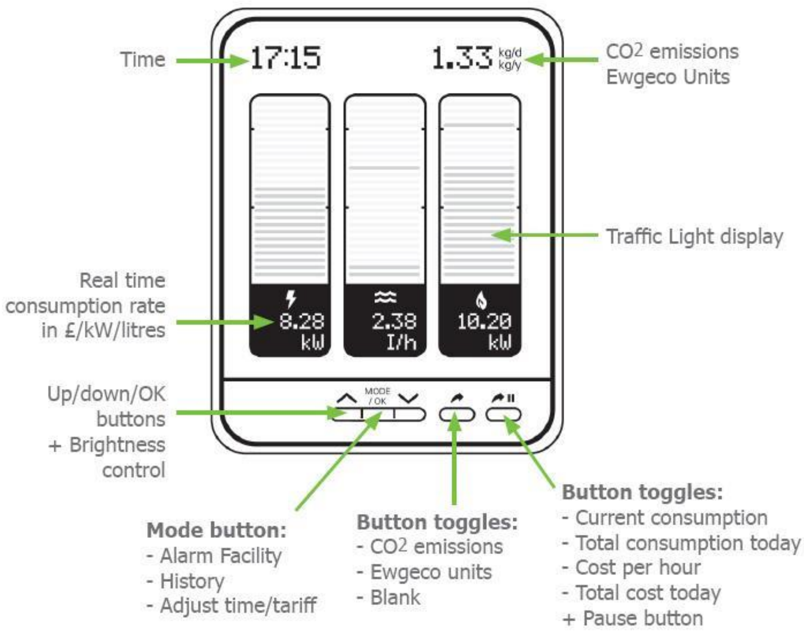


Figure 3.5: Ewgeco list of features

An ESTR (2011) consultation reported on the transmission rate of 12 commercially available home energy monitors, all of which ranged from 2 seconds to 60 seconds. The modal score of the group is calculated as being 6 seconds, with a mean of 11 seconds. Since that consultation, and at the time of undertaking this research, there has been no definitive specification for data transmission time. Therefore the majority of these energy monitoring displays provide energy consumption data at 6+ seconds per transmission. However, the Ewgeco system transmits information from its transmitter to the display at a rate of 2 seconds per transmission.

3.5.1 Accuracy and precision of Ewgeco logger

As mentioned in a previous section of this chapter, meter readings were collected from each participating dwelling. The cumulative consumption data collected by the Ewgeco system was compared to the actual billed energy consumption using figures taken from the electricity and gas meters. The type of electricity meter varied between each property, with both analogue and digital equipment installed. Ofgem (2004) states that the accuracy of the electricity meter used for billing purposes must be within the prescribed limits of +2.5% and -3.5%. The electricity meters were not tested at any site for accuracy because they were newly installed. By the same convention, Ofgem (2004) states that a gas meter is accurate when the readings are within the prescribed limits of +/- 2%.

As the electricity information to the EWGECO device was collected using a current transducer clipped to the mains electric cable (see Figure 3.6), the accuracy was anticipated to be within +/- 10% of the meter readings, based on the manufacturer's specifications. Had it been connected to a pulse-enabled electricity meter with the appropriate sensor, then the reading would have been closer to the readings of the meter itself. This type of connection was not pursued because it requires permission from the meter provider. With the various types, age and styles of electricity meters currently installed and being installed (see Figure 3.6) in these properties, the electricians on the various test sites found it appropriate to favour the use of the CT clip.

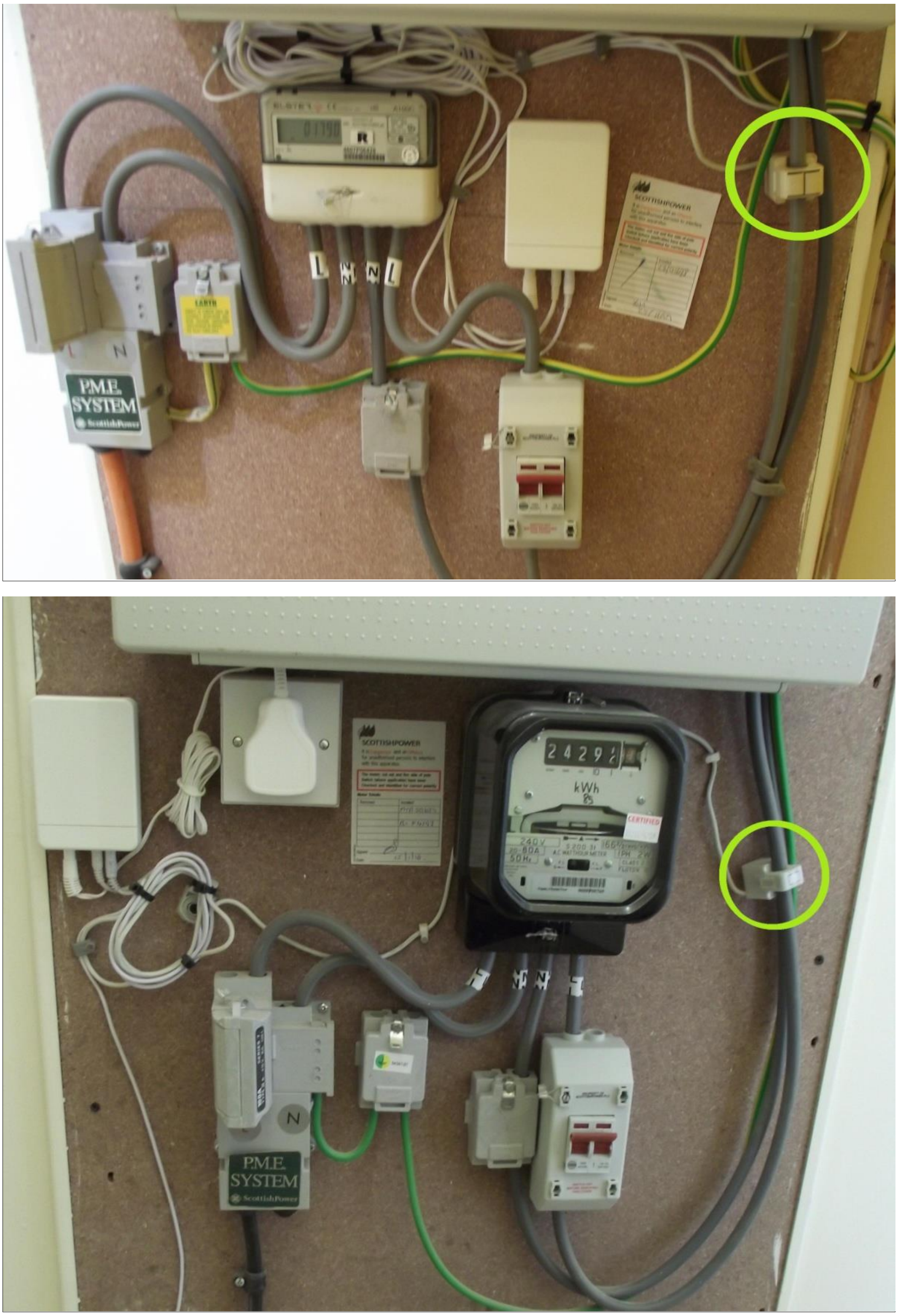


Figure 3.6: Photos of Ewgeco connection CT clip (highlighted) to electricity cables

Gas consumption data was gathered directly from the gas meter using a pulse block. The pulse block apparatus, pictured in Figure 3.7, attaches to the face of this type of gas meter, which is a pulsed enabled meter. The procedure requires a Gas-Safe registered engineer to make the connection. As the gas is consumed in the home, each turn of the analogue dial is picked up by the magnetic tilt switch located inside the pulse block. The speed and frequency of the turning dial is relayed to the transmitter and on to the Ewgeco display, where the data is converted and displayed as kWhs and, subsequently, as coloured bars.

Figure 3.7: Photo of Ewgeco’s pulse block (highlighted) connected to a pulsed enabled ‘dumb’ gas meter

The amount of gas used by the occupants for space heating, water heating and possibly cooking was not sub-metered. The limitations of the Ewgeco logger at the time meant that a heat meter or other sub-metering sensor could not be installed the combi-boilers or domestic plumbing network, which were the common heating system types to all of the participating properties. Therefore, the research focused primarily on the effects of the IHD on reducing all use of gas use in the homes. Questionnaire interviews are described later to differentiate the energy use behaviour between space and water heating appliances and controls.

The findings of the comparative analysis of the accuracy and precision of the Ewgeco readings yielded different yet expected results for the two monitored utilities being monitored. The accuracy of the Ewgeco logger was measured by comparing the electricity and gas consumption as recorded by the utility meters to the consumption as recorded by the Ewgeco logger over the same period. In this calculation, the consumption as measured by the utility meters was chosen as the ‘actual value’. This was decided because of the utility meters’ relevance to the utility bill. This calculation was done for each participant and for each utility being measured.

The accuracy and precision of the Ewgeco logger is analysed here. Due to malfunctions with the loggers, especially for the first month of the monitoring period, only 17 of the 52 installed Ewgeco units (including the concealed units) provided enough electricity data to make the comparison. The results comparing the difference in electricity readings from the Ewgeco compared to the utility meters are presented in Table 3.1 and Figure 3.8 for the first six month monitoring period. The electricity comparison shows that one of the Ewgeco loggers was outside the declared accuracy of the type of CT sensor used in all assessed properties, although the group average was within the expected accuracy range.

For the gas measurement accuracy study, 19 data sets were complete and robust enough to be compared to the utility meter readings. The measured range of the data sets shows that 4 of the loggers were out with the expected accuracy of +/-0% (see Figure 3.8). The largest deviance was 3%, which occurred in one logger. This difference may largely be due to rounding up the meter readings and the times when the meter reading was captured. For example, the logger records the measured consumption at the end of each hour, and if the meter reading is manual captured during that hour, then there will inaccuracy associated with the comparison. This is especially the case when the meter readings were captured during the heating season, as was the case during the initial six month monitoring period.

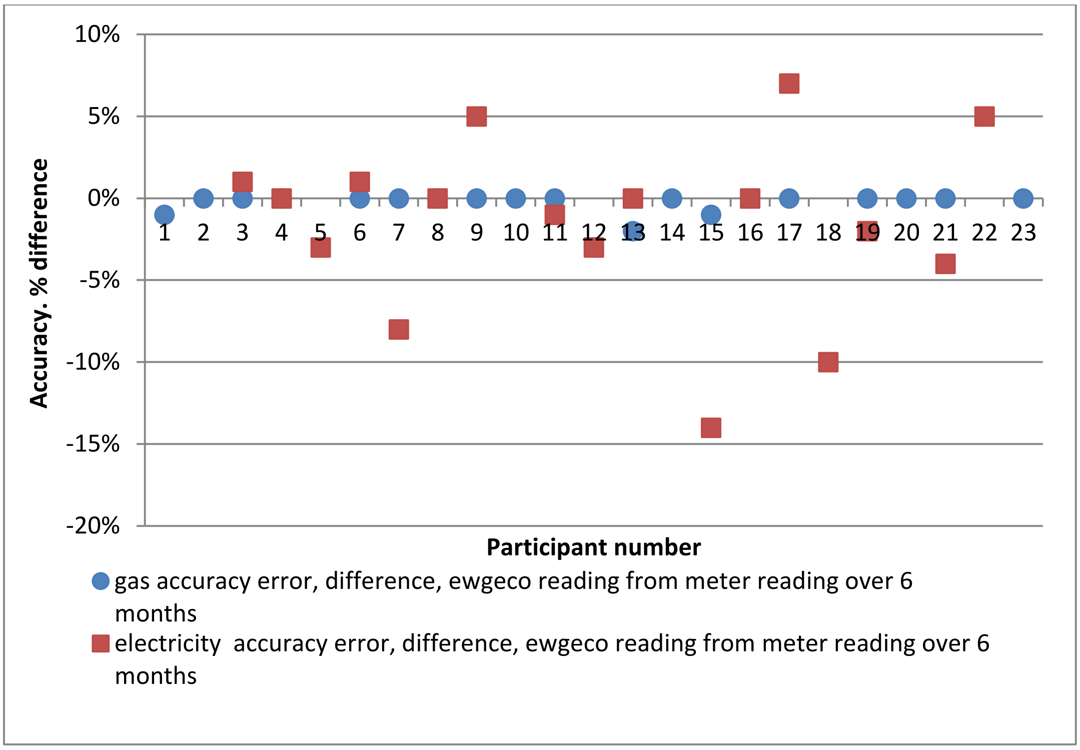


Figure 3.8: Results from accuracy assessment study for electricity and gas measurements

Expected range	Measured range	Mean average	Standard Deviation	Model average	Median average
+/- 10%	+7 to -14%	-2%	5%	0%	-1%

Table 3.1: Accuracy of Ewgeco logger compared to electricity meter (n=17)

Expected range	Measured range	Mean average	Standard Deviation	Model average	Median average
+/- 0%	+0 to -3%	0%	1%	0%	0%

Table 3.2: Accuracy of Ewgeco logger compared to gas meter (n=19)

The data retrieved from the longer term Phase 2 study was used to assess the precision of the Ewgeco logger and its repeated accuracy over a longer period. The difference between meter readings and recorded Ewgeco consumption was calculated for two periods using three data points over the complete 37 month monitoring period. Figures 3.9 and 3.10 present the findings of this analysis for the electricity consumption and gas consumption respectively. Many of the data sets used to construct Table 3.2 were unusable for this part of the study. Logger malfunction and participants changing their utility meter resulted in only a few properties providing enough data to generate results.

For electricity comparisons, there is no consistency in levels of accuracy between the Ewgeco loggers installed in different properties. However, the accuracy range for each consumption period does not go above the expected accuracy of 10%. For most of the electricity data sets, the accuracy of the Ewgeco logger fell within the 0-1 % range or 7-8% range. For 4 of the data sets, the second consumption phase (2011-2013) is within 1% of the accuracy calculated for the first consumption phase (2010-2011). For two data sets, the accuracy decreases (went up) considerably between Phase 1 and 2, increasing by 7-8%.

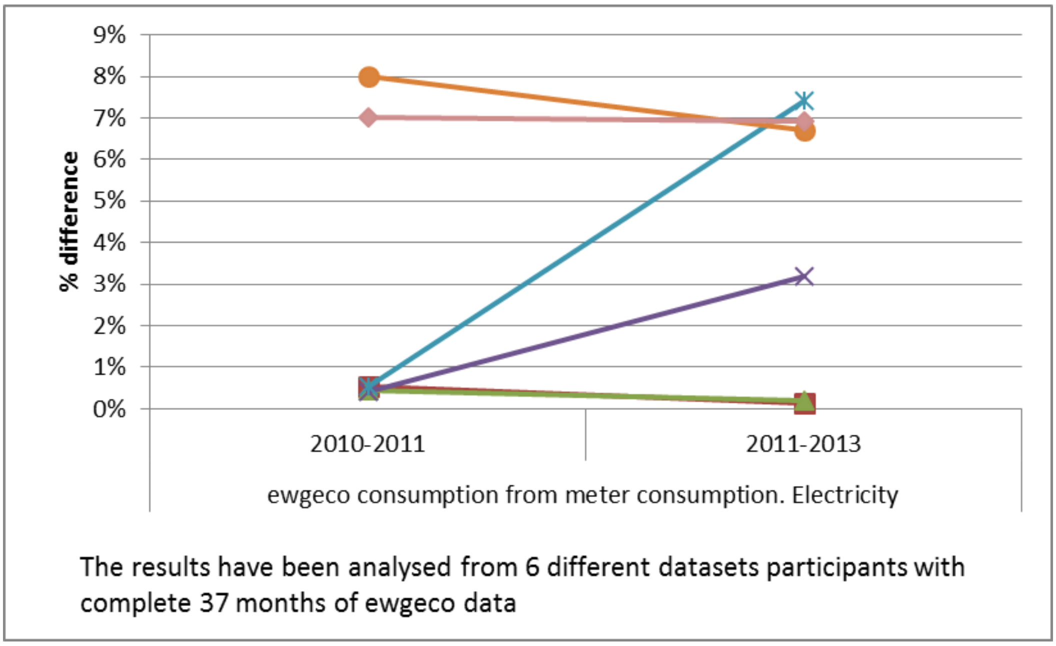


Figure 3.9: Difference between consumption of electricity as recorded by the Ewgeco logger and calculated from electricity meter readings (6 data sets).

The gas consumption comparison shows that many of the loggers were more accurate than was expected. This could be attributed to the rounding-up of the meter readings and times when the meter reading was manually recorded. Many of the data sets used in this study show an increase in accuracy between the Phase 1 consumption period (2010-2011) and the Phase 2 (2011-2013) period. In one instance we see a considerable increase in accuracy level. For Phase 1, the majority of the data sets used in this study are within 0.5% of each other and close to the expected 0% accuracy level.

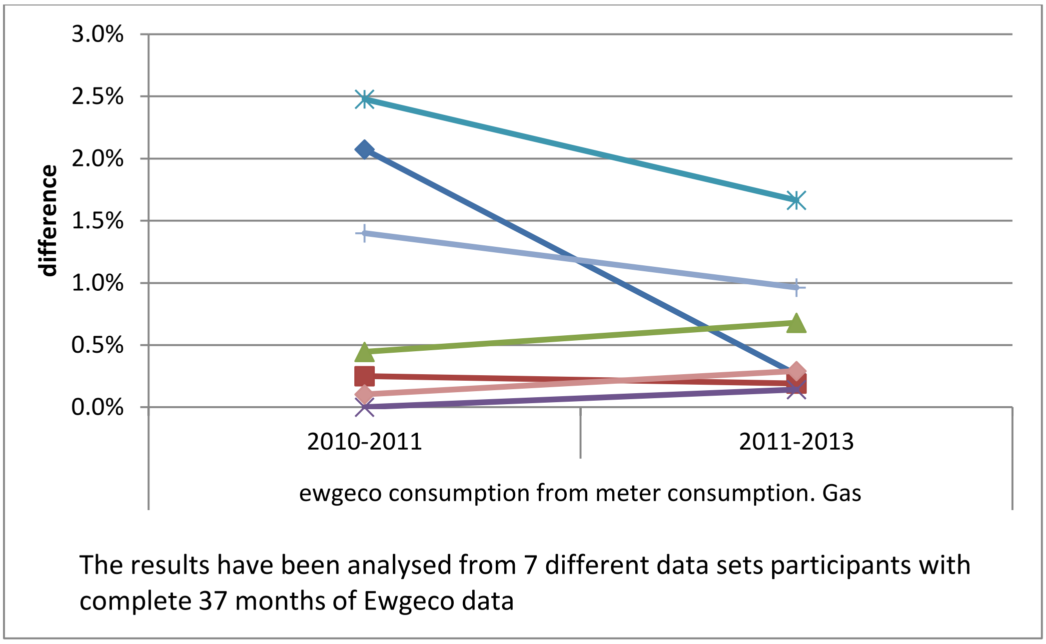


Figure 3.10: Difference between consumption of gas as recorded by the Ewgeco logger and calculated from gas meter readings (7data sets).

3.5.2 Loss of data

There were multiple failures of the measuring equipment despite it all being purchased new with manufacturers' warranties and bought on quality specification, not price. The failures resulted in the Ewgeco logger losing data for either electricity or gas consumption or both. This meant that less complete data was available to create daily, weekly, monthly and yearly profiles for all of the occupants. This is the case for both Phase 1 and Phase 2.

The Ewgeco system was designed so the transmitter collected the energy consumption data, and it is transmitted and stored on the display, which is also the logger. The capability of the logger to receive and consequently store the data relies on a robust mobile signal connection between the two. When this was not available some data was lost, although typically not enough to affect the objectives critically, because periodic meter readings were being recorded. Often this failure to log did not interfere with display's ability to present graphical information to the user.

This monitoring equipment must be designed so that it is more reliable. It would have benefited with a back-up system to support the loss of the mobile signal. The equipment was expensive and unfortunately unreliable. A suitable alterative to this design might have been for data to be stored in the transmitter and not in the display.

3.6 **Data collection**

During the construction phase at each of the housing developments, a Ewgeco system was installed in all of the flats and houses. For those elected as part of the control sample, their Ewgeco logger and IHD were concealed in a sealed box beside the utility meter. One month after the arrival and settling in of the new tenants, the author spent approximately 10 minutes at each residence to activate and programme the displayed monitor in the presence of the homeowners. Little help or advice was offered to the occupants, other than the description of the device in the introduction to the research and survey recruitment procedure.

Due to the social science investigative methods employed to complete this research, it was deemed prudent to be aware of the 'Hawthorne effect', which is often referred to as the 'observer effect'. The term 'Hawthorne effect' was introduced by the social psychologist French (1953) and refers to inconsistent results observed from a series of experiments on factory workers undertaken during the 1924-1933 period in the Hawthorne works of the Western Electric telephone manufacturing Factory near Chicago. The research conducted at the factory attracted much attention and debate because the variables (lighting, recess periods, payment) that the experimenters manipulated resulted in a short-term increase in productivity, with productivity eventually returning to pre-intervention levels.

Academic consultants Mayo (1933) and Roethlisberger and Dickson (1939) were primarily responsible for interpreting, reporting, and publicising the results of the Hawthorne studies. Their work gave rise to the now common interpretation of the Hawthorne effect: "*it was feeling they* [the research subjects] *were being closely attended to which was the cause of the improvements in performance"* (Draper 2014).

All contemporary references to the Hawthorne effect concern the effects on an experiment's results of participants' awareness that they are the subjects of an intervention. What appears to be lacking in much research is a comprehensive catalogue of the ways in which human awareness sometimes affects the outcomes of experiments on human participation (Draper 2014).

The impracticality of eliminating the Hawthorne effect during research on human behaviour is well recognised amongst social scientists. It is for such reasons that the maximum amount of time the researcher spent with each occupant was limited to 60 minutes per household, with 3 visits during Phase 1 and 1 visit during Phase 2.

Furthermore, in an attempt to reduce as much as was reasonably practicable the Hawthorne effect on this research, a strict code of conduct was established between the researcher and occupant. This code of conduct involved a scenario where occupants were not encouraged to ask questions to the author pertaining to the use of the display. Rather, each property with the monitor was left with a product manual and instructional DVD. In terms of using the monitors to achieve energy savings, the occupants were not given any specific goals, targets or encouragement. Each occupant was asked to use the monitor as he or she saw fit. The recruited participants were informed of the data collection schedule and were invited to discuss their experiences with energy saving and the technology during the arranged interview times. Minimal help was given in order to resolve technical issues or display settings for the participants in the intervention group. This was done in the interest of observing the extent to which residents would be motivated to engage with the Ewgeco IHD and incorporate the information from the IHD into their existing energy saving habits.

Hourly energy consumption data was obtained from all the participants in the trial. This was done using the Ewgeco's data logging functionality. Electricity and gas consumption data was collected for a six month period, starting on the 1st of September 2010, and ending on the 1st of March 2011. This data was then compared to the energy consumption of the control group over the same time period. To supplement the data from the energy monitors, the actual monthly meter readings were also gathered at several points throughout the trial. These readings served to validate the energy data provided by the Ewgeco logger and were used to test the loggers' accuracy.

Phase 2 started by default, immediately after the first six month period had ended. The Phase 2 period of monitoring ran until October 2013, and during this time the author did not contact or engage with the participants.

3.7 **Quantitative data analysis methods**

Along with the data captured for electricity and gas consumption, a profiling survey was completed for each participant. The information for this was collected from the interviewee at the start of the study and supplemented by a simple house survey and the data in the SAP worksheets. This participant profile information related to the:

- property type (flat or house)
- number of people
- number of bedrooms
- floor area
- property volume
- number of appliances
- calculated annual space and heating requirement (from the SAP)

The results of this study are presented in Chapter 4 for the gas consumption analysis and Chapter 5 for the electricity consumption analysis.

Data analysis techniques were employed to find the mean of the two samples as sub divided by property type and the number of people living in the property. The mean energy consumption for the intervention groups and the control groups were compared to identify any reduction or increase in consumption for those with the Ewgeco IHD. Conventional statistical techniques were used to measure the significance of any differences in consumption rate for electricity and gas between the two groups.

The list of variables collected for the participant profile was used as values to normalise each properties' gas and electricity consumption profile. Where relevant, the gas and electricity consumption was divided by the values in the variables above. The total consumption value for each property was then allocated to that property's respective sample type (intervention or control). The mean was calculated for each sample type and for each mean based on the normalisation condition. The standard deviation was calculated for these means. The coefficient of variation (CV), as a percentage, was used as an indicator to describe which normalisation condition was a best fit for the data. The lower the CV, the closer each individual data point is to the group mean. This would suggest that the mean is a good representation of the whole data set of that group.

Testing for statistical significance (*p*) between groups

The Gosset or Student independent means t-test (Field 2009) was used to test the statistical significance of the difference in means between the two sample groups. The alternative hypothesis was directional, stating that occupants with a Ewgeco IHD would consume less energy than the control group. Therefore, a one-tailed independent t-test was used. The conventional 95% ($p>0.05$) confidence was applied to this t-test.

The formula used to calculate the t-statistic is:

$$t = \frac{x - y}{\sqrt{\left[\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1 + n_2 - 2}\right]\left[\frac{n_1 + n_2}{n_1 n_2}\right]}}$$

Equation 1: Formula to calculate t-statistic for an independent samples test.

Where:

X=mean of sample 1

Y=mean of sample 2

S_1=standard deviation of sample 1

S2=standard deviation of sample 2

n_1=number of observations in sample 1

n2=number of observations in sample 2

The result of the formula is compared to the interpolated critical value found from a standard t-distribution table.

Testing for statistical significance (*p*) within groups

The dependent t-test was used to detect statistical differences between means of related groups, often referred to as dependent paired samples t-test. This is done when the data used to calculate the means comes from the same sample. Traditionally this is used in a 'pretest – posttest' experiment. The equation and dependent paired sample t-test are used in this thesis to test for statistical differences between the energy consumption of Phase 1 and Phase 2.

$$t = \frac{\sum D}{\sqrt{\frac{(n\sum D^2) - (\sum D)^2}{n - 1}}}$$

Equation 2: Formula to calculate t-statistic for a dependent paired samples test.

Where:

∑=sum of

D=the difference between the means of the two data sets

n=number of observations

The result from the formula is compared to the interpolated critical value found from a standard t-distribution table.

Standard error (SE):

For further statistical analysis, the standard error has been calculated for the sample means in Chapters 4 and 5. In simple terms, the standard error is the standard deviation of the sample mean. As such, it is a measure of how representative the test sample is likely to be of the wider population. A large standard error (relative to the sample mean) means that there is a lot of variability between the means of different samples. Therefore, a result like this would suggest that the calculated mean energy consumption for that sample may not be representative of the population as a whole. Likewise, a result of a small standard error indicates that most sample means are likely to be similar to the wider population mean, and so the experimental sample is likely to be an accurate reflection of the population. Standard error was calculated using this formula:

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Equation 3: Formula for calculating standard error

Where:

s=standard deviation

n=number of observations in that sample

Measuring the effect size:

To complement the result of the t-test, the size of effect is measured from the data to discern whether the t-test result is meaningful or important. The effect size is an objective and usually standardised measure of the magnitude of the observed effect. The effect size in the sample is measured to estimate the likely size or magnitude of the effect in the population. The effect size is calculated after rejecting the null hypothesis in a statistical test. If the null hypothesis is not rejected, the effect size is still calculated as a matter of interest.

The result from the effect size provides a standardised value that shows the separation of group means. For the statistical analysis of data in this research the Pearson’s ‘r’ formula has been chosen to report effect size. Many methods of calculating effect size exist, such as Cohan’s D, Spearman’s r and Kendall’s tau. However a convention in statistical analysis, especially in the field of social science, is to use Pearson’s r.

A convention in social science reporting is that correlations (i.e. r) are typically reported when summarising one or often a matrix of bivariate relationships. Pearson's r for effect size is often favoured because of its simplicity in interpreting the result. The r result is a standardised measure of the strength and direction of linear relationship between two variables, ranging from -1 for a perfect negative relationship and 1 for a perfect positive relationship. Perfect is used here to indicate that all the data points are on the calculated regression line of best fit through the data points. The result from the Pearson's r can broadly be interpreted using the conventional thresholds of effect size. Such as:

1. If r=0.1 this is a small effect=in this case the effect explains 1% of the total variance.
2. If r=0.3 this is a medium effect=the effect accounts for 9% of the total variance.
3. If r=0.5 this is a large effect=the effect accounts for 25% of the total variance.

(Field 2009)

The r value was calculated using the following formula:

$$\mathbf{r}=\frac{\mathbf{N}\sum \mathbf{XY}-\left(\sum \mathbf{X}\right)\left(\sum \mathbf{Y}\right)}{\sqrt{\left(\mathbf{N}\sum \mathbf{X}^2-\left(\sum \mathbf{X}\right)^2\right)\left(\mathbf{N}\sum \mathbf{Y}^2-\left(\sum \mathbf{Y}\right)^2\right)}}$$

Equation 4: Pearson's r formula

Where:

N=number of observations in that sample

X=mean score of one sample

Y=mean score of the other sample

The statistical analysis was completed using the SPSS statistic computer software package developed by IBM.

3.7.1 Translating logged gas consumption data

The gas consumption data captured from each of the participating households was recorded in pulses at hourly intervals. The Ewgeco logger was configured to read the number of pulses from the metric gas meter. These pulses were converted into m³ by applying a multiplier, as detailed on the face plate of the gas meter (e.g. Pulse=0.01³). This was the case for the installations on both sites. The result was converted from m³ into kWh by applying the standardised correction, calorific value and conversion factors as provided by the utility company information supplying each property.

39.7 MJ/m³ was selected as the calorific value for the two sites. This number was consistent on each utility bill provided to each of the households included in the study. The standard volume correction factor for temperature of 1.02264 (Gas Regulations 1996) was applied and then divided by 3.6 to convert from MJ to kWh.

The gas consumption (kWh) data from the trial properties was normalised using the combined space and water heating requirement (kWh) for each of the dwellings, as calculated by the Standard Assessment Procedure (SAP) methodology. The results from the study that evidence this choice are presented in Chapter 4.2 for gas consumption and Chapter 5.2 for electricity consumption. SAP remains the UK government's Standard Assessment Procedure for the Energy Rating of Dwellings. SAP was adopted by the UK Government as part of the national methodology for calculating the energy performance of domestic buildings. It is used to provide energy ratings for dwellings and to demonstrate compliance with Scottish Building Regulations (and those of England, Wales and Northern Ireland). This method provides an indication of the percentage of energy gains and losses in each dwelling due to house construction, size and orientation etc. and the energy input required to maintain certain temperature levels.

Normalising the measured gas consumption by SAP values takes into account the energy required in the properties over an annual cycle based on orientation, heat losses, heat gains, fabric efficiency and floor area etc. It therefore allows for the comparison of energy use across different dwellings. For the most part, this research has analysed the data from the two experimental samples separately for houses and flats.

The SAP output worksheets, as provided by each housing association, give information about the calculated amount of annual fuel required for space and water heating. New SAP models were created by the author to find each month's space and water requirements. Due to differences in the age of the SAP software, it was not possible for the new outputs to match the original version exactly. When creating the new SAP models, based on the input data on the original SAP output worksheets, a clear relationship became apparent between the amount of space and water heating fuel required per month for each of the different properties. The new SAP model results for fuel requirements were consistently different from the values in the original worksheets. However, the new SAP models showed that the percentage of fuel required for each comparable month for each property in the sites was the same, see Table 3.3.

Therefore a multiplier was applied to the annual totals for space and water heating from the original SAP worksheets as a calculated estimate to find the monthly gas fuel requirements. The percentage requirement for gas fuel for space and water heating is as follows:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
%	14	12	11	9	7	4	4	4	5	8	10	12

Table 3.3: Percentage of gas fuel required per month

These multipliers may not be applied to every SAP model outside of this study, but they do hold accurate for the properties involved in this research. This data was used for the Phase 1 comparative analysis of gas usage between the control and intervention samples for the first six months.

3.7.2 Interpreting the captured electricity consumption data

The electricity consumption was recorded on the Ewgeco logger using the current transducer (CT) clips attached to the main electrical cable between the meter and the consumer unit. The electricity consumption was converted by the Ewgeco system into watts and recorded at hourly sampling intervals. The raw Ewgeco logger data was converted into kWh by dividing the data sets by 1000. The consumption data was compared to the consumption data calculated by subtracting the meter readings.

3.7.3 Energy consumption normalisation

A number of normalisation conditions were applied to the energy consumption of each property. Common normalisation conditions include the total floor area of the property, the number of occupants, the dwelling volume etc. The energy consumption data from this study was normalised using these factors so to be consistent with other similar studies. Other normalisation conditions applied to the data included the SAP results, which are described in more detail in Chapter 4.2 for gas consumption and 5.2 for electricity consumption.

The normalisation conditions were applied to each data observation to calibrate each data point in a group, thereby reducing the variation between each data point and the group average (mean). In probability theory and statistics, the coefficient of variation (CV) is a normalised measure of dispersion for frequency distribution. It is defined as the ratio of the standard deviation to the average (mean) and is often presented as a percentage.

Multiple normalisation conditions for gas and electricity consumption have been examined. The different normalisation conditions are applied to the same energy consumption data originally recorded by the logger and converted to kWh. Calculating the CV returns a value for the variation of the calculated energy consumption for each property in the sample based on the unobservable model value (i.e. the sample’s average mean). The lower the CV number for the consumption data derived from a normalisation condition, the less variation between the energy consumption of each property in the sample and the average (mean) energy consumption of the whole sample. CV was adopted for this study as a statistical indicator of the normalisation condition which returns a data set for a sample that is most representative of the energy consumption for the respective sample average (mean).

The CV is the ratio of the standard deviation to the mean. This allows a meaningful comparison between multiple magnitudes of variation, as is the case with these data sets because they have different means and difference scales of measurement

For each normalisation condition applied to the raw recorded data, the absolute difference between the energy consumption value for each property in the sample and the sample average (mean) was determined for each property in the respective sample (deviance). To standardise the deviance across the multiple energy consumption data sets derived from the same sample using difference normalisation conditions, the deviance for each property's energy consumption value was then divided by its sample mean. This standardised deviance allows for statistical comparison across data sets that have multiple scales of measurement. A repeated ANOVA (analysis of variance), one-way within conditions test for multiple dependent conditions, was carried out to test for statistical differences between the results of the normalisation conditions applied to the same sample group. This is the method chosen to test for statistical differences between the calculated CV values from each normalisation condition and unconditioned (raw) recorded consumption data.

When reporting the results from the ANOVA test, the Greenhouse-Geisser result is reported to test for significance within subject effects. Mauchly's test is conducted to check for significant differences between variances of difference (sphericity). If sphericity is violated ($p < .05$) then Pillai's Trace statistic is reported from a multivariate test. This states the statistical significance because this test statistic is not dependent on the assumption of sphericity.

3.8 Qualitative data collection

As well as the quantitative element of measuring the change in energy consumption, qualitative techniques were also employed. These techniques, more common to the realm of social science, measure the change in energy use behaviour which might be linked to the difference in consumption rates between the two experimental samples.

Both the philosophical and sociological traditions assume that change is a constant feature of social life but that its specific directions needs to be accounted for; they also place special attention on social interaction and social processes (Strauss 1987). From its inception, sociology has emphasised the necessity of capturing, analysing and reporting actors' viewpoints and their understanding of what is happening around them. The question lists used for the semi-structured interviews are presented in Appendices 1, 2 and 3.

In an effort to grasp the viewpoints of the actors in this study (the occupants), a package of conventional qualitative data collection methods was designed. This included the construction of a questionnaire that included open-ended and closed-ended questions. The closed-end questions took the form of opinion questions, structured using techniques like multiple choice, checklists, ranking scales and Likert scales. The open-ended questions took the form of provocative statements concerning the Ewgeco IHD or energy use habits.

All of the interviews were conducted face to face with the author in the participants' homes. The participants were guided through the questionnaire by the author. During the interviews, participants in the intervention group were asked to comment on the following themes:

- Their initial thoughts on the Ewgeco display.
- Their current understanding of their energy bill, consumption and supplier.
- If the device had affected their energy awareness or behaviour, and if so in what way(s).
- Views and opinions of the myEwgeco web portal (where occupants could review their own household energy data on-line).

- Recommendations for improving the device and the myEwgeco system.

The qualitative data was collected using three semi-structured interviews. The first of these was conducted at the beginning of the study; it comprised a 15 minute interview in which the sample participants were asked to comment on:

- Their current understanding of their energy bill and supplier.
- Their energy consumption habits and routines.

One month after the monitor was activated, the intervention group participated in another semi-structured interview aimed at gathering their initial views on the monitor. These interviews lasted approximately 30 minutes, during which time the residents were encouraged to talk about their initial experience of owning the monitor.

The last of the semi-structured interviews for Phase 1 was conducted at the end of the six month trial period. A similar series of multiple choice questions was used to guide the interviews, supplemented by open-ended questions. This session lasted between 15 and 45 minutes for each household. All of the interviewees were encouraged to comment again on the same questions asked during the first session. Those with the monitor where asked to comment on their overall experience of the device, focusing on three main topics:

- In what ways the monitor had been useful to the household.
- What specific features of the monitor were used or not used, and why.
- Recommendations for improving the device and the myEwgeco system.

All of the interviews were conducted face to face with the interviewer at the participant's home.

Comments received during the interviews are used throughout Chapters 4 and 5 to illustrate particular points. The individual quotations chosen are representative of the wider themes under discussion and are used to convey a sense of how these devices are used in real life domestic settings.

Participating households in the sample were assigned code letters to ensure their anonymity. The code letter prefix E illustrates that the respondent had access to the Ewgeco IHD, whereas the prefix NE indicates those with no energy monitor i.e. a participant in the control group.

To mark the end of Phase 2, the 2011 questionnaire was repeated in October 2013. The same questions surrounding energy use behaviour and habits and energy consuming appliances where asked to the occupants. For those with an Ewgeco IHD, additional questions were asked relating to their use of the Ewgeco IHD over the three years and what benefits they perceived to owning it, if any.

3.8.1 Data analysis methods

The close-ended questions where coded, quantified and analysed using the statistics computer programs Microsoft Excel and IBM SPSS. The difference in response to some of the questions was tested for statistical significance between the two experimental conditions. This was achieved using the Student t-tests with 95% confidence levels, because this is the widely recognised threshold of confidence, and is statistically significant at the level $p < 0.05$.

A chi-squared was conducted as a type of correlation coefficient. This test was applied to identify any association between nominal data – data in which each variable has no meaningful rank or order. For example, the test can be used to discover whether the difference in the frequency of the use of the IHD is dependent in a statistically significant way on participants' circumstances i.e. their classification as a support tenant. The relationship between two variables was measured using the Spearman's rank coefficient. This formula was applied to data relating to two variables that showed a relationship, but not linearly i.e. curvilinearly.

Each interview was recorded on a digital Dictaphone, and first thought memos were taken during the data collection stage. The recordings were transcribed into Microsoft Word using the true verbatim style. The digital text of each interview was imported into QRP NVivo for further coding and for the formation of memos. Here the term memo refers to the method of making a short note to keep track of thoughts during the coding and to assist the qualitative analysis stage. The technique of thematic analysis was used to derive conclusions from the findings of the open-ended questions.

3.8.2 Thematic analysis methods

Thematic analysis is widely used in social science research and is seen by many as the foundational method for qualitative analysis (Holloway & Todres 2003). However, there is no clear agreement about what thematic analysis is and how one goes about doing it (Braun & Clarke 2006). Many researchers suggest that thematic analysis is a poorly demarcated, rarely-acknowledged yet widely-used qualitative analytic method (Boyatzis 1998, Roulston 2001) within and beyond social science, in that it does not appear to be explicitly named as a method of analysis. When reviewing the work of many other social researchers in the realm of energy use, is it clear that many researchers use analysis that is essentially thematic but it is either claimed as something else or not identified at all.

An example of this extends to Hargreaves et al. (2010), who state that they applied a grounded theory approach (Strauss & Corbin 1998, Charmaz cited in Gubrium & Holstein 2002) to analysing transcripts and identifying themes that are common across different households and devices relating to reduced electricity use. Also, Huebner et al*.* 2013 refer to clustering and grouping their responses to the questionnaires into negative and positive codes.

So, thematic analysis is not really a specific method or technique. Rather, it is a style of qualitative analysis that includes a number of distinct features, such as coding and analytical memos, which must be carried out early and then continually throughout the data collection phase

Both grounded theory (the stated qualitative approach of many authors in this field) and thematic analysis apply coding to key words and phrases used by the interviewee in order to define themes that are important or of interest to the research. These clusters of important words and phrases result in the formation of a set of themes that define the research. However, the basis of grounded theory relates to conducting the data collection and analysis simultaneously. Therefore theories or hypotheses remain grounded in the observations rather than generated before the data collection. The traditional research path, such as that conducted for this thesis, relies on a literature review leading to the formation of a hypothesis. The hypothesis is then put to the test by experimentation in the real world. In contrast, grounded theory investigates the actualities of the real world and analyses the data with no preconceived hypothesis (Allen 2003)

Other types of thematic coding or methods that incorporate a coding approach include Interpretative Phenomonology Analysis (Smith & Osborn 2003), template analysis (King 1998) and framework analysis (Ritchie & Lewis 2003). These approaches all share a similar thematic analysis approach: they all involve searching through the interview transcript, searching for major trends in the text that say or represent the same ideas, coding key words and phrases with numbers or colours to find the important crucial themes and clustering them together to develop a theory and/or produce conclusions (Braun & Clarke 2006).

Braun & Clarke 2006 describe thematic analysis as a method of identifying, analysing and reporting patterns (themes) in data. In very simple terms, this form of analysis organises and describes a data set in ‘deeper’ detail. One of the benefits of thematic analysis is its flexibility because thematic analysis does not require the detailed theoretical and technical knowledge of approaches like grounded theory and discourse analysis

3.9 Conclusion

This chapter introduced and explained the Ewgeco energy monitor in-home display. This energy logger has been utilised to collect the electricity and gas usage data of 52 homes during Phase 1 and 20 homes during Phase 2. The IHD portion of the Ewgeco has been used to provoke behavioural change in a portion of the recruited sample.

The equations used to carry out the statistical analysis on the energy consumption data collected from the sample, divided into intervention group and control group, have been presented and explained.

The thematic analysis technique, common in social science research, has been adopted as the best method to assess the qualitative data collected by the method known as semi-structured interviews.

The next chapters will present and discuss the findings from an investigative study which focuses on the role of demand side energy management technology in social housing. Through the use of smart energy monitoring and in-home displays, Chapters 5 and 6 will build on the findings from authors and the work presented in this chapter and will explore how the visualisation of both electricity and gas consumption can change energy use behaviour change and reduce domestic energy consumption.

Chapter 4

4 Influence of IHD on domestic gas consumption

4.1 Introduction

This chapter begins by describing the methods by which the normalisation condition to be applied to the recorded gas consumption data was chosen. The chapter continues by presenting and discussing the gas consumption findings from the 52 social housing tenants, divided into a control group (n=22) and an intervention group (n=30). Gas was used in all the properties for space and water heating. The data analysis is segmented into two phases. The first comments on the data captured during the initial TSB funded six month trial which took place over the winter months between 2010 and 2011. This part of the Chapter compares the gas consumption between the two groups and tests the difference for statistical significance. The two experimental groups are further divided by property type and the difference in consumption is examined. Comparative gas consumption is then explored per month over that winter period.

The chapter concludes by presenting and analysing the second phase of the gas consumption results captured in 2013. The data captured in 2013 provided an additional 31 months of energy consumption data for 20 of the flats that participated in the initial 6 month TSB funded study. This analysis investigates the gas consumption differences between the two groups and examines the changes in gas use over the 37 months. How their gas consumption had changed after the author had withdrawn contact with the participants at the end of the first six month period is further investigated. The chapter examines and briefly comments on each participant's yearly gas consumption compared to that predicted at the design stage using the then compliant SAP. The Phase 2 data collection and analysis was funded by the Low Carbon Building Technologies Gateway (LCBTg) and European Regional Development Finding (ERDF).

4.2 Normalisation calculations for gas consumption

Five normalisation conditions were selected and applied to the unconditioned recorded gas consumption for each property. The coefficient of variation CV is used as a statistical indicator to identify which factor was the best fit for the group. The normalisation condition that gives the data set the lowest CV value is chosen as the unit of measurement for use in the rest of the data analysis.

For gas consumption the normalisation conditions chosen for testing were:

Condition	**Equation**	**Units**
Gas/area(m^2)	Recorded gas consumption divided by total floor area as defined by SAP	kWh/m^2
Gas/volume(m^3)	Recorded gas consumption divided by total dwelling volume as defined by SAP	kWh/m^3
Gas/#ppl	Recorded gas consumption divided by total number of people living in the dwelling as defined by questionnaires conducted at household visit	kWh/person
Gas/SAP space and water heating required	Recorded gas consumption divided by the water and space heating requirement as defined from SAP calculation	kWh/kWh
Gas/SAP primary energy primary energy	Recorded gas consumption divided by the predicted water and space heating converted to primary energy as defined from SAP calculation	kWh/kWh

Table 4.1: Normalisation conditions for gas consumption

The first three normalisation conditions selected for application and analysis (see Table 4.1) are those typically used by building science and energy modelling professionals to identify variations in usage across building types.
These conditions were selected to test for consistency with other similar studies.

Normalising the measured gas consumption by SAP values takes into account the energy required in the properties over an annual cycle based on orientation, heat losses, heat gains, fabric efficiency, floor area etc. It thus allows for a comparison of energy use across dwellings, removing the bias of energy consumption based on fabric, orientation, technology performance and weather.

For the last listed two normalisation conditions, the multiplier described in Chapter 3.7.1 was applied to the first phase of collected data in order to allow the six months of recorded energy consumption to be comparable to the predicted annual energy requirement and primary energy figures provided by the SAP.

Primary energy factors are applied to the predicted energy requirements in the SAP to account for the type of energy being produced at the power system relevant to that compliance period. For example, the electricity requirement predicted by the SAP will have a higher primary energy factor than the gas requirement, which accounts for efficiencies and losses in the generation and distribution of the fuel (Pout 2011).

The provenance and use of the SAP in the context of the normalisation conditions is discussed in Chapter 3. The SAP includes weather files and degree days and balances heat gains over heat losses.

All the properties were divided into two groups, the control properties and the intervention properties (with an Ewgeco IHD on display). The coefficient of variation was calculated for each group and for each utility type. For the data collected in Phase 1, the two groups were then divided into houses and flats and the CV test was conducted again.

2010-2011 Phase 1 normalisation results

Normalisation conditions applied to all 52 properties and split into the two experimental groups (i.e. the control (n= 22) and intervention (n=30)) based on the presence of the IHD monitor. When applied to the full 52 properties, regardless of property type or experimental grouping, all the normalisation conditions reduced the CV compared to the unconditioned gas consumption data recorded for the Phase 1 data. This held true when the group was divided into control group and intervention group (Figure 4.1).

Intervention group

Normalising the gas data by accounting for the SAP predicted gas requirement returned the lowest CV, but the CVs for all conditions were within 8% of each other. The results from the one-way repeated ANOVA show that the differences in the level of standardised deviance between any of the normalisation conditions, including the unconditioned (raw) gas data, was not statistically significant for the intervention group data ($F(1.93, 55.82)=.52$, $p> .05$). Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(14)$ 174.47, $p <.05$) and therefore the multivariate test is reported ($\varepsilon=.39$). The results show that the level of deviance for the normalisation conditions applied to the intervention group is not significantly affected by the normalisation condition ($V=.29$, $F(5,25)=1.92$, $p>.05$).

Control group

Recorded gas consumption normalised by SAP predicted gas requirement provided the lowest CV value. It was not much lower than normalising by floor area, but it was considerably different than the CV calculated from the unconditioned data. Normalised consumption data from the control group showed that the level of deviance for each normalisation condition result was not statistical different, either between each condition or in comparison to the unconditioned gas consumption data. This was detected in the Greehouse-Geisser test of within-subjects effects ($F(1.85, 38.76)=1.60$, $p> .05$) because the data violated Mauchly's test of sphericity ($x^2(14)$ 125.79, $p <.05$, $\varepsilon=.37$). Therefore Pillai's Trace statistic returned a significance value of $V=.42$, $F(5,17)=2.42$ $p>.05$ for the control group.

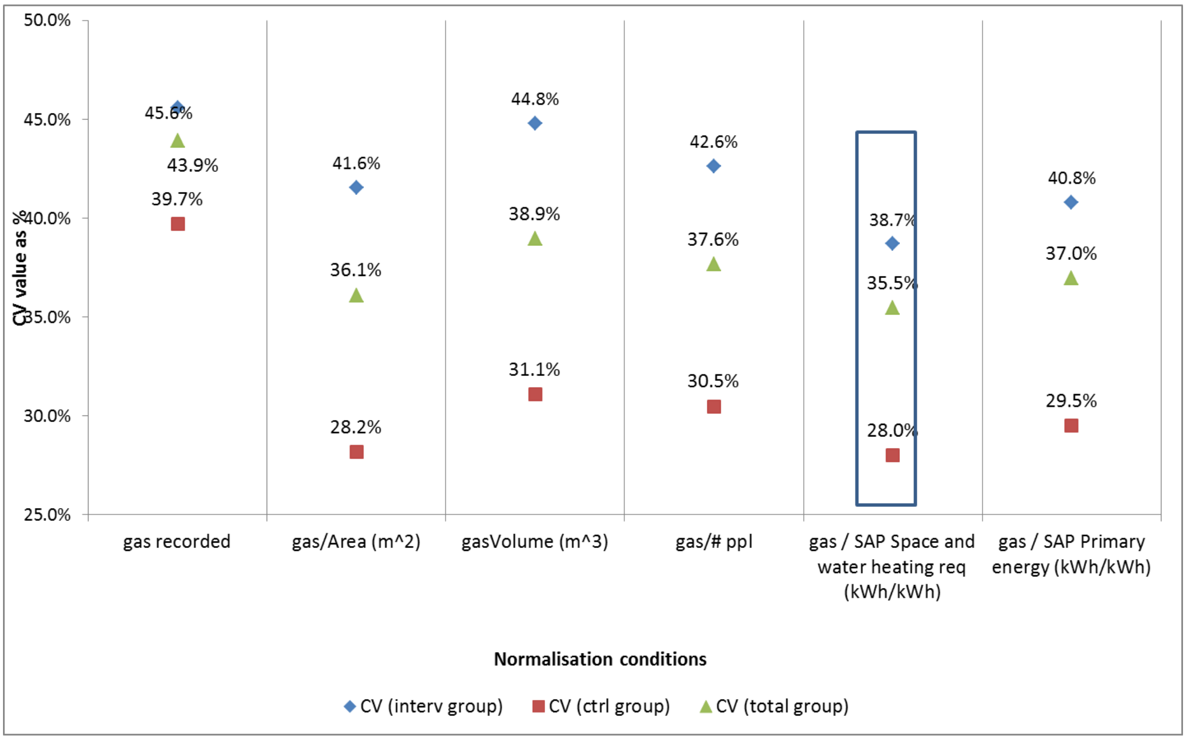


Figure 4.1: Comparison of CV values for normalisation conditions relating to recorded gas consumption (flats and houses not divided)

In summary, the ANOVA test statistics suggest that there are no statistically significant differences between the levels of deviance within each data set after it has been normalised in line with the noted gas normalisation condition applied to either the intervention group or the control group. The CV values for each normalisation condition have suggested that applying the normalisation conditions as derived from the SAP will result in a smaller variation (or residual) relative to the group average (mean) value.

Although the normalisation condition of total floor area also gave one of the lowest CV values for conditions not influences by SAP (see Figure 4.1), the results suggest that normalising the data sets by the amount of gas predicted to be required by the SAP is the better fit for the sample groups because it gives the lowest CV value when applied to the 52 properties and applied separately to the intervention group and control group. Although not statistical significant from the other applied normalisation conditions, normalising the recorded gas consumption for each property by the SAP-predicted space and water heat requirements returned the lowest CV.

The intervention and control groups were further divided into property type, giving four groups. The calculated CV values for the properties in each of these four groups were tested for statistical differences.

Gas normalisation conditions for sample living in flats (n=31)

For the sample living in flatted accommodation, Figure 4.2 shows the calculated CV values for the unconditioned gas consumption and gas consumption when normalised by the five noted normalisation conditions. The chart plots the CV values for the entire 31 flats and for each experimental condition, i.e. for the control group (n=13) and the intervention group (n=18).

The results show that, on average, the lowest CV for the sample living in flats comes from normalising the recorded gas consumption by space and water heating conditions predicted by the SAP. This is the same as that calculated for the whole sample of 52 (including those living in houses). The normalisation condition constructed from the SAP predicted primary energy data also provided the lowest CV value for the intervention group and one of the lowest values for the total group.

Intervention group

The calculated CV values for the conditions show that the normalisation condition derived from the SAP and the SAP primary energy provides similar CV values. These are slightly lower than the other conditions. The differences between the levels of deviance within each normalisation condition, including the unconditioned, for the sample living in flats were not statistically significant for the intervention group data ($F(1.88, 32.01)=.80$, $p>.05$). Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(14)$ 111.04, $p<.05$) and therefore the multivariate test is reported ($\varepsilon=.38$). The results show that the levels of deviance within the data sets are not significantly affected by the normalisation condition ($V=.52$, $F(5,13)=2.83$, $p>.05$) for the intervention group living in flats.

Control group

The lowest CV comes from the normalisation condition 'gas/ floor area (m²)'. The results from the ANOVA test show that the difference in deviance levels within each normalised condition is not statistically significant between the different normalised consumption data sets, including the unconditioned data ($F(1.94, 23.29)=.19$, $p>.05$) Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(14)$ 126.65, $p<.05$) and therefore the multivariate test is reported ($\varepsilon=.39$). For Pillai's Trace $V=.39$, $F(5,8)=1.03$ and $p>.05$.

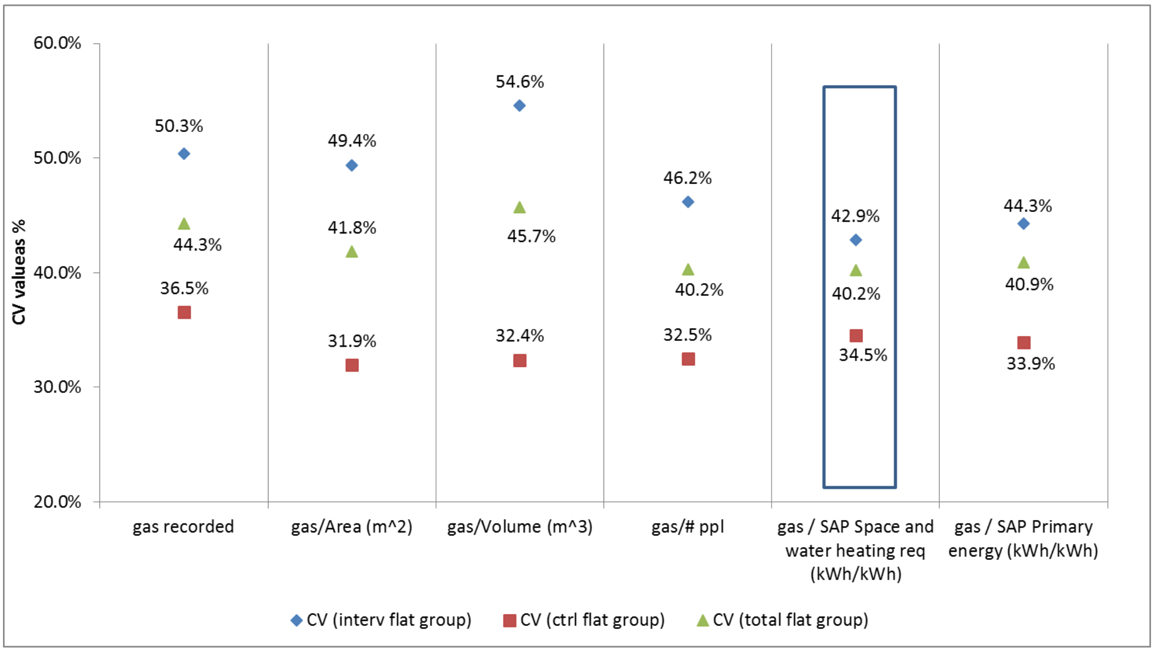


Figure 4.2: Comparison of CV values for normalisation conditions relating to recorded gas consumption for sample property type: flats

This result would suggest that the gas consumption for those living in flatted accommodation is slightly more dependent on building dimensions, thermal performance and degree days (as predicted by the SAP) than on building dimensions alone, and is similarly dependent on the number of occupants in the dwelling. The amount of standardised deviance in the data set for each normalisation condition was not statistically significant between the four normalisation conditions with the lowest CV value.

Gas normalisation conditions for sample living in houses (n=21)

Applying the normalisation conditions to the sample only living in houses returned another set of magnitudes between the normalisation conditions and the experimental groups (intervention group n=12, control group n=9). Normalising by SAP data and building dimensions provides the lowest CV values. However, normalising conditions involving the SAP space, water heating and primary energy predictions did not always provide the lowest CV values (see Figure 4.3), as seen in the other analyses of CV in this chapter. Unobserved in the other CV analysis, the unconditioned recorded gas data returned the lowest CV value for the intervention group living in houses. The difference between the CV values for the normalisation conditions divided by the number of occupants and the other normalisation conditions was much larger for the group living in houses. This result suggests that the amount of gas consumed by the sample living in houses is less dependent on the number of occupants and more dependent on the dimensions and thermal performance of the building.

Intervention group

The unconditioned recorded gas consumption returned the lowest CV value for the intervention group. The levels of deviance within each consumption data set were not statistically affected by the normalisation condition type when applied to the intervention group ($F(1.68, 18.47)=.04$, $p>.05$). Mauchly's test indicated that the assumption of sphericity was not violated ($x^2(14)$, $p>.05$, $\varepsilon=.34$).

Control group

The data normalised by SAP gas requirement returned the lowest CV value: the CV from the unconditioned data set was higher for this group. Normalising the data by number of occupants returned the highest CV. The levels of deviance within each consumption data set were not statistically affected by the normalisation condition type when applied to the control group ($F(2.3, 18.3)=.3.3$, $p>.05$). Mauchly's test indicated that the assumption of sphericity was not violated ($x^2(14)$, $p>.05$, $\varepsilon=.46$).

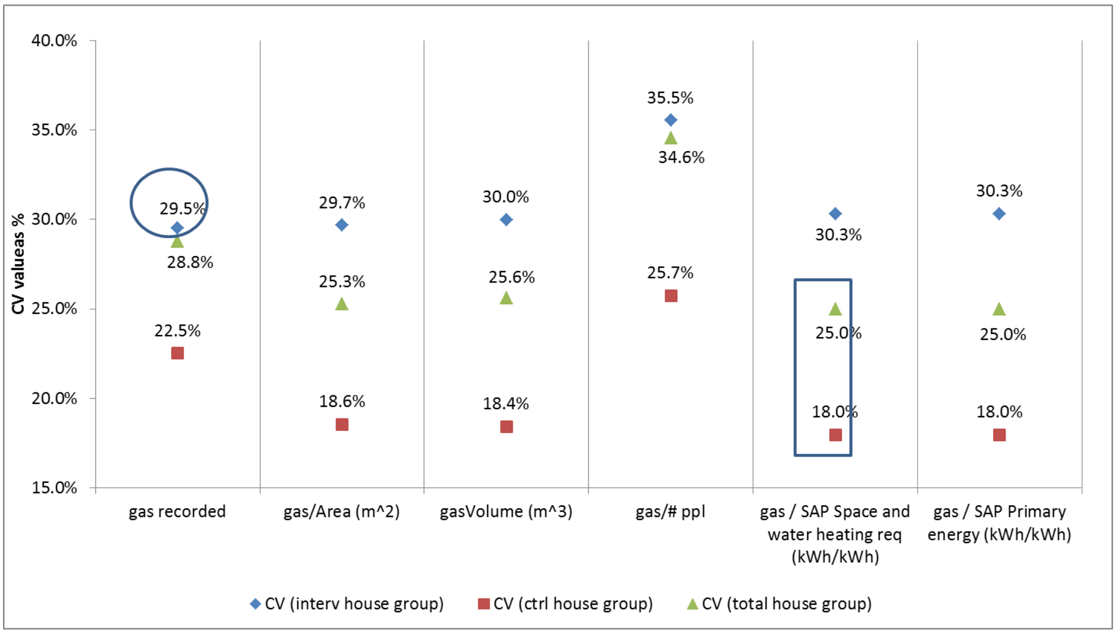


Figure 4.3: Comparison of CV values for normalisation conditions relating to recorded gas consumption for the sample property type: houses

The analysis of normalisation conditions through the correlation of variation shows that the CV values from the gas consumption data from the part of the sample living in flatted accommodation were larger than the CV values from the housing sample. This would suggest that the level of variation for gas consumption within all the normalisation conditions for the sample living in flats is higher than that of the sample living in houses. The range of CV values between experimental groups for each normalisation condition in the housing sample is much larger than in the data for those in flatted accommodation. There is a distinct closeness in CV between the CV for all flats and that for those just in the intervention group; this is not the case for the housing sample data. In both property types, the control sample returned the lowest CV, suggesting that there is less variation in gas consumption for that group. However, no statistical difference was detected between the two experimental groups before the data was collected (see Section 3.4)

Further normalisation conditions could be analysed based on other variables in relation to occupancy type or style and building design. This could be done on a large sample of properties, and possibly of a sample of different types of tenure, to identify whether the level of deviance within the sample is always higher for gas consumption in flatted accommodation.

The results suggest that overall normalising the gas consumption data by space and water heating requirements predicted by the SAP gives the least amount of variation between each observed value and the group mean, although this normalisation condition was not statistically lower than the other examined normalisation conditions, which had slightly higher CV values. In one instance this normalisation condition was 0.8% higher than the lowest CV value (for the housing intervention group). It is, however, the most suitable normalisation condition collectively for gas saving analysis because of the consistently low CV value across the experimental groups and property types.

2011-2013 Phase 2 normalisation

The gas consumption data collected for the 31 month period after the initial 6 month study is referred to as the Phase 2 data. It relates to 20 of the same flats which were part of the Phase 1 results. In this sample, ten are in the intervention group and ten are in the control group.

The sample size changed due to occupants moving home and leaving the site. This was to be expected because the housing association stated that their properties typically change occupant every 36 months. An independent t-test found no statistical difference between the two groups in terms of the mean (average) number of occupants, the SAP calculated space and water heating requirements and the floor area.

The gas consumption data for this sample was normalised in the same way and using the same conditioning method explained above. In order to normalise the 31 months of gas consumption data, the SAP-predicted gas requirement value for each property was scaled up to represent 31 months of predicted gas requirement.

This was done by multiplying the SAP-predicted gas value by 2.44. This value accounts for two years of SAP predicted data plus the additional 7 months of SAP data to account for the extra months between 24 and 31 months. The additional 7 months of SAP data was calculated by applying the same technique described in Chapter 3.7.1. The total gas consumption for each property for the 31 months was divided by the SAP value for that time period to give the Phase 2 gas consumption score. The resultant value is normalised for time and is comparable to the other gas consumption scores.

When comparing gas consumption scores over time, especially in the knowledge of the anomalous weather condition of 2010, it is important to account for months when the household gas consumption may be higher than its respective SAP gas requirement due to periods of unusually low temperatures. This was explored in an attempt to account for increases or decreases in gas consumption between Phase 1 and Phase 2 related to space heating.

SAP 2005 uses the predicted heat gains, estimated internal temperatures and heat loss coefficient to define a base temperature, which is then used to find the number of Heating Degree Days (HDDs). The HDDs are used in SAP 2005 to reflect how weather influences the energy used to heat homes. The HDDs are calculated relative to a base temperature which is used by the DECC (2014b) and derived from the Hitchin formula (1983, 1990). If a day has an average (mean) temperature that falls below 15.5°C, the HDD for that month is multiplied by the number of days in that month and added to the total yearly HDD. If the monthly average temperature exceeds the base temperature, the HDD for the days in that month will be 0. SAP 2005 does not clearly state the monthly temperatures; for the purpose of this study, the HDDs are summed for each year of the monitoring periods, as shown in Table 7.1 (DECC 2014b) and plotted in Figure 4.4.

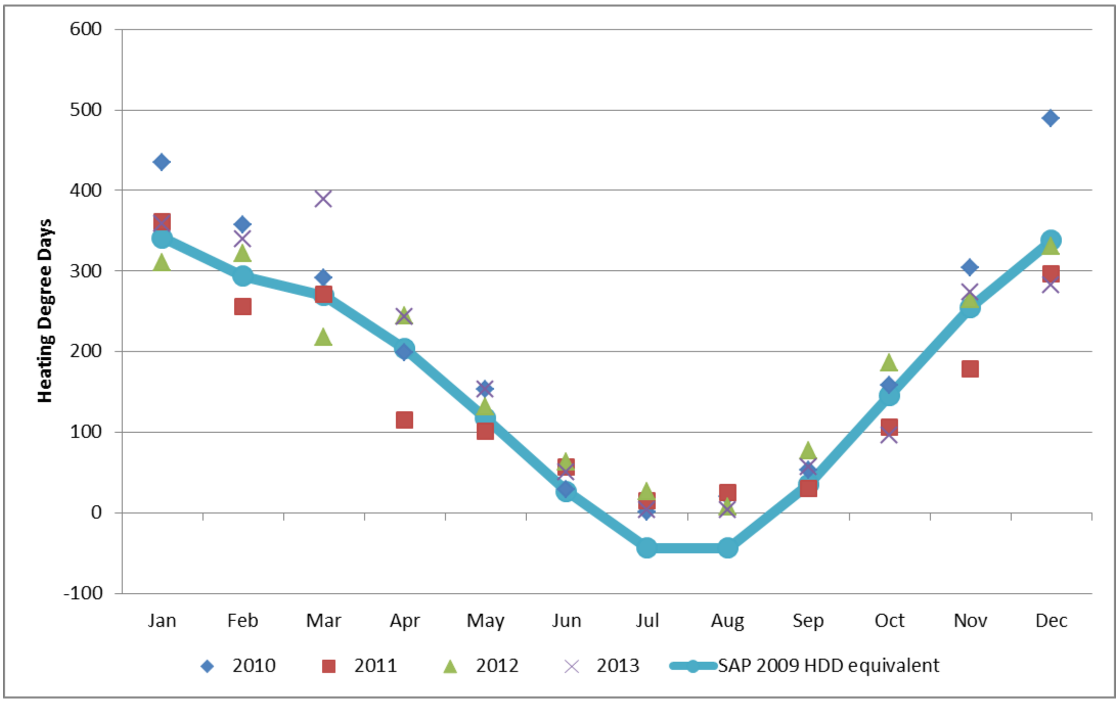


Figure 4.4: Temperature margin between four years of average monthly temperature data and SAP 2009 defined monthly external temperature

Although not directly comparable to the HDD as calculated by the SAP 2005, the HDD for the monitoring period September 2010 – February 2011 (Phase 1) was calculated as 1621 (average of 270). For the equivalent 6 months the following year (first winter of Phase 2), the HDD was calculated as 1246 (average 208). For the equivalent 6 months for the second winter of Phase 2, the HDD was 1557 (260). As the successor to SAP 2005, the equivalent HDD for SAP 2009 has been plotted to contextualise the temperature data provided by DECC. At time of writing, the SAP 2009 was the most current version of the standard assessment procedure. The SAP 2009 uses one external weather file for monthly temperatures to calculate space heating requirements, and this temperature file will be expanded to account for regional external temperatures in the SAP 2012. The HDD for the SAP 2009 is not directly calculated, because SAP 2009 assumes that no fuel is used for space heating between June and September.

The gas consumption score is derived from gas consumption for space and water heating, so the calculated average temperature margin for both phases was not applied to the score.

4.3 Gas consumption comparison

Gas remains the dominant fuel for space and water heating in the domestic sector, making up 81% (30,913 thousand tonnes of oil equivalent) of consumption for heat purposes and 68% of overall domestic consumption. Almost 98% of gas consumption is used for space and water heating (DECC 2010). However, Darby (2010a) suggests that demand is largely saturated and is possibly starting to decline due to more efficient boilers, better controls and improved insulation. Household gas customers reduced their use by 12% overall from 2005 to 2007 in response to higher prices. However, in 2008, when the winter was colder, household gas use rose by 3% despite prices rising. These figures appear to suggest that demand can be responsive to rises in price, although Owen and Ward (2010) note that people will understandably choose extra heat rather than saving money if the weather is very cold.

4.3.1 Effects of Ewgeco on total gas consumption

The recorded gas consumption data has been divided from the SAP-predicted gas requirement to normalise it for the participating 52 properties, creating a gas consumption score. Normalised gas consumption data over the initial six month winter trial period is charted for each of the property types and experimental conditions and displayed as a boxplot in Figure 4.5 and as a bar chart with confidence intervals in Figure 4.6.

As anticipated, those living in flats have a slightly lower gas consumption score than those living in houses. This maybe be attributed to how people perceive comfort in relation to the size of their property (the trial properties averaged a size of 154m^3 for flats and 202m^3 for houses). This means that people in houses, who have more rooms and therefore a greater floor area and a wider distribution of occupants, might be heating up a greater volume to achieve the same desirable temperature. The average (median) values presented in Figure 4.5 show that the intervention groups are lower than the median values for the control samples, indicating that the Ewgeco IHD may have had an effect on gas consumption levels for those in the intervention group.

The control house group is stacked towards the upper end of the gas consumption score, and the scores are less distributed across the control house group. In both property type groups, the lowest consumption scores are in the intervention group and the highest consumption scores are in the control groups. However, there is considerable overlap between the consumption scores for the control group and intervention group for both property types.

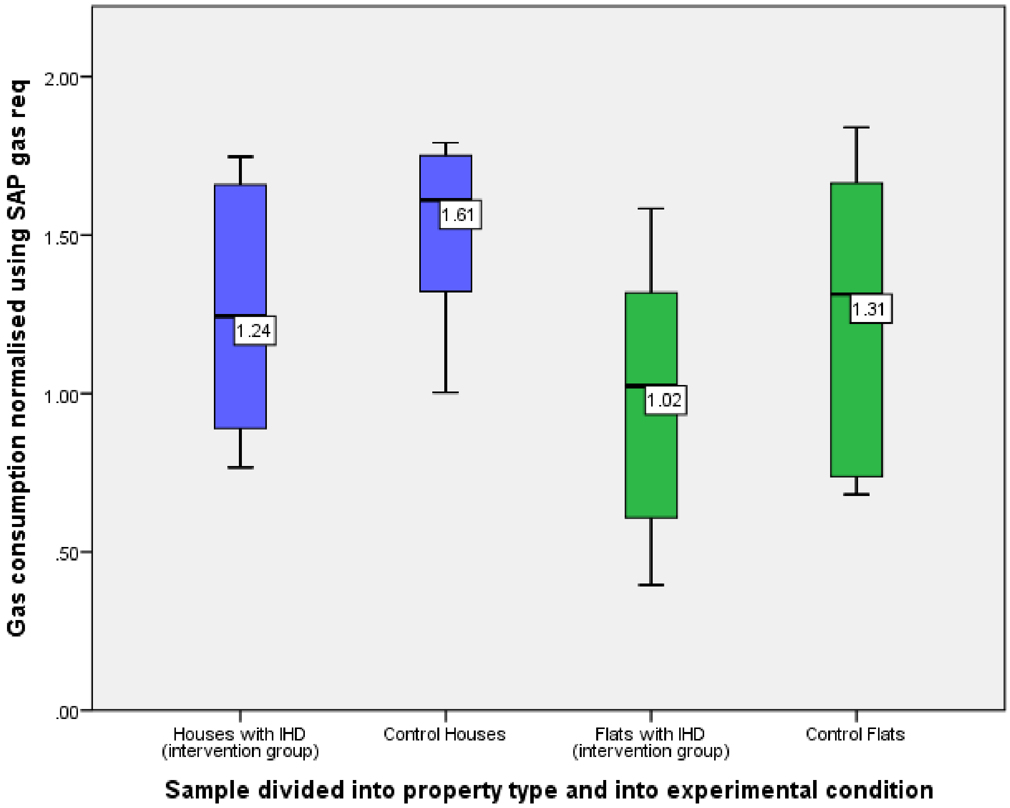


Figure 4.5: Box plot displaying the range and median normalised gas consumption, sample grouped by experimental condition and property type

The average (mean) normalised gas consumption in the housing group and control flats had scores greater than one, which indicates that on average the gas consumption scores for the properties within those groups are higher than those for their respective SAP-predicted gas requirements. Perhaps coincidently, the properties in the intervention group living in flats have an average consumption score closer to that predicted by the SAP.

The results illustrated in Figure 4.6 indicate that both sets of properties with the Ewgeco IHD on display had a lower gas consumption score on average (mean) compared to the comparable control groups. The houses with an Ewgeco IHD on display (M=1.26, SE=0.11) consumed 17% less gas, on average, than those in with no Ewgeco on display (M =1.52, SE=0.09). This difference is significant (t(19)=-1.73; p=<.05) and the data indicates a medium-sized effect (r=0.37). Therefore, the alternative hypothesis 1 is supported: those living in houses and who have an IHD on display consumed less gas when normalised by SAP than those with no IHD on display.

On average, the occupants living in flats and who had an Ewgeco IHD on display (M=0.98, SE=0.09) had a normalised gas consumption score 22% lower than those averaged by the occupants living in flats with no visual access to an IHD (M =1.25, SE=0.12). The difference between group means was statistically significant (t(29)=-1.78; p=<.05). The data indicates a medium-sized effect (r=0.31). Therefore, alternative hypothesis 2 has been supported: those living in flats with an IHD on display consumed less gas when normalised by SAP than those living properties with no visual access to the Ewgeco IHD.

Overall, independent of property type, the intervention group (M =1.09, SE =0.08) consumed 20% less normalised gas than the control group (M =1.36, SE=0.08). The difference between the group means was statistically significant (t(50)=2.36, p=<.05). The result indicates a medium-sized effect (r=0.32). Therefore, the null hypothesis can be rejected for gas consumption.

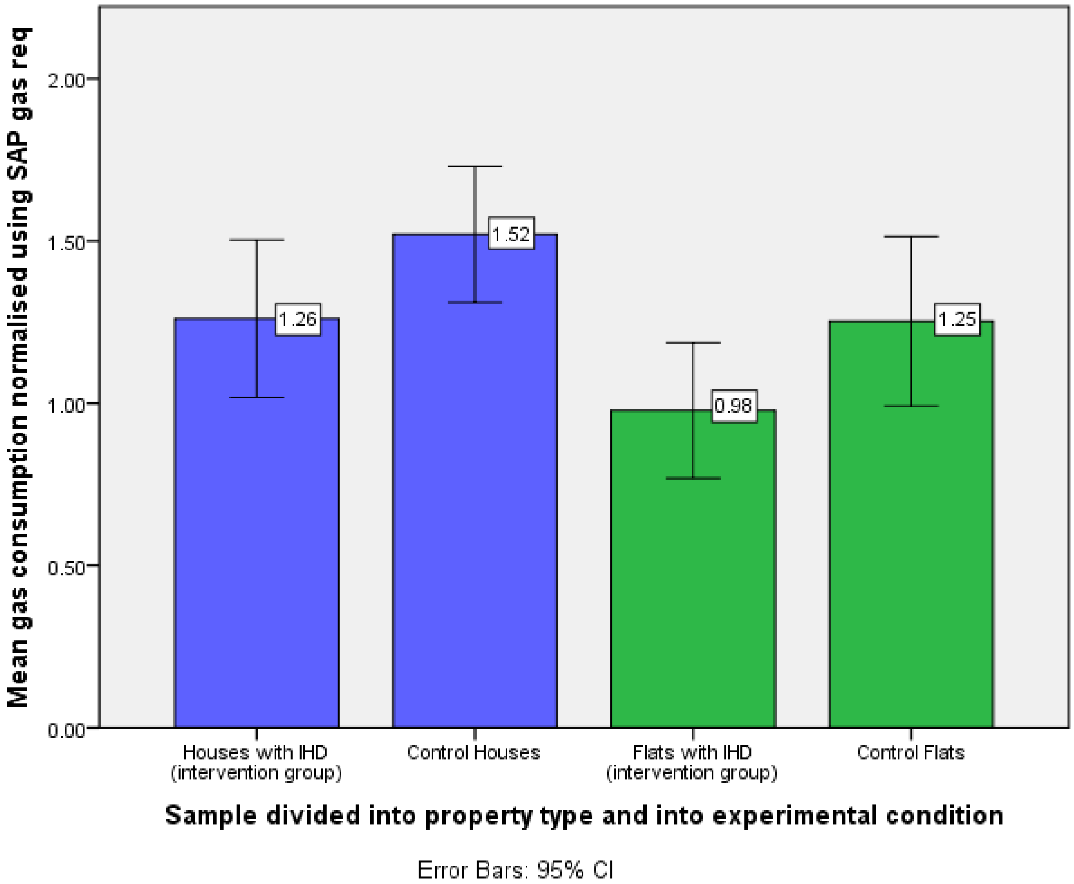


Figure 4.6: Mean normalised gas consumption scores, sample grouped by experimental condition and property type

4.3.2 Monthly gas consumption pattern

The mean value of the groups' monthly gas consumption has been examined, offering a more detailed picture of the differences in normalised gas consumption month on month in the experimental conditions. The first finding of note from Figure 4.7 is the energy pattern, which is as would be expected from the time of year: gas consumption related to space heating rose as outside temperatures decreased. The minimum recorded temperature for the east of Scotland by the UK Met Office for December 2010 was considerably lower than that of any other month during the trial period. The met office reported that December 2010 was the coldest December in over 100 years. December 2010 was also one of the coldest calendar months in the last 100 years and the coldest since February

1986 (MetOffice 2013). The gas consumption score includes gas consumed for space and water heating, but it is likely that the increase in gas consumption during the winter would almost solely be related to the need for more space heating.

Secondly, and consistent with the previous findings shown in Figure 4.6, the mean monthly gas consumption score dependent on experimental condition was lower in the flats than in the respective house groups. Within each property type, the intervention group had a lower consumption score than the control group. The control group in the flats and houses had much the same gas consumption score for the first two months and the last month of the six month trial.

The contrast in consumption between the experimental conditions for each property group is noticeable from the mean monthly data. After the first month of the trial, the intervention groups from the flat group and from the house group had already begun to consume less than those properties in the respective control groups. This difference in consumption score appears to be constant for the mean consumption in September 2010 and October 2010. For each of these two months, the properties in the flat intervention group had a gas consumption score 27% lower than the comparable control group. The properties in the house intervention group had a gas consumption score 10% lower than the control houses for these starting two months. These results suggest that during these months those living in flats were more responsive to the information presented by the Ewgeco IHD than the housing intervention group.

During November 2010 the difference between the mean consumption score for the control group ($M=2.04$, $SE=0.18$) began to increase significantly compared to the intervention group for the group who lived in houses ($M=1.54$, $SE=0.11$), ($t(19)=-2.54$, $p=<.05$). This result indicates a large-sized effect ($r=0.50$). For December, the difference between the gas consumption score for the control group in houses ($M=2.16$, $SE=0.17$) compared to the average gas consumption score for the intervention group ($M=1.58$, $SE=0.15$) was also statistically significant ($t(19)=-2.56$, $p=<.05$). This result also indicates a large-sized effect ($r=0.51$).

This increase in consumption score difference was also observed for those living in flats for the December consumption period. The intervention group (M=1.25, SE=0.14) on average had a lower consumption score than the control group (M=1.63, SE=0.19). This difference was statistically significant (t(29)=-1.69, p =.05) and represents a medium–sized effect (r=0.30). This is a considerable finding given the recorded external temperatures.

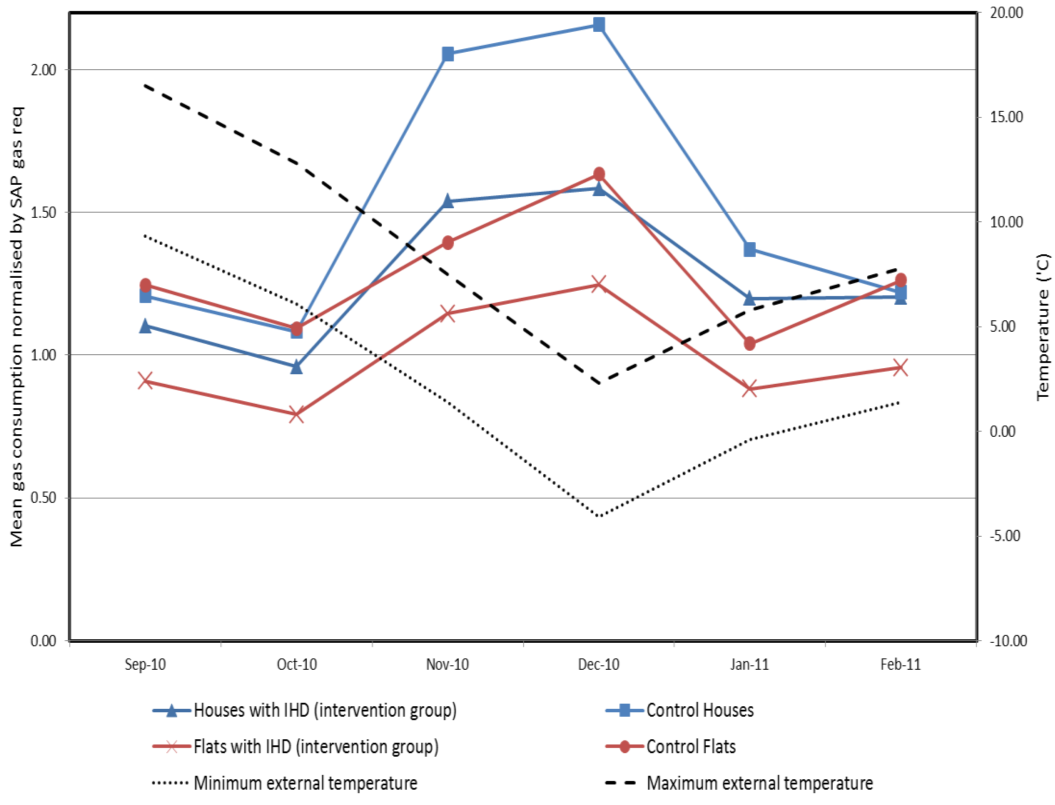


Figure 4.7: Mean gas consumption scores for properties with Ewgeco compared to those without Ewgeco, plotted against time in months

Towards the end of the six month trial, the average gas consumption score reached similar levels for the intervention and control groups for the houses. The external temperature had begun to rise in the previous month, so it can be argued that the intervention group had raised their consumption above their predicted trajectory. Accepting the statistical result from the independent t-test, which shows that the intervention group had a reduced average (mean) gas consumption score because of the presence of the Ewgeco IHD, then we might say that the increase in consumption in month six (February) was due to disengagement with the Ewgeco IHD. Alternatively, the average gas consumption score for February for the control group may have been lowered by external factors, perhaps relating to the arrival of a gas bill or other energy saving media. The exact reason is unknown, but the drop in difference is considerable. The results plotted in Figure 4.7 indicate the Ewgeco IHD's effect on households' peak gas demand over the coldest months, thereby positively reducing the amount of gas used for space and water heating compared to a control sample.

The sample with Ewgeco in the flats also reduced their gas consumption compared to their control counterparts, although their month on month consumption scores tracked much closer together. Towards the end of the trial the consumption level for the control flats began to increase, which may suggest that the visual presence of the energy monitor helped the occupants in the intervention group to better stabilise their monthly gas consumption after the colder months.

The monthly consumption data shows that the intervention group consumed less gas than the control group. However, these differences are not consistent month on month (see Figure 4.8). The differences in gas consumption scores for the group living in flats fluctuate about 5% after the first two months. Although the fluctuations are slight, a subtle downward trend is observed. The month on month differences between the experimental conditions in the housing group displays a parabola, with the gas consumption score for the intervention group peaking in December, but falling to be 1% lower in February 2011.

The large differences in month on month gas consumption scores provide an insight into the upper range of gas reduction made possible by the presence of the Ewgeco IHD. The fluctuations in gas savings over the months may be explained by inconsistences in how the information from the Ewgeco IHD was being implemented by the occupants to reduce unnecessary gas consumption. The fluctuations in savings may be a case of the users settling into their homes for the first winter of occupation and finding the limits of their new dwelling and the new energy monitor technology. That there was less fluctuation in the savings made by the flat intervention group offers more confidence that this group are perhaps more likely to maintain lower gas consumption scores in comparison to their control group for longer.

The large drop in savings made by the housing intervention group may point to the IHD technology becoming ignored or the information being disregarded because the occupants lose interest or become distracted by the newer technology which may have arrived at Christmas. Alternatively, the occupants in the control houses may have been responding to energy saving prompts from their utility bills or energy saving campaigns, which would not have affected the intervention group if they had already reduced their gas consumption to the minimum allowable levels. A longer study was not conducted for the housing sample. Future work could revisit this site, because the technology is still installed.

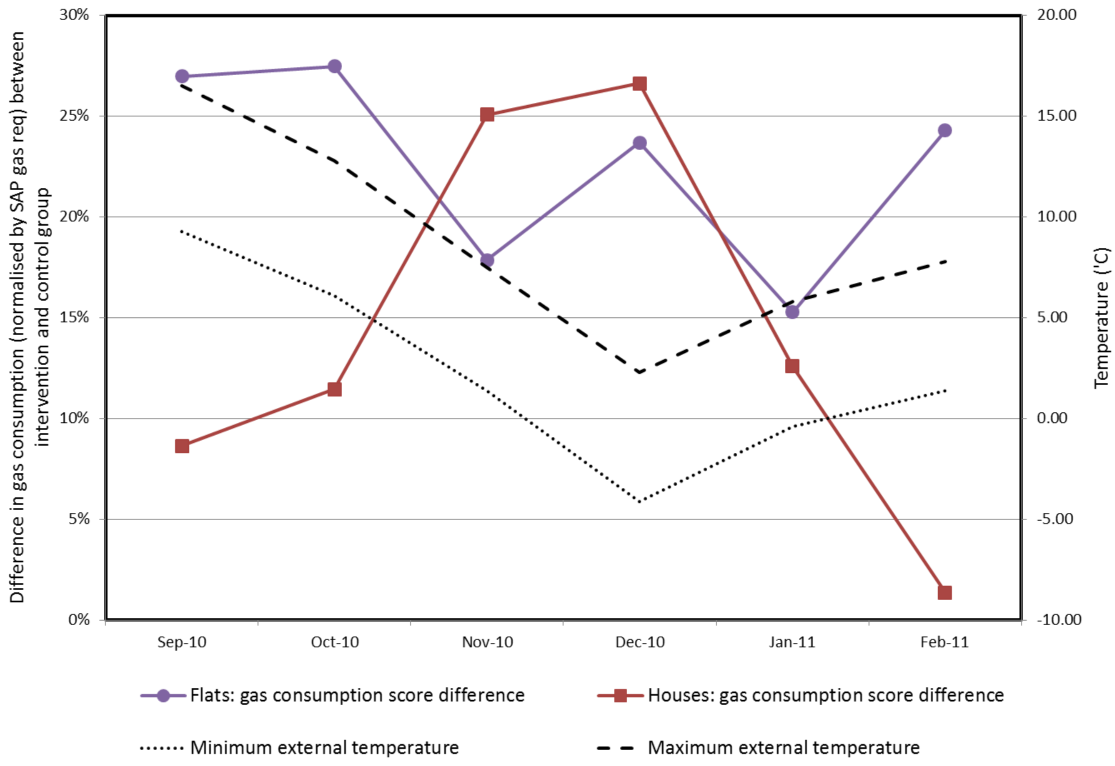


Figure 4.8: Percentage difference in gas consumption scores for properties with Ewgeco compared to those without Ewgeco, plotted against time in months

The results from the longer trial period provide greater insights into the differences in gas consumption scores between the experimental conditions and persistence effect of the Ewgeco IHD for the group living in flats.

4.3.3 Gas consumption based on occupancy levels

The number of occupants in each of the dwelling types and experimental conditions may account for some of the higher values of gas consumption within each group. Figure 4.9 shows the difference in gas consumption scores between experimental conditions for the different occupancy levels across the two property types. The results show that those in flatted accommodation with an Ewgeco IHD on display have considerably lower gas consumption than the controls. The results are similar for the housing group. There is no clear trend from the data explaining how occupancy levels affect the gas consumption scores.

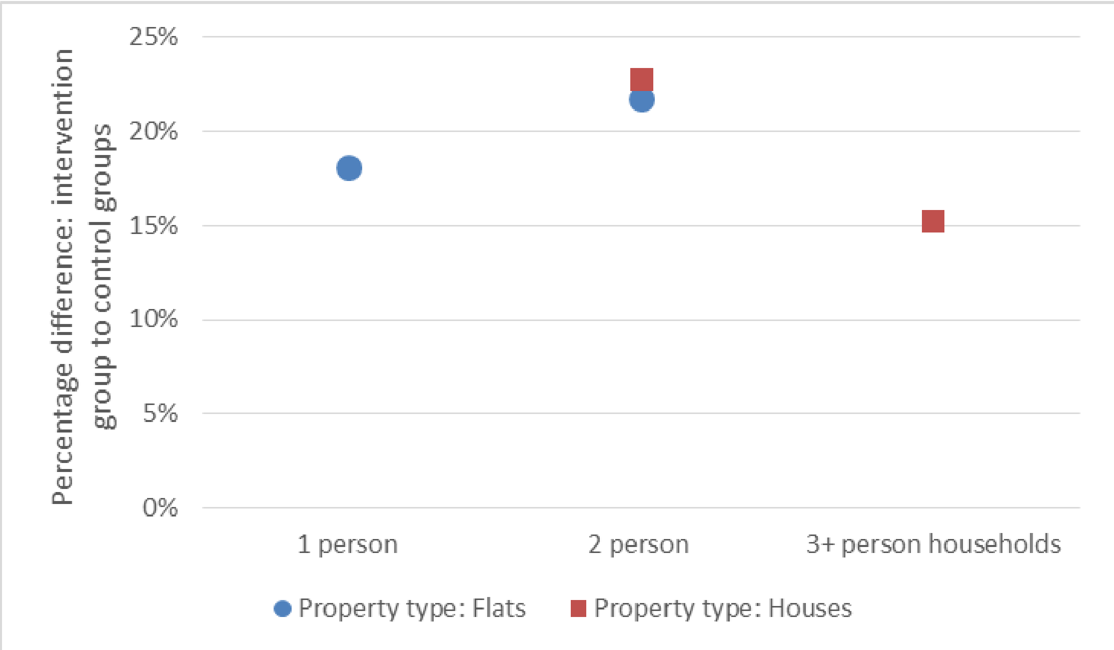


Figure 4.9: Percentage difference gas consumption for flats and houses based on occupancy levels

The three or more person group can be separated into three and four person households. For the three person houses, the intervention group had a 2% higher gas consumption score than the controls and the four person intervention group had a score 7% lower than the control group. However, due to participant withdrawal, this group had only one control property in it, which arguably is not enough data to draw a conclusion. Therefore the three person and four person dwelling sizes were grouped together. During the qualitative data capture, the occupants in the three and four person households commented on the difficulties they faced when trying to persuade or enforce energy saving habits relating to gas usage (heating). This is further explored in Chapter 6.

4.4 **Gas consumption over time: A longitudinal study**

Due to the available resources and to participant drop out, only 20 of the original 31 participants in the flatted accommodation were available for the 2013 data capture. The analysis of the difference in gas consumption between the experimental conditions (n=20) was isolated for the monitoring period Sept 2010 to Feb 2011 (Phase 1) and then calculated for Phase 2. The results are plotted in Figure 4.10. Similar to the findings for all 31 available flats, the average (mean) gas consumption scores for Phase 1 for the 10 intervention flats ($M=0.93$, $SE=0.12$) available in 2013 was 25% lower than for the 10 flats in the control group ($M=1.24$, $SE=0.10$). A one-tailed independent t-test showed that this difference was statistically significant ($t(18)=1.97$, $p < .05$) and that it represents a medium–sized effect ($r=0.42$).

When the average (mean) gas consumption scores were compared for the monitoring period Phase 2, the same 10 properties in the intervention group ($M=0.84$, $SE=0.15$) had a gas consumption score that was 26% lower than the score for the control group ($M=1.13$, $SE=0.14$). A one-tailed independent t-test showed that this difference was not statistically significant ($t(18)=1.44$, $p=.08$) and that it represents a medium–sized effect ($r=0.32$)

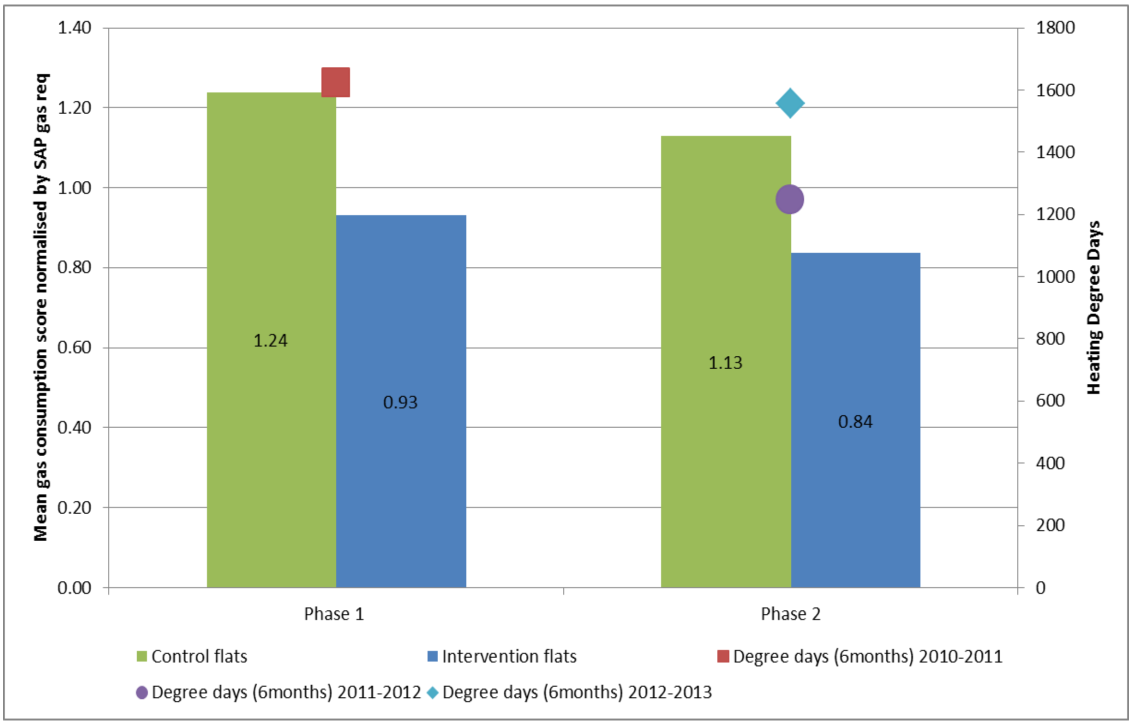


Figure 4.10: Mean gas consumption scores for 20 flats within the experimental condition across phase 1 and phase 2

During Phase 2, the control group (M=1.13, SE=0.14) reduced their mean (average) gas consumption score by 9% compared to the mean (average) consumption for the Phase 1 monitoring period (M=1.24, SE=0.10). A two-tailed dependent paired samples t-test showed that this finding was not significant (t(9)=1.06, p> .05). This was a large-sized effect (r=0.68). The mean gas consumption score calculated for Phase 2 for the intervention group (M=0.84, SE=0.15) showed that they reduced their consumption by 10% compared to their average (mean) gas consumption score for Phase 1 (M=0.93, SE=0.12). This was not statistically significant (t(9)=2.11, p=.06), but it was measured as having a very large-sized effect (r=0.96).

The decrease in gas consumption score between the two periods is of a similar magnitude. Assuming that the internal temperatures of the dwellings and the consumption of hot water have not changed significantly, then the drop in gas consumption score may be a result of less extreme cold weather during the winters of 2011-12 and 2012-13. The temperature margin between the SAP and local temperatures is much closer for the monitoring period Phase 2. Working with the assumptions made by the SAP based on research carried out by the Energy Savings Trust (2013) on the linear relationship between the number of occupants and hot water use, it is likely, because the number of occupants living in each property has not changed over time, that their hot water consumption has not changed a great deal. As the boilers are less than five years old, it is conceivable that the boiler efficiency has not dropped to levels that would impact on water heating.

The change in gas consumption over time is likely to be a result of differences in year on year winter temperatures. The HDD plotted in Figure 4.10 gives an indication of one reason why the gas consumption score in Phase 2 is lower than that of Phase 1, which is arguably the most influential reason for the change. Other reasons include the increase of the average UK domestic gas bill, which increased by 10% from 2011 to 2012 and by 7% from 2012 to 2013 (DECC 2014c).

Overall, for the entire 37 month monitoring period, on average the intervention group of 10 flats ($M=0.84$, $SE=0.14$) reduced their average gas consumption score by 27% compared to the control group ($M=1.15$, $SE=0.13$). This difference was statistically significant ($t(18)=1.71$, $p=.05$), and the result represented a medium-sized effect ($r=0.37$).

4.5 **Conclusion**

The results from the normalised gas consumption data for the first six month Phase 1 monitoring period show that the intervention group had on average (mean) significantly lower gas consumption than the control group. This was also the finding when the groups were divided by property type. The intervention group for those living in flats and houses had a significantly lower gas consumption score than the respective control groups for December 2010, which was the coldest December for 100 years.

When the property types were further divided by number of occupants, a large difference in energy savings was observed between the lower occupancy (one and two person) homes and the larger occupancy (three and four person) homes. The three and four person properties where typically occupied by two adults and a person below the age of 18. In contrast, the two person houses and flats where typically occupied by 1 adult and a child below the age of 18. The interviewees who lived in houses with households of three or four people and an Ewgeco IHD commented on the increased difficulty of trying to regulate the use of gas that resulted from the number of people, specifically adults who had access to the heating controls. The person in the three and four person homes who professed to be the more energy efficient and therefore the more likely to obverse the IHD was not always the person responsible for paying the utility bills. Often the person who paid the bills had little time for changing their existing energy saving habits.

This type of conflicting dynamic between the two adults appeared to be commonplace across the group, where energy saving or energy efficiency was subconsciously seen as another household chore that was then allocated to or voluntarily done by one of the adults. Furthermore, energy saving actions or accomplishments made by one adult were often undermined by the other. Both adults would criticise each other for their role in ‘wasting’ or saving gas (heating). These actions did not seem to be any more than a trivial annoyance. This finding suggests a weakness in the ability of the IHD alone to both implement and maintain long term energy savings for homes with multiple adult occupancy and for households with more than two people.

This type of energy use dynamic within the home suggests that the likely reason for the smaller savings in gas consumption score made by the intervention group who lived in four person rather than two person homes. However, the self-professed energy champions of the three and four person intervention homes praised the gas display portion of the device, describing how they could for the first time see the benefits of turning down the thermostats.

According to the UK census data collected in 2011, the ONS and National Records of Scotland estimate that the average household size in the UK is 2.3

people (ONS 2013) and the average household size in Scotland is 2.2 people (National Records of Scotland 2013). Two person households accounted for the largest single household group (34% UK, 34% Scotland), followed by one person households (31% UK, 35% Scotland). The average household size (number of occupants) has shown a downward trend over the past 50 years. However, this means that households with three or more persons collectively account for the largest group in the UK (35%) and are still a substantial proportion of the dwelling population in Scotland (31%).

The census data does not differentiate between two person households with two adults or one adult and one child (under the age of 18). While the IHD appears to provide saving in gas usage for the two single largest household size types in the UK, it may not be as effective in homes with more occupants, which may also have a higher demand for gas fuel.

The additional 31 months of data collected for the 20 participating flats shows that on average those with the Ewgeco IHD had a significantly lower gas consumption score than the control group for the full 37 months of data. This is a significant finding and demonstrates that occupants with the coloured dual fuel Ewgeco IHD not only had a significantly lower gas consumption score than those properties with no IHD, but also maintained that same level of lower gas consumption score for the three years after they had begun to interact with the device.

Many authors in the field of domestic energy use change have reported that the participants in their trials become detached from the energy monitor after six months and that the energy consumption of the intervention group either rose or become higher than the control group's. As discussed in Chapter 2, many other studies have only focused on electricity use, and many used only monochrome or numerical style energy monitors.

Effect of selecting a normalisation condition

As discussed in Chapter 4.2, the normalisation condition applied to the raw gas consumption data for each property was chosen from a list of well recognised normalisation conditions. Dividing the gas energy by the SAP-predicted energy requirement for space and water heating overcame a plethora of variables, such as fabric and ventilation heat loss, heat gains and floor area, which are applicable but in this case different for each property. The SAP gas requirement normalisation condition was selected because it had consistently lower coefficient of variation (score).

The difference in gas consumption, as calculated through the use of the other normalisation conditions, has been summarised in Table 5.2. These differences are listed for the intervention group and for the control group; the normalisation condition used to calculate the results in this chapter is highlighted in grey.

If the raw gas consumption data was used to provide the results, then the overall energy difference result would be the same – a 20% reduction over the control group. However, the magnitude of gas savings would be different between the property types. The occupants living in houses would have saved 6% more gas over their control group than those living in flats.

If the gas consumption data were normalised by total floor area, the percentage difference in gas consumption would be considerable lower for the flatted properties, but the same for the housing sample. If the data were normalised by the number of occupants or dwelling volume, the percentage difference made by the flatted sample would have been significantly lower.

	Intervention group mean (average) consumption value was less than the control groups mean (average consumption by:		
Normalisation condition	for the entire sample (n=52):	For sample grouped to flatted accommodation (n=31)	For sample grouped to housing accommodation (n=21)
gas recorded (unconditioned)	20%	17%	23%
gas/Area (m^2)	14%	11%	17%
gas/Volume (m^3)	10%	2%	17%
gas/# ppl	14%	2%	29%
gas / SAP gas req	20%	22%	17%
gas / SAP gas primary energy	20%	23%	17%

Table 4.2: Gas consumption differences by normalisation condition for data collection during Phase 1

This chapter has analysed the gas consumption data collected from the 52 social housing tenants for six months and the 20 social housing tenants for 37 months. The analysis shows that those in the intervention group with a new generation of coloured real-time IHD consumed significantly less gas than a group of similar control properties. The longer term study shows that the intervention group with the IHD continued to consume less gas than the control group.

The next chapter presents and discusses the effects on domestic electricity consumption of the occupants having visual access to the coloured real-time electricity consumption IHD.

Chapter 5

5 Influence of IHD on Domestic Electricity Consumption

5.1 Introduction

This chapter is structured similarly to Chapter 4. It begins by describing the methods by which a normalisation condition to apply to the recorded electricity consumption data was chosen. The chapter presents and discusses the electricity consumption findings from the same 52 social housing tenants presented in Chapter 4. The electricity consumption for the participants relates to all electricity use at the point of the electricity meter. This refers to electricity used for lighting, typical plug-in domestic electrical appliances and fans and pumps. The data analysis is segmented into two phases. The first comments on the data captured during the initial TSB funded six month trial which took place over the winter months between 2010 and 2011. This part of the chapter compares the electricity consumption between the two groups and tests the difference for statistical significance. The two experimental groups are further divided by property type and the difference in consumption examined. Comparative electricity consumption is then explored per month over that winter period.

The chapter concludes by presenting and analysing the second phase of the electricity consumption results captured in 2013. The data captured in 2013 provided an additional 31 months of energy consumption data for 20 flats that participated in the initial 6 month TSB funded study. This analysis investigates the electricity consumption differences between the two groups and examines changes in gas use over the 37 months. How electricity consumption changed after the author had withdrawn contact with the participants at the end of the first 6 month period is investigated further. The Phase 2 data collection and analysis was funded by the Low Carbon Building Technologies Gateway (LCBTg) and European Regional Development Finding (ERDF).

5.2 Normalisation analysis and calculation for electricity consumption

As was discussed in Chapter 4.2, many normalisation conditions can be applied to recorded electricity consumption, including those which take account of building dimensions or occupancy. The first three normalisation conditions selected for application and analysis (see Table 5.1) are those typically used by building science and energy modelling professionals to normalise electricity usage across building types. They are applied to this research to ensure its consistency with other similar research. The last four normalisation conditions have been investigated in an attempt to focus on user behaviour alone by isolating the electricity consumption required by the fans and pumps designed to be in the dwelling.

Each of the normalisation conditions are applied to the unconditioned (actual recorded) electricity consumption from each property in the given sample groups. The average (mean) and standard deviation are then calculated for the sample group, i.e. for the houses and flats in control and intervention groups. The correlation of variation (CV) is calculated as a ratio of the standard deviation to the mean and is presented as a percentage. The lower the CV number for that normalisation condition group, the less variation there is between each observed score and the group mean (average).

Condition	**Equation**	**Units**
Actual electricity use per floor area	Recorded electricity consumption divided by total floor area as defined by SAP	kWh/m^2
Actual energy use per volume	Recorded electricity consumption divided by total dwelling volume as defined by SAP	kWh/m^3
Actual energy use per person	Recorded electricity consumption divided by total number of people living in the dwelling as defined by questionnaires conducted at household visit	kWh/person
Actual electricity use – SAP calculated fan and pump usage	Recorded electricity consumption minus the electricity consumption calculated by SAP for fans and pumps	kWh
Actual electricity use – SAP calculated fan and pump usage per floor area	Recorded electricity consumption minus the electricity consumption calculated by SAP for fans and pumps divided by total floor area as defined by SAP	kWh/m^2
Actual energy use – SAP calculated fan and pump usage per volume	Recorded electricity consumption minus the electricity consumption calculated by the SAP for fans and pumps divided by total dwelling volume as defined by the SAP	kWh/m^3
Actual energy use – SAP calculated fan and pump usage per person	Recorded electricity consumption minus the electricity consumption calculated by the SAP for fans and pumps divided by total number of people living in the dwelling as defined by questionnaires conducted during the household visit	kWh/person

Table 5.1: Normalisation conditions for electricity consumption

2010-2011 phase 1 normalisation results

First, the seven normalisation conditions were applied to all 52 properties and the CV values were reviewed. The group was then split into the two experimental groups, control and intervention, based on the presence of the IHD monitor.

When the SAP calculated electricity demand for fans and pumps is subtracted from the unconditioned electricity consumption, the resulting CV values are considerably higher than the other CV values presented in Figure 5.1.

Control group

Using a one-way repeated measures ANOVA, the difference between the CVs of the eight conditions was found to be statistically different for the control group. This was not detected in the Greenhouse-Geissers test ($F(1.39, 29.24)=1.3$, $p>.05$), but because the Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(27)$ 403.82, $p<.05$), the multivariate test results were therefore reported ($\varepsilon=.20$). The results show that the CV values for the eight conditions applied to the control group are significantly affected by the normalisation condition ($V=.86$, $F(7,15)=13.17$, $p<.05$).

Repeating the ANOVA test, omitting the normalisation conditions and subtracting the SAP data shows no statistical difference between the conditions which did not subtract the SAP data ($F(1.35, 28.33)=.36$, $p>.05$). Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(5)$ 79.81 $p<.05$), so the multivariate test is reported ($\varepsilon=.45$). The results from the Pillai's Trace statistic show that the four CV values for the conditions applied to the control group are not significantly affected by the normalisation condition ($V=.11$, $F(3,19)=.75$, $p>.05$). This means that the difference between the lowest CV values and the other CV values is not statistically significant. The normalisation condition with the lowest CV was chosen as a best fit for the data because it is the lowest, but it is not statistically lower than the others. The other normalisation conditions, when applied to different data sets, may have a lower CV value than the results presented here.

Intervention group

The ANOVA test was conducted for the intervention group and showed the same type of result. The difference between CVs for the seven normalisation conditions and the unconditioned electricity data was statistically significant. This was not detected in the Greenhouse-Geissers test ($F(2.09, 60.52)=2.46$, $p> .05$), but because Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(27)$ 359.50, $p <.05$), the multivariate test are reported ($\mathcal{E}=.30$). The results show that the CV value for the eight conditions applied to the intervention group are significantly affected by the normalisation condition ($V=.68$, $F(7,23)=6.96$, $p <.05$). Repeated the ANOVA test and omitting the normalisation conditions with SAP data subtracted shows there was no statistical difference between the conditions which did not subtract SAP data for the intervention group ($F(1.81, 52.46)=.58$, $p> .05$). Mauchly's test indicated that the assumption of sphericity has been violated ($x^2(5)$ 51.34 $p <.05$), so the multivariate test is reported ($\mathcal{E}=.60$). The results from the Pillai's Trace statistic show that the four CV values for the conditions applied to the intervention group are not significantly affected by the normalisation condition ($V=.14$, $F(3,27)$ =.1.5, $p>.05$). This would suggest that the method of normalising the electricity consumption is most suitable when the SAP fans and pumps are not removed from the recorded electricity consumption prior to normalisation.

Unlike the findings from the normalisation analysis for gas consumption, when the electricity normalisation conditions were applied to the full 52 properties and separately to the intervention and control groups, the normalisation conditions increased the CV values. The increases in CV values between the unconditioned recorded electricity, electricity/floor area and electricity/dwelling volume are marginal. The CV values for the groups are much larger when the data is normalised by number of occupants.

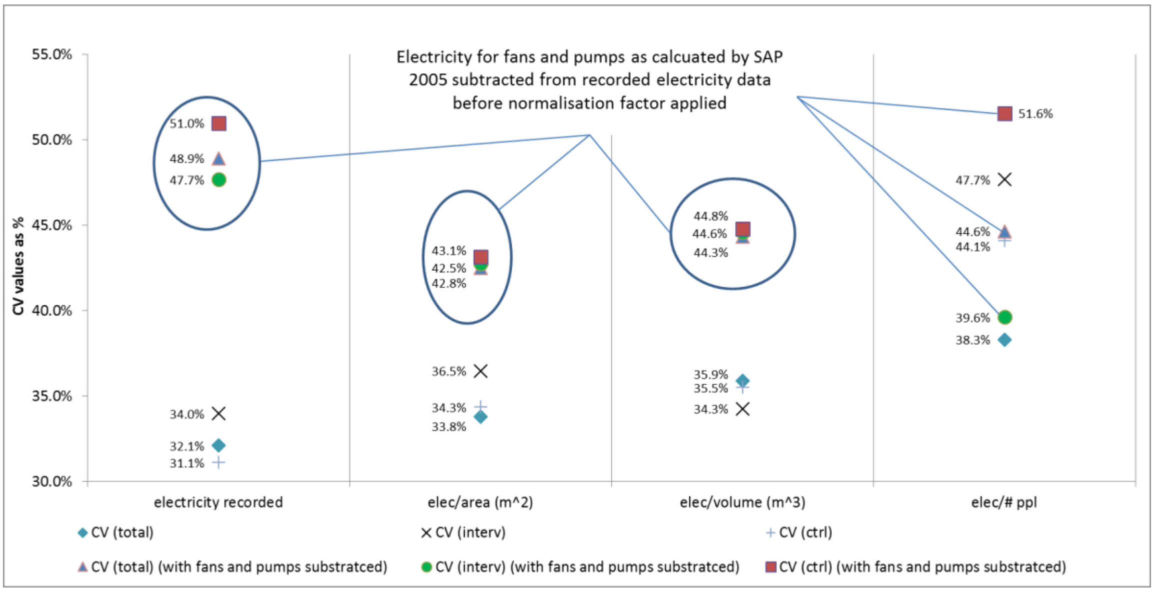


Figure 5.1: Comparison of CV values for normalisation conditions relating to recorded electricity consumption (flats and houses not separated)

The intervention and control groups were further divided by property type in order to examine the changes in the correlation of variation for the normalisation conditions when applied separately to the sample living in flats and the sample living in houses. The difference between the CV values for these four groups was tested for statistical significance.

Electricity normalisation conditions for sample living in flats (n=31)

Figure 5.2 shows the calculated CV values for the sample living in flatted accommodation for the unconditioned electricity consumption and electricity consumption when normalised by the seven normalisation conditions. The chart plots the CV values for the entire 31 flats and then for the flats divided into the control group (n=13) and the intervention group (n=18).

The findings suggest that normalising the electricity consumption by the condition which removes SAP calculated consumption for fans and pumps produces values that are too high, meaning that the variation of electricity consumption per property and the sample mean fluctuate considerably between flatted properties. These normalisation conditions were not considered a reasonable method of normalising the electricity consumption for the sample.

Control group

The results from an ANOVA which included only the first four conditions show that Mauchly's test indicated that the assumption of sphericity had been violated ($x^2(4)$ 57.30, $p < .05$), so the multivariate test is reported ($\mathcal{E}=.46$). The results from the Pillai's Trace statistic show that the amount of standardised deviance in the data set was not statistically affected by the type of normalisation condition ($V=.26$, $F(3,10)=1.14$, $p>.05$).

Intervention group

An ANOVA test comparing the standard deviance within each normalised data set and the unconditioned data set shows the statistical differences between the conditions. Mauchly's test indicates that the assumption of sphericity had been violated ($x^2(5)$ 40.08, $p < .05$), so the multivariate test is reported ($\mathcal{E}=.56$). The results from the Pillai's Trace statistic shows that the amount of standardised deviance in the data set was statistically affected by the type of normalisation condition ($V=.55$, $F(3,15)=6.158$, $p < .05$).

To discern whether the level of significance was still found with the normalisation conditions with the lowest CVs, the ANOVA test was repeated to exclude the normalisation condition 'ele/volume' (kWh/m^3), because this was the highest CV value of the first four. Mauchly's test indicates that the assumption of sphericity had been violated ($x^2(2)$ 11.92, $p < .05$), so the multivariate test is reported ($\mathcal{E}=.66$). The result from the Pillai's Trace statistic shows that there was no statistically significant difference between level deviances between the three conditions ($V=.25$, $F(2,16)=2.64$, $p < .05$).

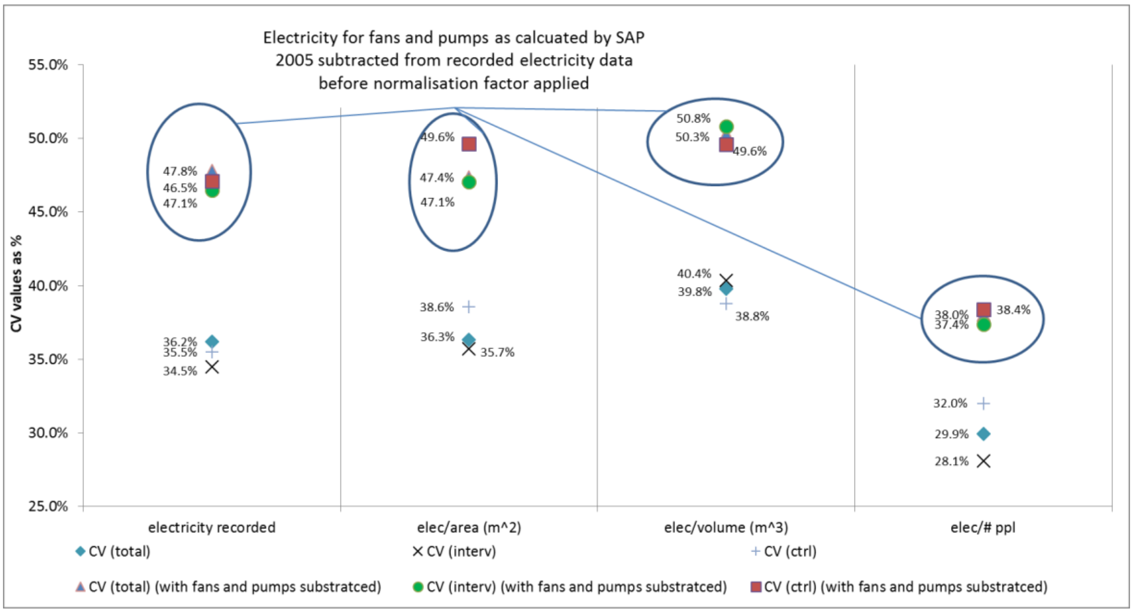


Figure 5.2: Comparison of CV values for normalisation conditions relating to recorded electricity consumption for the sample living in flats.

The positioning of the CV results for the normalisation conditions for the sample living in flats differs from the findings for the whole sample (n=52) and from the data for the houses alone. The normalisation condition ‘elec/#ppl’ (kWh/person) provided the lowest CV values for the whole flat sample and the two experimental conditions. This suggests that the electricity consumption of those living in flats is more dependent on the number of occupants, because dividing the electricity consumption by the number of people in the property reduces its dependence on the number of people in the property, making it a more suitable normalisation condition.

Electricity normalisation conditions for sample living in houses (n=21)

Contrary to the observations from the calculated CV values for the flatted group, the normalisation condition elec/#ppl returned much higher CV values for the group living in houses. This was the case for both the intervention (n=12) and control (n=9) groups. The unconditioned electricity data gave the lowest CV, so is arguably the most suitable unit of measurement for representing the data. Furthermore, the CV results from the data normalised by conditions which remove the SAP calculated fans and pump electricity requirement are much closer to the other normalisation conditions than was observed for the data for those living in flats. All eight conditions have been compared through an ANOVA test because of the closeness of the CV values for this group.

Control group

The results of an ANOVA test which included all eight conditions show that Mauchly's test indicated that the assumption of sphericity had been violated ($x^2(27)$ 190.53, $p < .05$), so the multivariate test is reported ($\varepsilon = .15$). The results from the Pillai's Trace statistic show that the amount of standardised deviance in the data set was not statistically affected by the type of normalisation condition applied to the electricity data from the control group living in houses ($V = .92$, $F(7,2) = 3.33$, $p > .05$).

Intervention group

The ANOVA test shows that the Mauchly's test indicated that the assumption of sphericity had been violated ($x^2(27)$ 254.17, $p < .05$), therefore the multivariate test is reported ($\varepsilon = .15$). The results from the Pillai's Trace statistic show that the amount of standardised deviance in the data set was statistically affected by the type of normalisation condition applied to the electricity data from the intervention group living in houses ($V = .91$, $F(7,5) = 7.35$, $p < .05$).

The test was repeated using the three data sets that returned the lowest CV values: the unconditioned data and data normalised by floor area and dwelling volume. The results show that Mauchly's test indicated that the assumption of sphericity had been violated ($x^2(2)$ 9.19, $p < .05$), so the multivariate test is reported ($\varepsilon = .63$). The results from the Pillai's Trace statistic show that the amount of standardised deviance in the data set was again statistically affected by the type of normalisation condition applied to the electricity data from the intervention group living in houses ($V = .50$, $F(2,10) = 5.0$, $p < .05$).

A Students T-test was carried out on the standardised deviance for the two lowest CV values: the unconditioned data and the data normalised by dwelling volume. On average, the standardised deviance within the data set was not statistically different between the unconditioned data ($M = .24$, $SE = 0.05$) and the data normalised by dwelling volume ($M = 0.25$, $SE = 0.51$, $t(11) = -.37$, $p > .05$).

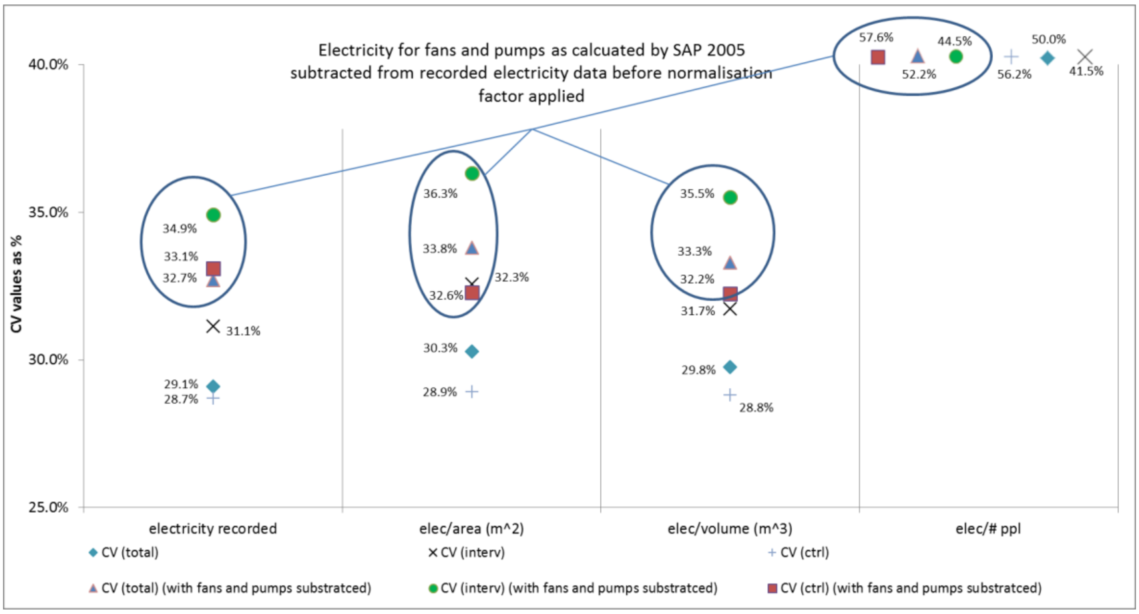


Figure 5.3: Comparison of CV values for normalisation conditions relating to recorded electricity consumption for sample living in houses.

The CV results from the housing group are slightly lower for each normalisation condition if the condition labelled 'elec/#ppl' is excluded than if the flat accommodation group is excluded, suggesting that the groupings in this sample show less variation between the electricity consumption for each participant and the respective groups' average (mean).

The normalisation conditions which incorporated the removal of fans and pumps from the SAP returned a much higher CV value for the whole housing group and for the flatted group. However, these SAP derived normalisation conditions returned a CV much closer to (yet still higher than) most of the other normalisation conditions which did not include SAP derived fan and pump consumption in the housing group. This may suggest that the calculation of the consumption of fans and pumps using the SAP for the housing group was much more accurate than that for the flatted accommodation.

One reason for the difference between the normalisation conditions with and without the SAP derived fans and pumps is that the proportion of electricity consumption predicted by the SAP for fans and pumps is much too high. The housing group consume more electricity than the flat group yet the electricity calculated for fans and pumps is 100 kWh/year higher for the flats. The predicted electricity consumption for fans and pumps accounts for, on average, 26% of the electricity consumption recorded. Meanwhile, some of the flatted properties were predicted to expend 40-57% of their electricity consumption on running fans and pumps. The picture is much different for the housing group, where the prediction for fan and pump consumption by the SAP was, on average across the housing group, 12% of consumption, with only two examples of the proportion rising to between 16-25%.

The factors influencing the amount of electricity calculated for fans and pumps, i.e. manufacturer data and installation commissioning, are unknown, cannot to be separately metered and were not the primary focus of the outline hypothesis. This requires further investigation.

For this group, the unconditioned electricity data provided the lowest CV, which is arguably the most suitable unit of measurement to represent the data.

2011-2013 Phase 2 normalisation

The same findings apply to the data sets captured for Phase 2. The results of the longitudinal study are presented in both unconditioned and conditioned forms by applying the normalisation condition ‘per person’. This normalisation condition is applied to the Phase 2 data because it consists solely of consumption information from flatted accommodation. The results from the CV analysis in Chapter 5.2 show that normalising the electricity consumption of the sample living in flats, this yields the lowest CV value for this sample and therefore represents the best fit for the statistical model.

5.3 **Characteristics of interview respondents**

Throughout this chapter, quotations have been extracted from the interview transcripts and used to illustrate or substantiate particular points relating to the energy use figures. The individual quotations chosen are representative of the wider themes under discussion and are used to convey a stronger sense of how this device was used by the occupants in their daily routines. A fuller discussion of the data from the interviews is presented in Chapter 6. The quotations used to supplement the initial 2010-2011 (6 month Phase 1) consumption figures are labelled as follows:

ID	IHD on display	Gender	No. of occupants	Age of occupants	Household income (£) thousand	House type
E02	Yes	Female	3	23, 20, 1	10-15	Semi-detached house
E13	Yes	Female	4	58, 33, 36, 3,	15-20	Ground Flat
E14	Yes	Male	1	62	15-20	Ground Flat
NE02	No	Male	2	35, 36	15-20	Mid-Flat

Table 5.2: Summary of quoted interviewees from Phase 1

5.4 Electricity consumption comparison

The 2011 Digest of United Kingdom Energy Statistics (DUKES) found that since 1990 electricity consumption from consumer electronics had increased by 74% and from wet appliances by 22%. Work undertaken by Darby (2010a) and Wood and Newborough (2007) also commented on the increasing numbers of appliances appearing in each UK household and note that appliances are managed and operated in a range of different ways, with few indications that householders are confident in controlling and reducing their consumption, either in terms of purchasing or maintaining equipment or of day-to-day operations.

Owen and Ward (2010) note that tariff price increases for electricity between 2005 and 2007 suggested a modest demand reduction in 2007. Yet in 2008, despite tariff price increases, demand for domestic electricity rose by 2.4%.

Around one fifth to one quarter of household electrical appliance load could be ‘discretionary’ or price responsive (Darby 2010a), although this is mainly associated with wet appliances. Predictions of domestic electricity consumption have pointed out the likelihood that increased household electrical load going forward into the 2020s may be due to the increasing use of Electricity Vehicles (EV), rather than to use for heat. However, as EVs are currently still in development, it is more likely that increased electricity demand from households will be attributable to an increased number of electrical appliances and technology.

5.4.1 Effects of Ewgeco on total electricity consumption

The average (median) figures for all 21 houses and 31 flats are further subcategorised by experimental group and plotted in Figure 5.4. These initial findings show that there is little difference in electricity consumption between experimental groups. The plots per experimental condition and property type show that median energy consumption is similar within the groups, as are the minimum and minimum energy consumption values.

As shown in Figure 3.4, approximately 60% of the face of the Ewgeco displays information about electricity and gas consumption levels, and 60% of the information displayed is represented by a coloured speedometer. Therefore those occupants who observed the gas consumption data on the Ewgeco display would have also had direct visual access to the electricity consumption levels, because Ewgeco constantly displays both side by side, and they both cover the same portion of the screen. This raises questions about the end users' need, or perhaps their willingness, to see their electricity consumption. One train of thought would suggest that, on average, both the intervention and control properties could be consuming low levels of electricity because the occupants in both groups are equally confident on practices aimed at reducing consumption and maintaining low levels of electricity consumption. Alternatively, perhaps those with Ewgeco IHDs were unaware of the necessary actions required to implement the information presented to them by the Ewgeco's display of electricity consumption. Chapter 6 will develop this line of enquiry in more detail.

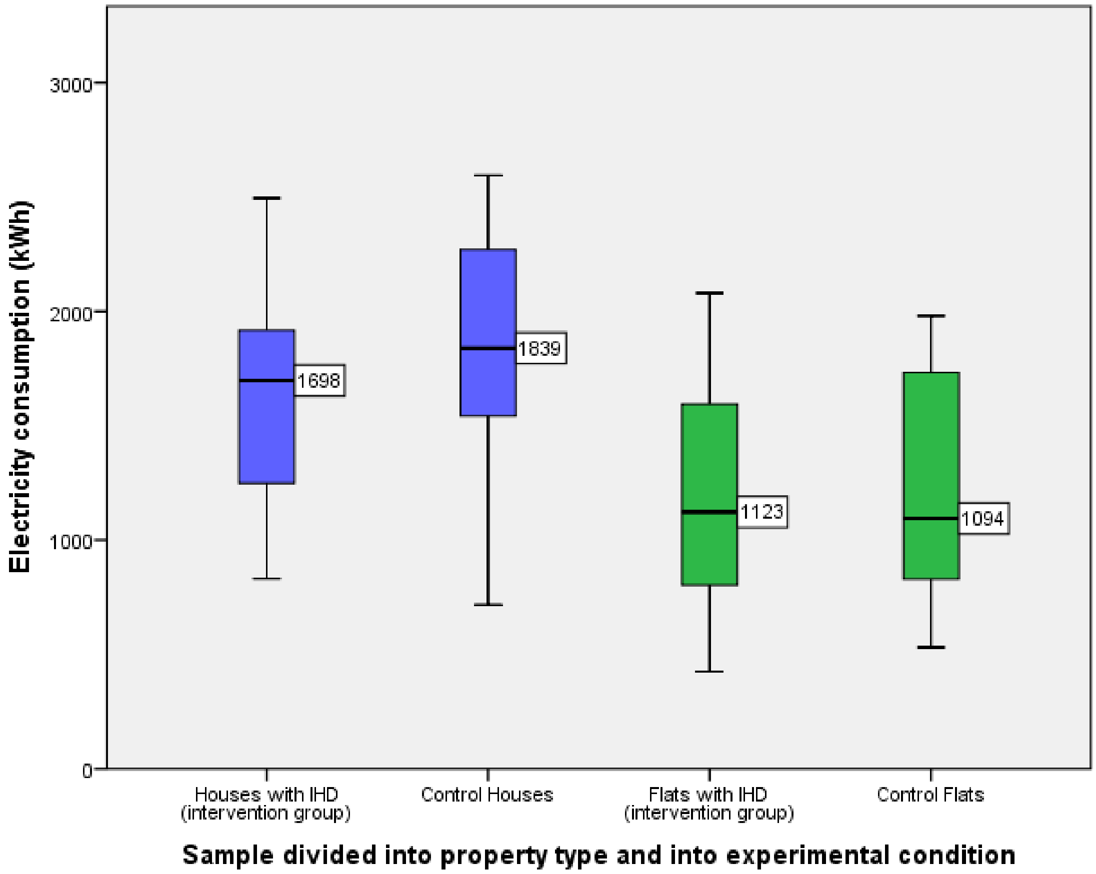


Figure 5.4: Box plot displaying the range of median electricity consumption values

The averaged (mean) electricity consumption data shown in Figure 5.5 is similar to the median values shown in Figure 5.4. The standard deviation of the energy consumption within the experimental group and between the property types is close to the mean, and therefore the mean energy consumption for the groups is reported for t testing.

The results from a one-tailed independent t-test show that the houses with a Ewgeco energy monitor on display (M =1658, SE=149) consumed 10% less electricity on average (mean) than those in the control group (M =1849, SE=195), although this difference was not significant (t(19)=-0.793, p<.05) and the data indicates only a small-sized effect (r=0.18).

For those living in flatted accommodation, the intervention group (M =1194, SE=105) had an average electricity consumption level 2% less than that of the control group (M =1222, SE=137). The t-test results reveal a non-significant difference in the consumption levels (t(29)=-0.170, p> .05) and the data shows a very small-sized effect (r=0.03).

Overall, there were some differences in electricity use between the properties with a Ewgeco and those without, but these differences were small and not statistically significant. This provides further insight into the potential existence of external factors that could have influenced the consumption levels of electricity. These factors could include influence from family or friends and influence from electricity reduction campaigns.

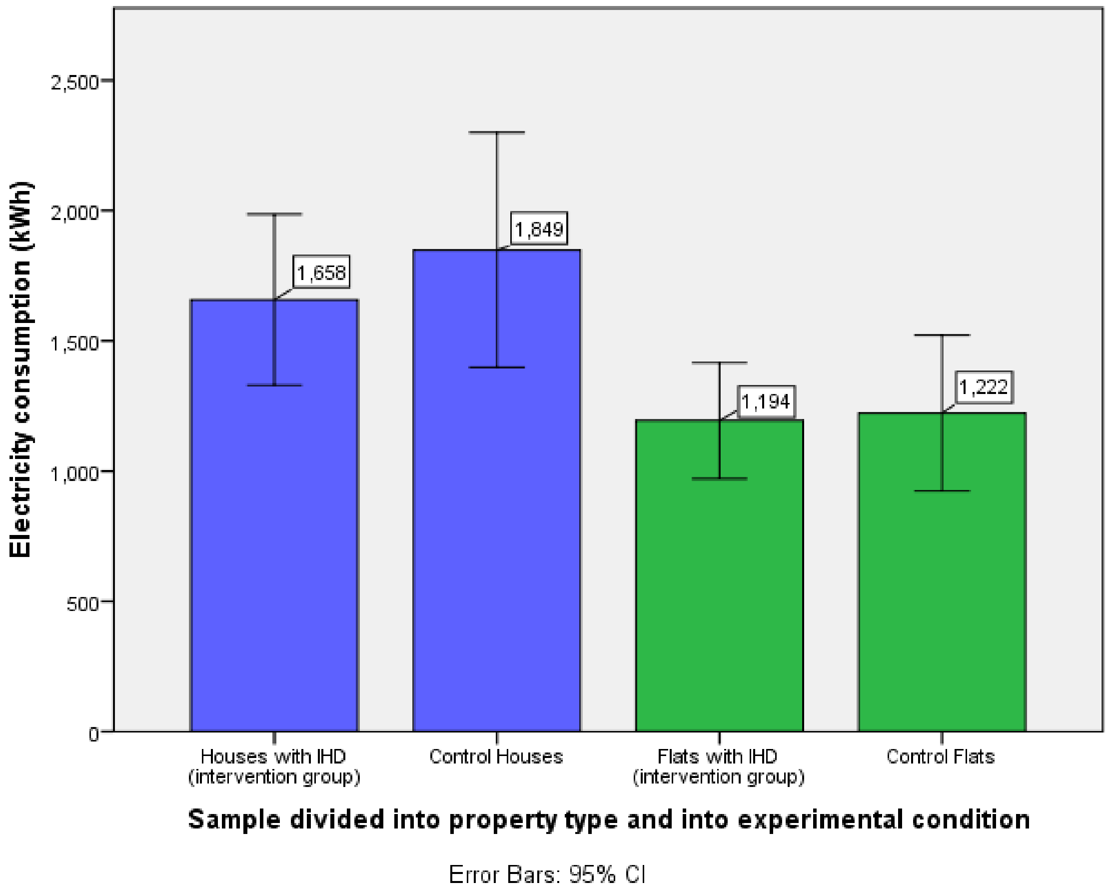


Figure 5.5: Mean electricity consumption over 6 months (Phase 1) based on properties with Ewgeco compared to those without Ewgeco

As observed with the gas consumption results by property types, flats consume, on average, less electricity than houses. However, unlike gas, which is used as the primary fuel for space heating and hot water, the electricity consumption of the properties in the trial is attributed to appliances and electronic equipment, and the difference was not statistically different. It can therefore be argued that the amount of electricity consumed should not be intrinsically linked to the size of property, but rather to the number of appliances and other technologies in the property and the frequency of their use. For this reason the number of occupants may play an integral role in helping to understand why electricity levels are similar. An understanding of the usage profiles for electric appliances is thus needed here in order to further understand electricity use in home. Sub-metering technology is required to capture this highly granular data and should form the objective of future studies in this context, together with a full energy audit of appliances.

5.4.2 Monthly electricity consumption pattern

Figure 5.6 shows the results of the mean monthly electricity consumption levels for the different groups. As inferred from the findings of Figures 5.4 and 5.5, the difference between the experimental groups in each of the property types is considerably less than that of gas levels. This is especially the case for those living in flatted accommodation.

Figure 5.6 clearly shows why the electricity savings in the flats with Ewgeco were low and statistically insignificant. Once plotted, the mean levels of monthly consumption from the Ewgeco and control flats follow a similar pattern over the six period. Furthermore, the occupants in the intervention group consumed, on average, more than the control flats between October and December 2010. This finding supports the earlier discussion in Section 5.4.1: both sets of samples in the flats may be confident in their electricity reduction practices and the Ewgeco may not be able to induce further electricity conservation behaviour. Alternatively, those with the Ewgeco may be unaware of how to convert the information provided into electricity saving measures. A final possibility could be that those who have used Ewgeco to modify their gas consumption behaviour have decided not to react to the electricity consumption data. The difference in monthly consumption failed to reach statistical significance.

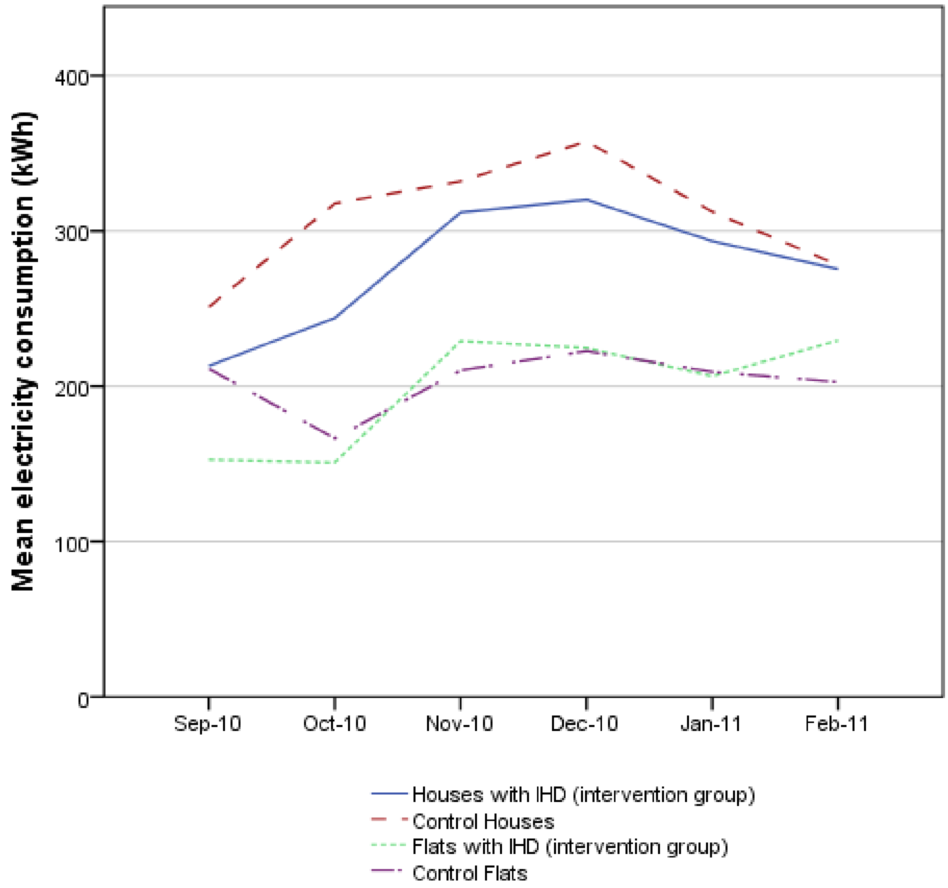


Figure 5.6: Monthly mean electricity consumption values

5.4.3 Electricity consumption based on occupancy levels

As with the gas consumption, there appears to be an electricity usage correlation with occupancy, perhaps suggesting the increased use and availability of consumer appliances. Figure 5.7 shows electricity consumption figures per person.

The results show a strong positive correlation between the difference in electricity consumption reduction for the intervention groups (compared to that for the control groups) and the number of people leaving in the property. Those that lived in houses and flats with more people consumed less electricity than those in the respective control properties. These results also show that the intervention groups also consumed more electricity than those in the control groups. These results suggest that those with the Ewgeco IHD are no more or less likely to reduce their electricity consumption over time than their control counterparts.

As described earlier, Ewgeco uses the same proportion of the screen to display both electricity and gas consumption and there is no need for the user to toggle between screens. It may be the case that the occupants require further assistance to interpret the electricity data shown on the Ewgeco, or perhaps the control group were able to main a low level of electricity consumption without an energy monitor. The qualitative data collected from the participants will provide a deeper understanding of the behaviour of those with and without an Ewgeco.

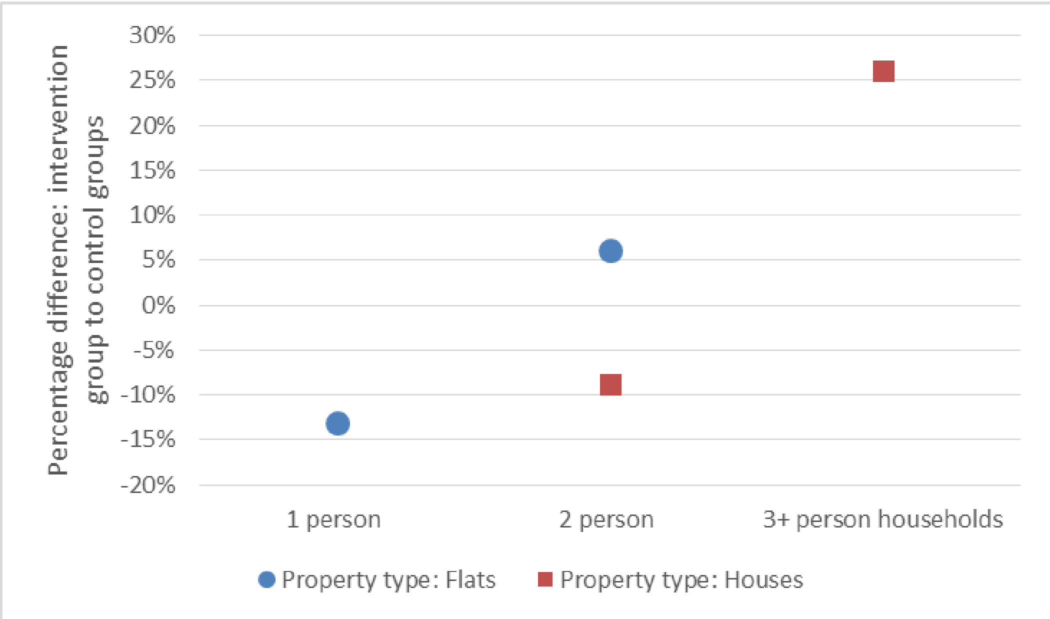


Figure 5.7: Electricity consumption per occupancy

Supplementary research in the form of qualitative feedback from the occupants, which is further described in detail in Chapter 6, documented the number of appliances each property possessed at various points throughout the trial. Although the number of the appliances and the equipment remained relatively the same for each property, on average two person dwellings possessed more electrical equipment than did other levels of occupancy. It was unfortunately outside of the scope of this research to investigate the reasons behind this, but observations suggest that two person dwellings generally consisted of two adults and no dependents, and, although this group did not have the highest average annual income, they may have had a higher level of disposable income.

The results displayed in Figure 5.7, supplemented by the information provided by both sets of interviewees, suggest that people are more confident in regulating their own electrical energy use. Those within the control dwellings appeared to have found it as easy to control their electrical appliances as those with a monitor.

Certain aspects of electricity consumption behaviour appear to be related to an existing pattern of routines and habits, making it difficult for people to connect specific behaviours to the electricity they consume. In this respect, the monitor appeared to have become an instrument that reinforces existing levels of electricity consumption. In these cases, the device tended not to be associated with reductions in energy consumption:

> *I think that the monitor has helped me to prove to the rest of the family that we need to stop wasting electricity. In our last house I was forever chasing after everyone turning of light, I think I was always like that, definitely with electricity, I got that from my mother, she would scream and shout when I used to leave lights and stuff on. But yeah it's helped me to convince everyone, I'm not wasting my breath anymore*. (E13)

> *I guess I have always been extremely conscious with the electricity we use, it's all over the TV and radio, turn this off, turn that off, and now I can't find the old light bulbs anywhere, the monitor simply now reminds us when something electrical has accidental been left on*. (E14)

> *You can't turn the T.V. on without seeing an 'ad' telling you how to save electricity, they've been on for as long as I can remember, at first they were informative, now they are annoying, but I have listened to them, it just seems like common sense to turn of things from standby, and unplug stuff, and turn things off when you leave a room.* (NE02)

Allen and Janda (2006) had similar results in their trial with 10 households in Oberlin, USA: electricity consumption increased by a significant amount after the monitor was installed and compared to a similar control property. They attribute this result to the theory that the use of the monitor may be correlated with income; however, the small scale of their study prohibited them from making a definite conclusion.

5.5 Electricity consumption over time: A longitudinal study (n=20)

The sample size available for Phase 2 was reduced from 52 to 20. Phase 2 recorded data only from participants in flatted accommodation on one of the original housing association sites. 11 of the original participants had moved away from this flatted development. Given that the average length of time that occupants change home in housing association accommodation is estimated to be three years, the author was advised by the housing association that reduced numbers of participants could be expected.

An independent one tailed t-test was conducted on the average (mean) of the 37 months of electricity consumption data between the control group (n=10) and the intervention group (n=10). The results show that the intervention group (M=5779, SE=914) consumed 21% less electricity than the control group (M=7322, SE=728). This finding, coupled with the findings from the analysis in Chapter 5.4, shows that the intervention group consumed less electricity than the control during both the six month trial and the longer 37 month trial. However, this difference was not statistically significant ($t(18)=1.32$, $p>.05$) and therefore, we cannot with 95% confidence state that the mean electricity consumption of the populations or another sample of people would be similar to that measured in this study.

Comparison of electricity consumption over time

Analysis of the 37 months of electricity data for the 20 properties shows that the consumption is independent of climatic conditions, unlike the gas consumption data. When enough data was available, the electricity consumption profiles for the participants involved in Phase 1 and Phase 2 show that the highest period of electricity consumption is as likely to be in July as it is in December. Therefore, to create a comparison between the Phase 1 and Phase 2 monitoring periods, the electricity consumption have been divided by the number of months in each period.

Analysis of the electricity consumption level between the two periods, independent of duration (month) shows that those who consumed higher levels of electricity per month in Phase 1 were also likely to be among those who consumed higher levels of electricity during Phase 2. Figure 5.8 shows this relationship. The results of a Pearson's Correlation test suggest a very strong positive correlation (r=0.81) between electricity consumption per month for Phase 1 and Phase 2 for each of the 20 participants. This correlation is significant at a 0.01 level.

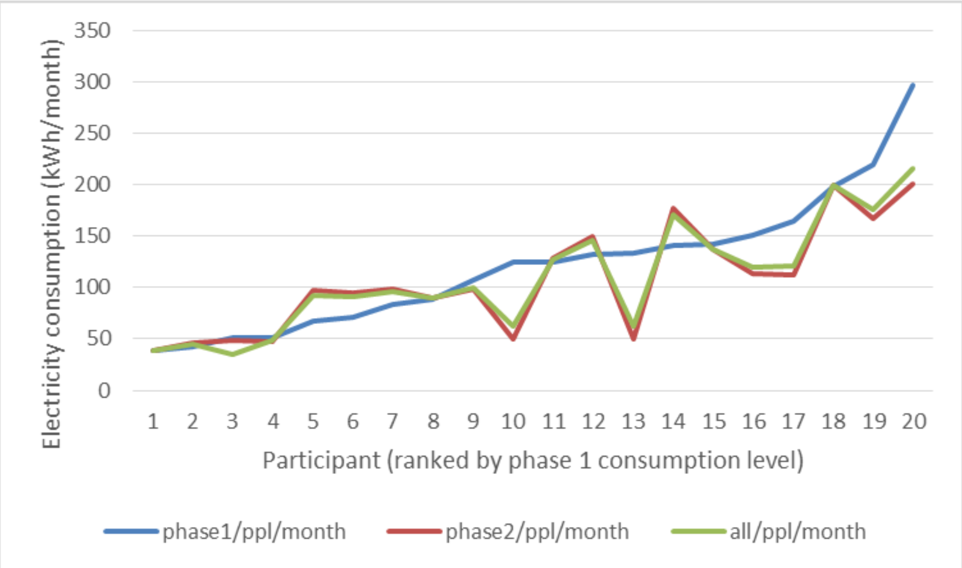


Figure 5.8: Relationship between electricity/month consumption and the two phases

The first six months of electricity consumption data for the 20 participants who comprised the sample for Phase 2 was isolated from the findings detailed in Chapter 5.4 and analysed for use in the longitudinal study. The differences in electricity consumption between the two experimental groups for the two phases are presented in Figure 5.9. An independent t-test was carried out on the average (mean) electricity consumption per month for both the control group (n=10) and the intervention group (n=10).

During Phase 1 (6 months), the intervention group (M=167, SE=20.7) consumed 24% less electricity per month than the control group (M=220, SE=24.5). This difference was not statistically different (t(18)=1.66, p=>.05) and was measured to have an effect size of r=0.4.

During Phase 2 (31 months), the intervention group (M=154, SE=26.0) consumed 24% less electricity per month than the control group (M=203, SE=20.2). This difference was not statistically different (t(18)=1.47, p=>.05) and was measured to have an effect size of r=0.3.

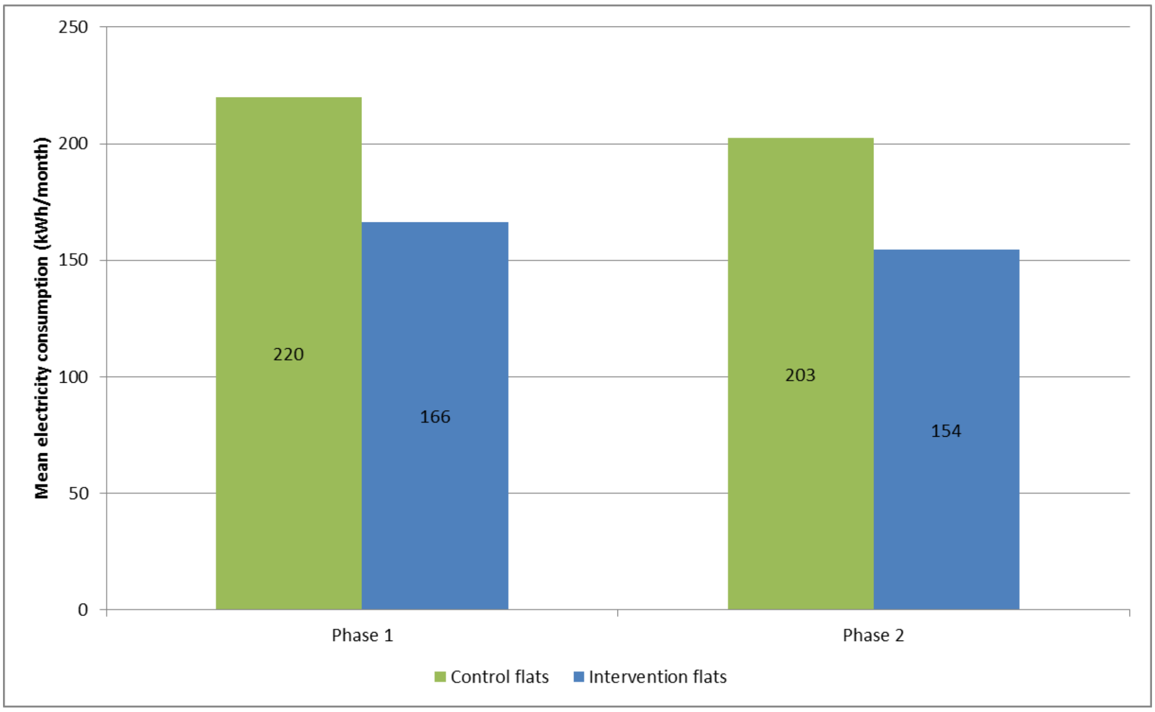


Figure 5.9: Electricity consumption per month for each experimental condition for each monitoring phase

The mean (average) electricity consumption score (kWh/month) for the control group during Phase 2 (M=203, SE=20.2) was 8% lower during Phase 1 (M=220, SE=24.5). A paired sample t-test shows that this difference was not statistically significant (t(9)=1.05, p>.05), but the difference had a large effect (r=0.8).

The mean (average) electricity consumption score (kWh/month) for the intervention group during Phase 2 (M=154, SE 25.9) was 7% lower than for Phase 1 (M=167, SE=20.7). A paired sample t-test shows that this difference was not statistically significant (t(9)=0.90, p>.05), but the difference had a large-sized effect (r=0.85).

Applying the 'per person' normalisation condition

The evidence from the analysis in Chapter 5.2 shows that the correlation of variation for the sample living in flats is lower, and therefore a better fit, when the 'per person' normalisation condition is applied to the raw electricity data. For the analysis of the 52 participants, the consumption data was not normalised because it returned the lowest CV for the whole sample (houses and flats). This longitudinal analysis relates only to those living in flatted accommodation, so the electricity consumption score (kWh/month) for the same 20 participants has been normalised by the number of occupants.

The results from the independent t-tests show that the difference between the experimental groups is lower when the electricity consumption scores for each Phase are normalised by the number of people living in the flat.

The mean (average) electricity consumption per month per person for Phase 2 for the intervention group (M=114, SE=16.8) was 12% lower than that of the control group (M=130, SE=24.6). This difference was not statistically significant (t(18)=0.54, p=>.05). It had a small effect (r=0.13). This difference of 12% is considerable higher than the difference in the Phase 1 results, which included all 31 flats; in Phase 1 the electricity consumption of the intervention group was only 2% lower than that of the control group.

The one-tailed independent t-test was repeated for the normalised electricity consumption for Phase 2. The difference between the groups in Phase 2 was of a similar magnitude to that of Phase 1. The mean (average) electricity consumption for the intervention group was 13% lower that of the control group. Again, this difference was not statistically significant ($t(18)=0.61$, $p <.05$). However, the effect size was very large ($r=0.8$)

Investigating the statistical difference between the electricity consumption scores per person for each of the experimental conditions shows that the consumption rate reduced by 12% between Phase 1 and Phase 2 for both the intervention and control groups.

Using a two-tailed paired sample t-test, the difference was found not to be statistically significant. For the control group ($t(9)=1.3$, $p>.05$), this was found to have a very large-size effect ($r=0.9$). For the intervention group ($t(9)=1.0$, $p>.05$), this was found to have a large effect size ($r=0.7$).

5.6 Conclusions: Comparisons in energy consumption

Although the intervention group for both property types consumed less electricity on average than the control group, these differences were not statistically significant. Therefore the null hypothesis cannot be rejected. Using the independent one-tailed student t-test to test the hypothesis, the alternative hypotheses 2 and 4, which state that a statistical difference will be detected between the electricity consumption of the experimental groups in each housing sample tested at $p<0.05$, are rejected.

The differences in electricity consumption made by the properties in the intervention group are lower than their reductions in normalised gas consumption. Monthly consumption for electricity was much closer between the intervention group and control group. The energy pattern in the flats overlapped for three months of the trial during Phase 1. Unlike the results from the gas consumption figures, the savings and difference between the Ewgeco properties and the control properties may be influenced by the number of household electric equipment and appliances.

With regard to the display of electricity information, the interviewees regularly commented on the importance of having the monitor to which they could quickly refer and which also enabled energy consumption to become more comprehensible. The monitor could also be used to support and encourage those who were already conscious of their electricity consumption.

When comparing consumption with occupancy, a trend appears which seems to suggest that dwellings with more occupants will consume more electricity and gas. However, when comparing the electricity and gas consumption differences between the experimental groups within property types, the results indicate that the larger improvements in gas consumption occurred in the properties with fewest occupants. This may indicate how priorities in homes impact on energy consciousness as the number of occupants increases, especially when the additional members of the household are dependants. This trend was not evident for the electricity consumption.

The energy consumption improvements in the one and two person dwellings are both much higher; the figures are similar for gas but not for electricity. There is an opposite trend for electricity consumption: within the two property types, those with higher occupancy levels demonstrated increased savings.

An increase in the number of occupants in the home appears to have brought about two fundamental contrasts in how savings were attributed to different utilities. This may indicate how occupants implement the instantaneous feedback they receive. The use of gas through space heating is often perceived as a household utility, so is in the control of only one or two members of the household. Not every member of the household is able to set and use the heating, and some members of the household, especially dependents, have no permission to modify the heating. In contrast, for electricity consumption members of the household plug-in and use electrical appliances more freely, despite the fact that electricity consumption has been described as ‘invisible’ by many authors in the field. Additional factors also play a role in larger occupancy households in relation to energy consumption and wastage such as family dynamic, parental control etc.

This difference between savings in utility type may reveal the levels of electricity reduction knowledge already present within the properties for both experimental types, in contrast to their lower levels of gas reduction knowledge.

Effect of selecting a normalisation condition

The electricity consumption data was analysed in its unconditioned state, and not normalised, because this method provided the lowest CV value and represented the best fit for the data. This is described in Chapter 5.2. The differences in electricity consumption, as calculated through the use of the other normalisation conditions, have been listed in Table 5.3. These figures show the impact an IHD might have on the intervention group when the electricity consumption is analysed using common normalisation conditions.

There is little difference in the magnitude of savings between normalisation conditions that have or have not accounted for SAP calculated fans and pumps. The intervention group had reduced their electricity consumption by different magnitudes when each of the normalisation conditions was applied. When the other normalisation conditions were applied to the flatted accommodation, the intervention group consumed considerably more electricity than the control group.

The per person normalisation condition provided the lowest CV for the sample living in flats. This percentage difference statistic is therefore arguably more suitable to the flatted accommodation sample. When analysed further, the intervention group of flatted properties (M=818, SE=54) consumed 15% more than control group (M=709, SE 63). This difference was not statistically significant ($t(29)=1.3$, $p>.05$).

	The intervention group's mean (average) consumption value was different to the control group's mean (average) consumption by:		
Normalisation condition	for the entire sample (n=52):	For the sample grouped to flatted accommodation (n=30)	For the sample grouped to housing accommodation (n=22)
electricity recorded (unconditioned)	-7% (decrease)	-2% (decrease)	-10% (decrease)
elec/area (m^2)	+1% (increase)	+5% (increase)	-3% (decrease)
elec/volume (m^3)	+6%	+14% (increase)	-3% (decrease)
elec/# ppl	0%	+15% (increase)	-20% (decrease)
elec - (SAP fans and pumps)	-8% (decrease)	-2% (decrease)	-11% (decrease)
(elec -fans)/area m^2	+1% (increase)	+5% (increase)	-4% (decrease)
(elec - fans)/volume m^3	+5% (increase)	+15% (increase)	-4% (decrease)
(elec - fans) /# ppl	-1% (decrease)	+17% (increase)	-20% (decrease)

Table 5.3: Electricity consumption differences by normalisation condition for data collection during Phase 1

This chapter has shown that properties with an IHD that displays electricity consumption information consumed less electricity than the control groups. This difference was not as significant as the difference in gas consumption. However, the IHD electricity consumption display has been praised by users for its 'at a glance' functionality that provides peace of mind to users regarding issues relating to electricity safety.

The next chapter explores the self-reported feedback from the users of the IHD and analyses and discuss the changes to energy efficient behaviour displayed by the IHD users and the control groups.

Chapter 6

6 Qualitative Feedback on Interaction with IHD

6.1 Introduction

There is a consensus amongst previous researchers that behaviours leading to inefficient energy use can be attributed to a lack of knowledge on the part of the user about how much energy is being used for various purposes. In order to begin to generate household energy conservation, it is necessary that the user be given this information at as high a level of specificity as possible (Hargreave et al. 2013, Van Dam et al. 2010, Boice 2009).

The review of past work and case studies has demonstrated that changing in-home energy use behaviour has the potential to be a promising means of energy conservation. Sonderegger (1978) find in the United States that 33% of in-home energy use is due to residents' behaviour, while Van Raaij and Verhallen (1983) attribute 26% of energy use to household behaviour in a study in the Netherlands.

Studies in Norway by Wilhite and Ling (1995) find that wasteful space heating and lighting habits and linked to misunderstandings of where energy goes in the home. This is a particular problem because of the high contribution of space heat to the energy end uses of the typical Norwegian home (60%-70%), which is also the case in the UK. In 2013 domestic consumption was 29% of total UK final energy consumption, and of that natural gas accounted for 68% and electricity for 22% (DECC 2014d).

The UK Government has given serious attention to the reduction in carbon emissions from new homes through such mechanisms as the Climate Change Act (2008), the Code for Sustainable Homes (2007) and Scotland's 'A low Carbon Building Strategy for Scotland' (2007). As a result of these publications, and similar reports, legislation and targets have been set, with a large focus on 2016, by which all new homes must be constructed to nationally set zero-carbon standards.

However, over 85% of the homes standing today will still be lived in by 2050. This means that if the UK government’s long ranging national carbon reduction targets are to be met, then the radical refurbishment of over half a million homes a year will be required between now and 2050 (EHA 2008).

With the current increase in the purchase of electrical appliances by consumers, and the continuing increase in the number of households, due to more people living alone, the demand for energy in the UK is expected to keep rising (Darby, 2010b, McCalley & Midden 2002).

Improvements and advancements in home and appliance energy efficiency will go some way towards meeting the low carbon design criteria, but action is required to encourage more domestic energy saving habits with the goal of sustaining the efficient use of domestic energy. This needs to be considered, regardless of the age of property or its energy rating or of the design and efficiency of appliances. This is where in-home energy monitors (IHDs) can be useful, reducing demand and lowering domestic carbon dioxide emissions.

IHDs are intermediary products that can collect, display and/or communicate the energy use of other products or whole households. IHDs have increasingly received attention for their role in energy conservation in households.

In a regulatory environment in which conservation can only be encouraged by voluntary actions, we must ask whether a certain level of energy feedback is sufficient to produce a change in either understanding or behaviour of residential customers. Through a case study conducted in the town of Oberlin, USA, Allen and Janda (2006) investigate the impact of attitudes and household characteristics on the effectiveness of energy feedback in general, and on the potential success of real-time feedback in a residential setting. Like many others, they conclude that the monitors have a greater effect on energy consciousness and behaviour in both high-income and low-income homes.

Most residential consumers only receive feedback on their energy use in the form of a monthly or quarterly bills from their utility provider. It is not uncommon for these utility bills to be constructed using estimated meter readings. Arguably, this form of aggregated energy feedback does not encourage consumers to examine how their energy is used. It is difficult for consumers to identify the energy use behaviours which could have the largest effect on lowering future energy bills.

Since the 1970s, many researchers in various fields have studied how feedback on energy use impacts residential consumer understanding and behaviour. Studies involving informative billing and periodic feedback have realised energy savings of between 10 and 20% (Gaskell et al. 1982, Wilhite & Ling 1995). It is assumed, based on theory and field research, that if residential consumers had more detailed and/or frequent information about their consumption then they would both better understand their energy use patterns and be able to change them more effectively (Boardman & Darby 2000, Ehrhardt-Martinez 2011).

Anderson and White (2009) and Hargreaves et al. (2010) use focus groups to explore the design of the display and find that the impact of actually using an energy monitor was greater than simply being told about energy use. They observe that householders develop a sense of a normal baseline and a range of responses to feedback, ranging from the immediately reactive to the more strategic. Studies of this nature also make a range of family dynamics in energy decisions more transparent.

Chapters 4 and 5 presented and illustrated the findings of a 37 month trial, during which time the occupants of newly built properties were given the use of a real time coloured dual fuel IHD. Their consumption of gas and electricity were compared to that of a control sample. The properties with access to the IHD made reductions in both their electricity and their gas consumption. This chapter highlights observations and themes that appeared during the qualitative portion of the 37 month trial with an interest in identifying behavioural changes and users' opinions of the energy monitor.

Hargreaves et al. (2013) present the qualitative findings of their 12 month study, which has similar parameters to this research project and focuses on participants living in the east of England. They use multiple types of IHD with varying levels of sophistication. The paper does not comment on the quantitative results of the project, nor does it comment on the statistical significance of the findings. Rather it defines itself as the "*first attempt to use in-depth qualitative to explore householders use of IHD over a 12 month period".* The author has no previous evidence to dispute that claim other than the work presented in Chapters 4, 5 and in this chapter.

From their findings of the 15 telephone interviews conducted at the start of the project and the 11 interviews conducted 12 months later, Hargreaves et al. (2013) state that the occupants quickly embedded the energy monitor into their everyday household routines. They observe and describe the transition of the energy monitor from its initial conspicuous 'nag factor' to a 'casual', unthinking and routine form of use. 12 months after the initial interviews, Hargreaves et al. find that their sample appeared to learn what counted as 'normal' consumption for their household in considerable detail. Therefore, the energy monitor succeeded in prompting some initial behavioural changes that cut out unnecessary and wasteful energy use. However, once this 'normal' level of consumption had been learnt, the monitors then appeared to be used only for very specific reasons and provided little or no motivation to reduce energy consumption further. Hargreaves et al. (2013) comment on how 'worried' they were from an energy policy prospective when they observed how the monitors were being used in some cases to reinforce and harden this 'normal' level of consumption. This led the householders to react defensively to any subsequent calls to cut their energy use.

6.2 **Summary of methods and sample**

The findings presented in Chapter 6 relate to those collected from questionnaire interviews conducted, with the same sample of participants whose energy consumption data was analysed in Chapters 4 and 5. The author conducted the semi-structured interviews in the home of the participant. Each interview lasted for between 20 and 60 minutes. For those in the intervention group, the interview lasted on average 47 minutes; for a control group participant the interview lasted on average 29 minutes. The length of the interview was to some extent dependent on the interest of the occupant in the topic of energy consumption. For many participants, that interest was considerably higher than was expected.

For households with more than one adult, the semi-structured interviews were conducted with both adults. The closed-ended questions were answered after some negotiation between the two adults. The discussions between the occupants before they decided on an answer were recorded using a digital Dictaphone. In the higher occupancy households, the dependent, often of late primary school or early secondary school age, was also present and participated in the interview.

These discussions and the subsequent open-ended questions that arose during the interview were transcribed verbatim. Throughout this chapter quotations are used to illustrate particular points. The individual quotations chosen are representative of the wider themes under discussion and are used to convey a strong sense of how these devices are used in real life domestic settings. Table 6.1 gives the details of those quoted in this chapter.

The semi-structured interviews were conducted at 3 points over the 37 month project. Two interviews were conducted during Phase 1, one that marked the start of the project in September 2010 and a second in March 2011, which marked the end of the initial 6 month findings. The final set of qualitative findings were collected in October 2013; this marked the end of Phase 2 and the end of the 37 month period. During each of the Phase 1 interviews, the author completed a questionnaire with each of 52 participants. During Phase 2, the author completed an interview with all 20 participants.

An interview in 2010 was conducted to establish a baseline for questions that relate to the households' views on their energy consumption, utility bills and energy practices, as well as defining those that live in the house and their daily routines. The later interviews were slightly modified to measure whether their energy use practices and their attitudes toward energy use had changed and to check whether their household profiles or routines had changed. For the intervention group, an additional set of questions were asked relating specifically to the design and feedback provided by the Ewgeco IHD. Participants were asked to comment on the perceived usefulness of the IHD and how they would rate its features and functions.

The last questionnaire asked the same questions with an emphasis on how any changes in response may have changed over time.

The quotations are labelled as follow:

ID	Monitor on display	Gender	No. of occupants	Age of occupants on Sept 2010	Household income (£) thousand	House type
E01	Yes	Female	2	46, 20	15-20	Semi-detached house
E02	Yes	Female	3	23, 20, 1	10-15	Semi-detached house
E03	Yes	Male	1	38	10-15	Top flat
E04	Yes	Male	3	62, 59, 29	10-15	Semi-detached house
E05	Yes	Female	4	29, 29, 4, 2	10-15	Semi-detached house
E06	Yes	Male	2	64, 61	10-15	Ground Flat
E07	Yes	Male	1	38	5-10	Mid Flat
E08	Yes	Female	2	42, 38	10-15	Ground Flat
E09	Yes	Male	2	50, 21	10-15	Bungalow
E10	Yes	Female	2	75, 63	10-15	Bungalow
E11	Yes	Male	1	35	10-15	Mid Flat
E12	Yes	Female	2	47, 45	45-50	Ground Flat
E13	Yes	Female	4	58, 33, 36, 3,	15-20	Semi-detached house
E15	Yes	Male	1	41	20-25	Semi-detached house
E16	Yes	Female	1	54	10-15	Ground Flat
E17	Yes	Male	2	58, 68	Not declared	Ground flat
E18	Yes	Female	1	40	Not declared	Mid flat
NE01	No	Female	2	29, 3	5-10	Semi-detached house

Table 6.1: Particulars of Noted Interviewees

6.3 Indirect energy use feedback: The energy bill

Much work has been done that approaches socioeconomic variables and attitudes towards energy use. Income has consistently been found to be a significant determinant of baseline energy use, but not of energy conservation behaviour in reaction to feedback (Brandon & Lewis 1999, Heslop, Moran & Cousineau 1981, Matsukawa 2004). This may be due to the fact that low-income consumers are unable to further reduce their energy use, and high-income consumers prefer to make onetime efficiency improvements to changing their energy use habits (Cunningham & Joseph 1978). Heslop, Moran and Cousineau (1981) suggest that higher income consumers tend to be more environmentally conscious, but this general concern for the environment may not translate into personal energy use consciousness.

In this study, concerns about cost were fairly widespread. A large proportion of the sample were on a relatively low income and energy bills represented a significant outgoing. Even those on a higher income did not want to pay ‘over the odds’ for their gas and electricity and some resented paying as much as they did.

When asked about reducing their energy bills, most respondents spontaneously assumed that this was a question about switching suppliers, and not a question about their own use. There is some evidence that aggressive marketing from energy suppliers conducted through telephone calls and door to door sales has increased the assumption that the best way to save money on bills is to switch suppliers. However, such switches are not always successful. Two interviewees felt they had been “duped” into switching energy suppliers, which they later regretted. Many others commented on how they felt that switching would cost them more in disruption than they would receive in savings.

In the first interviews (n=52), 60% of all the respondents indicated that they did not understand their energy bills and commented that they felt that the wording and format of the bills had become confusing and difficult to interpret. At the same time, many of those who were paying by standing order and direct debit commented that they felt detached from their bills, and had chosen that type of payment method out of convenience rather than consumption control.

> *We have never questioned our bills before, actually I don't think we actually ever looked at our meters, but I guess, when you pay by standing order, and you pay the same amount every month, and as it is now, now we were encouraged to pay by paperless billing. I can safely say that I haven't looked at our quarterly statements since then*. (E13)

65% of the interviewees said they did not know or were not sure what they paid for their energy (i.e. what the tariff was that was used to calculate the cost of their energy use). However, most participants (77%) indicated that it was important for them to understand their energy bill, while only 15% felt hat it was not important. From this sample, we can conclude that understanding energy bills is important to many people, even if they do not check their readings often.

A large majority of people (77%) said that they liked to know how much energy they use; an even higher proportion (89%) said they liked to know how much money they spend on energy. The second interviews found that many of the participants with an Ewgeco professed to have become increasingly confident about their utility bills.

An overview of the comments and the state of the existing indirect feedback mechanisms that are currently in place across the experimental groups suggests that bills are infrequent, and there is no evidence to suggest that the billing system has enough 'nudge' to motivate consumers to change their energy use habits. During the interviews conducted during Phase 1, many interviewees commented that the presentation of information on their bills was confusing and that no comparative standard was provided. Wilhite and Ling (1995) call this an information vacuum, and as such, it is difficult for consumers to see the relationship between their behaviour, or changes in their behaviour, and their consumption. They have difficulty putting a price on their consumption habits. In addition, they have no way of knowing which of their habits is the most expensive and no way of attributing cost to priority decisions. The existing paper billing system experienced by the sample does not sufficiently support a cognitive learning environment, nor is it conducive to promoting pro-conservational behaviour or the control of costs.

2013 observation

The interview results for 2013 showed that 60% of participants (n=20) did not understand their utility bills. This finding is comparable to the 65% of the sample who stated the same in 2010. This finding suggests that knowledge of the energy bill tariff did not considerably increase. During the interviews, the majority of those in the control and intervention group (85%) agreed or strongly agreed that it was important that they understand their bill. None of those interviewed disagreed or strongly disagreed with this statement. The increase from 77% (2010) to 85% (2013) of those who agreed that it was important to understand their bill was statistically significant ($t(16)=-2.14$, $p <.05$, $r=0.130$. A common theme related to how the participants felt that it very hard to afford other household items and consumables during 2012 and 2013. Many stated that they felt it was necessary to pay more attention to their utility bill because they could no longer afford to ignore discrepancies in meter readings or being over charged. This increased awareness of expenditure appeared to extend to other similar debt type bills such as those for the phone, internet, online subscriptions etc.

Only four participants in the 2013 interviews still received paper bills. Those whot still received paper bills where older than the average age for the sample. Those who had received paper bills were more likely to spend more than five minutes reviewing the information on the energy bill. Prior to the 2013 interviews, Ofgem had instructed the major six utility companies to redesign the graphics and information on the bill to create a single, ‘user to understand’ format that would be consistent across energy companies. Occupants who claimed to review their energy bills frequently commented on this redesign:

> *I am the one that checks the utility bill, yes, every time it arrives. I have to. I have to check it, to see that it’s right, and see we are paying the right amount. I spend half an hour looking at the bill. I get the older bills out and everything. The new bills look different from my older bills… Well, they are*

> *simpler and brighter, definitely easy to work out what's going on now. But I still need to get my calculator out (laughs). But then again I'm retired and have time to do this sort of thing, I doubt any of the younger ones you talk you would be bothered to do all that*. (E06)

During 2013 interviews many of those with the Ewgeco and who also inspected their utility bill commented that the cost value on the Ewgeco and the cost figure on the utility bill were often different. However, this did not seem to be an annoyance to those who raised this point, but they did wish that the Ewgeco cost figure be lined up so that it was 'exactly' the same as what would be later printed on their bill. Many felt that this would eliminate the need for them to spend time looking at the bill at all.

DECC (2014d) have produced figures that show the average domestic electricity and gas bill in Scotland has increased year on year from 2010 to 2013. This topic was not covered so much in the interviews of 2010 and 2011, during that time 53% (n=52) agreed or strongly agreed that they believed they were paying too much on their utility bills. During the 2013 interviews (n=20), 65% neither agreed nor disagreed with the statement. None of those interviewed disagreed with the statement. Whether the 2010 score on this question is a valid benchmark is arguable. The properties were less than 12 months old and the occupants had only received their first two or three energy bills. The 2013 findings would suggest that most people in this sample are accepting of their energy bill, justifying the cost of electricity and gas by comparing them to the other costs of living such as transport, food and media services.

At the time at which the third interviews were conducted at the end of Phase 2, one of the larger utility companies announced an 8% price rise on utility bills, to be introduced in November 2013. This announcement dominated some of the interviews with the participants who had access to the energy monitor. Those who mentioned the price rise made reference to either re-doubling their energy saving efforts or commented on how they felt deflated:

> *They said on the news that they're* (a well-known utility company) *putting up the energy bill, I'm not with them (a customer of the utility company) but they say all the companies will be putting up their prices. I'll really have to pay even more attention to that thing* (the energy monitor).(E17)

> *It feels like no matter how much I do* (reduce their energy consumption) *the utility companies will put up the price anyway.* (E18)

Although the majority of the 2013 interviews felt that their energy bill was reasonable in respect to their other household expenditures, a strong theme for many of them was a sense of disenchantment with their achievements in energy reduction in the face of rising energy tariffs.

The presence of the IHD made no difference, significant or otherwise, to the average (mean) response of the participants to questions about whether they understood their energy bill, whether they felt that they were paying too much or how important it was to understand their bill.

6.4 Using the IHD to change energy use behaviour

Of those respondents with an Ewgeco installed in their homes (n=30), 91% had not used an energy monitor before the study. 87% stated they had used the Ewgeco monitor during the study and 84% that they viewed the information on the display either several times a week or more than once a day. Only 9% of respondents said they were not interested in using the monitor. In the follow-up survey, conducted in March 2011, 90% of respondents claimed to still be using the IHD, with 47% checking the monitor at least once a month.

In the interview in 2013 100% of the intervention group (n=10) stated they were using the energy monitor. Three of the Ewgeco IHDs on display had stopped displaying information at the start of the 2013. A further seven had stopped logging or had corrupted energy data saved on the internal memory. 80% said they looked at the monitor more than once a day and, 20% said they looked at it weekly or monthly.

The questionnaire study conducted in October 2010 and again in March 2011 posed the same question concerning the frequency with which the occupant engaged with the Ewgeco display. Between the two questionnaires, the results found a significant trend: people interacted less often with the monitor during the day ($t=10.77$, $df=29$, $p=0.001$). This may be a factor of energy consumption behavioural change having already occurred during the period of the study, given the resultant energy savings found in accessible display properties. Many of those in the intervention group who were interviewed in 2013 stated that the increased attention they gave to the IHD was in part due to their desire to have greater control of household budgets. The IHD provided some degree of control over their energy finances. The 2013 interviewees used the cost/day information from the Ewgeco to gain insight into what their monthly/quarterly energy bill might be. This allowed some users to be prepared for the arrival of the bill, thereby reducing the chances of being surprised by the cost of energy used over that period.

Participants who reported that they did not use the Ewgeco energy display device in 2010 were significantly more likely to say that they did not think very much about the energy they used in 2010 ($t=2.12$, $df=28$, $p <.05$). Those who reported not using the Ewgeco energy display device in 2011 were not significantly more likely to say they did not think very much about the energy they used in 2010 ($t=2.12$, $df=28$, $p <.05$).

The 2011 interviews found that those with young dependents were more likely to say they did not use the Ewgeco IHD (25%) than those without young dependents (6%), but this difference was not significant (Chi-square=2.34, $df=1$, $p=0.13$).

6.4.1 Changes in energy use activities

During the first interview questionnaires, conducted at the start of the trial in September 2010, the respondents (n=52) commented on the frequency with which they conducted energy saving activities. The activity list was drawn from the common list of energy saving behaviours used by many energy-reduction awareness campaigns and related to those appliances responsible for the majority of energy use. Cooking habits with the oven and/or microwave were not explored in this questionnaire.

The responses in 2010 represent a behaviour baseline for both experimental groups. During the 2011 (n=52) and 2013 (n=20) interviews the participants were asked to state whether they increased or decreased the regularity with which they conducted the same list of activities.

The figures in Tables 6.2 and 6.3 are from the participants who specifically stated that they had increased the frequency with which they conducted each activity. This was identified from the answers in the questionnaire, where the participant responded that they conducted the activity either ‘a bit more’ or’ much more’ since the last interview. This section aims to identify changes to energy use behaviours between the two experimental groups that would reduce energy consumption further over the monitoring period. A very small percentage of respondents in either experimental group reported doing the activity ‘less’ or ‘much less’ in either the 2011 or 2013 questionnaires. Therefore, the majority of those that did not state that they increased their energy saving behaviour in 2011 or 2013 stated that there had been ‘no change’.

Activity		(Sept 2010) % stating they always or sometimes do this	(March 2011) % stating they have done this a bit or much more since last interview	(Oct 2013) % stating they have done this a bit or much more since last interview
Controlling radiators temperature by TRV	Interv	73	50	70*
	ctrl	63	26	30*
Using system thermostat to reduce temperature in the home	Interv	37	50	70
	ctrl	32	32	30
Using the boiler timer to regulate when heating is used	Interv	33	24	30
	ctrl	26	21	20
Closing windows / put on clothes before heating	Interv	60	63	80
	ctrl	84	37	50
Put less water in the bath. *(all properties had baths – % include all those that professed that they use the bath)*	Interv	46	39	29*
	ctrl	78	34	0*

Table 6.2: Domestic activates relating to the use of gas

*The Chi-square test shows that there was a statistical association ($p<.05$) *between* the single activity and the experimental group.

Activity		% stating they always or sometimes do this (Sept 2010)	% stating they have done this a bit or much more since last interview (March 2011)	% stating they have done this a bit or much more since last interview (Oct 2013)
Switching off lights when leaving a room	Interv	90	70*	50*
	ctrl	79	11*	10*
Switching off appliances rather than put on stand-by	Interv	70	60*	73
	ctrl	63	26*	40
Boiling and cooking using the minimum amount of water	Interv	54	57*	60*
	ctrl	79	11*	0*
Keeping time in the shower to a minimum	Interv	53	37*	50*
	ctrl	32	5*	0*
Turning the temperature down on the washing machine	Interv	77	40*	50
	ctrl	58	11*	20
Hanging clothes out to dry rather than tumble	Interv	77	30	50
	ctrl	73	0	0

Table 6.3: Domestic activities relating to the use of electricity

*The Chi-square test shows that there was a statistical association ($p<.05$) *between* the single activity and the experimental group.

6.4.2 Behaviour change to reduce gas consumption

2010 results

A Likert scale (answers listed from 1 to 4) was used to measure the respondents' behaviour score. The behaviour score was calculated for each participant, grouped by the type of utility associated with its use and analysed for each experimental condition. At the start of the trial (the 2010 interviews), the majority of the intervention and control group stated that they controlled the use of gas for space heating in the same way. On average, those with an Ewgeco IHD had a similar score for gas reduction behaviour ($M=2.52$, $SE=0.11$) to those in the control group ($M=2.63$, $SE=0.15$). For this first questionnaire, before the use of the Ewgeco IHD, there was no statistically significant difference between the mean scores of the two groups, ($t(47)=-0.60$, $p>.05$). For this numerical analysis, a mean score closer to four would represent that the group 'always' carried out the energy saving behaviour. A mean score closer to one represents that the group 'never' carried out the energy saving activity.

2011 results

A Likert scale (answers listed from 1 to 5) was used to measure the respondents' behaviour score. The views expressed in the second interviews (March 2011) suggest that the occupants in both the control and the intervention groups felt that they had not used large amounts of gas over the winter period. However, a larger percentage of the intervention group stated that they used the various types of heating controls more often to control the heating of their home. In contrast, a large majority of the participants in the control group stated that they had not changed their behaviour towards the list of gas related activities.

Many in the intervention group referred to using the TRV to isolate rooms that were rarely occupied and to using the system thermostat to reduce the temperature so that it could be kept on for longer but at lower, more 'tolerable temperatures'. Fewer participants referred to using the timer on the boiler, stating that the interface was complex and unintuitive and that they were concerned that they might disrupt the heating configuration, which could have left them without any heating. On average, the 2011 interviews found that those in the intervention group had a higher mean (average) score for increasing the frequency with which they conducted energy saving activates for gas use ($M= 3.50$, $SE=0.07$) than did those in the control group ($M=3.22$, $SE=0.08$). This difference was statistically significant ($t(47)=-2.43$, $p<.05$) and this was a medium-sized effect ($r=0.34$). For this numerical analysis, a mean score closer to five would represent that the group increased doing the activity ‘much more’. A mean score closer to one means the group carried out the energy saving activity ‘much less’ that 2010.

2013 results

Due to the reduced resources and the participant drop-out, the 2013 interviews involved a smaller sample, n=20 as opposed to n=52 for the 2010, 2011 interviews. The 20 participants interviewed in 2013 were also part of the interviews during 2010 and 2011. The results show that in 2013 a larger majority of those in the interview group reported that they had increased the frequency with which they conducted gas saving activities. For many of the activities, the percentage was as high as or higher than the 2010 baseline. An independent t-test showed that the average (mean) behaviour score for increasing the frequency of conducting gas saving activities was statistically higher for the intervention group (M=3.85, SE=0.19) than for the control group (3.28, SE=0.09), ($t(18)=-2.76$, $p<.05$). This had a large effect (r=0.55).

Many of the interviewees in the control groups for both property types commented that they felt divorced from the control of their heating system. As a result, they claimed to possess very little awareness of how much gas they actually used to heat their home or run a bath, but still felt as though their gas bill was acceptable. This quote was taken from an interview with one of the participants in the control group (who did not have access to the IHD).

> *To be honest we use the heating when we want it, I am not going to sit in a cold house. The gas is either on or off. We couldn’t be using that much. (NE01)*

The majority of interviewees in the control group had the same view and approach to the use of gas. Later in the monitoring period, fewer of the control group interviewees increased the frequency with which they conducted gas saving activities. These finding shows that the null hypothesis can be rejected: the introduction of the Ewgeco IHD changed the gas saving behaviour of those in the intervention group. Coupled with the findings from Chapter 4, the results show that this gas use behaviour change also translates into actual gas reduction when compared to a control group.

6.4.3 Behaviour to reduce electricity consumption

A similar trend in electricity saving activities over time and between experimental conditions was observed. A large portion of the occupants in both experimental conditions stated in the first questionnaire that they ‘always’ or ‘sometimes’ conducted most of the listed electricity saving activities. The second questionnaire showed a difference in how the intervention group responded to the energy saving list, compared to the control group. More of the control group stated that they had not changed their electricity saving behaviour, whereas significantly more participants in the intervention group stated that they and other members of the household increased the frequency with which they conducted electricity saving activities. This finding complements Chapter 5, in which the electricity consumption of the intervention group was seen to be lower than that of the control group. This trend continued in the 2013 interview, in which the majority of those in the control group stated that their electricity saving behaviour had not changed and those in the intervention group stated that they continued to increase their electricity saving activities.

2010 results

The results of the 2010 baseline questions show that the majority of those in both the intervention ($M=3.03$, $SE=0.11$) and control ($M=2.91$, $SE=0.14$) properties reported ‘sometimes’ or ‘always’ conducting electricity saving activities. This was tested and shows no statistically significant difference between the two group means ($t(47)=0.65$, $p>.05$). Those interviewed in both the intervention and control group gave examples of how diligent and conscious they were in relation to reducing the amount of electricity they used; this was a strong theme in the first interview. Participants in both groups stated that they were motivated in their electricity saving habits by concern about electrical fires and/or electrocution. On average, both groups gave strong anecdotal evidence that they were confident and capable of maintain low levels of electricity consumption to balance household needs and low electricity bills.

2011 results

For this numerical analysis of the 2011 and 2013 responses, a mean score closer to five would represent the group conducting electricity saving activity ‘much more’. A mean score closer to one represents the group carrying out the electricity saving activity ‘much less’.

During the second interview (March 2011), those in the properties with an Ewgeco IHD had on average a higher electricity saving score ($M=3.46$, $SE=0.08$), than the mean score for the control properties ($M=2.99$, $SE=0.08$). This difference was statistically significant ($t(43.9)=-4.09$, $p<.05$) and found to have a large effect ($r=0.50$). The second interviews showed the same strong theme of confidence in maintaining low electricity consumption levels, as noted in the qualitative findings from 2010. Very few in the control group stated that their electricity saving behaviour had increased, but the majority still adamantly stated that they were diligent in turning off appliances for fear of electrical fires and electrocution.

An interesting theme arose during the interviews with the multiple occupant households. Most of the interviews were conducted with the self-professed household energy champion – those in the intervention group who suggested that they did not require the Ewgeco IHD to convince them to reduce the amount of the electricity they were using. Many participants strongly felt that they were already using the least amount of electricity necessary to balance the bill with the household’s quality of life. However, the IHD was quoted as an instrument that could be used to convince other members of the household to maintain the low level of electricity use. This was described as a kind of ‘electricity house rules’. The properties with multiple occupants considered the £/day feature of the IHD as an effective method of shaping energy saving behaviours for those in the home who were less conscious of using excessive and unnecessary amounts of electricity.

During this time, many also professed their annoyance with ‘energy-saving’ light bulbs. Many, from both groups, who had installed these types of bulbs during 2010 had since replaced them with the older tungsten filament bulbs, stating that they strongly favoured the reliability, colour and instantaneous light of the older bulbs. Many where conscious that the older bulb would cost them more to operate, but the cheaper initial cost and personal preference of output and operation justified the replacement.

2013 results

31 months later, 20 of the original 31 participants in flatted accommodation commented on the same set of electricity saving activities. On average, those in the intervention group ($n=10$) had a higher electricity saving behaviour score ($M=3.80$, $SE=0.23$) than those in the control group ($n=10$) ($M=3.07$, $SE=0.08$). This difference was statistically significant ($t(11.5)=-2.90$, $p<.05$) and was found to have a large effect ($r=0.56$). The anecdotal evidence captured in 2013 suggested that the participants used the IHD to reinforce their already ingrained electricity saving behaviour. The IHD did not inspire new energy saving behaviours, but acted as a visual reminder that increased the frequency with which they conducted their established activities.

The interviewees from the group who had IHDs who stated that they had increased their energy saving behaviour seem to fit with the findings discussed in Chapters 4 and 5: the Ewgeco aided in reducing the electricity and gas consumption of the dwelling, and the interviews suggested that, on average, those who had an Ewgeco also became aware that their energy reduction behaviour had increased since they started interacting with the device. The electricity saving behaviour was tested to be significantly significant between the two experimental conditions. However, the quantitative findings show that the difference between the mean electricity consumption for the two conditions was not statistically significant. More work is needed to define what energy saving behaviours impact the most on energy consumption profile.

6.4.4 Limitations and frustrations

This method of measuring behavioural change was relatively non-intrusive and simple, and was in-keeping with the available resources and with the scale of the trial. The findings here provide an insight into and an explanation of the quantitative findings of Chapters 4 and 5. Reasonable steps were taken at the interview stage to consolidate the energy use behaviours of the whole family by inviting everyone in the home to participate, although this was often not achieved. Arguably the responses of one householder may not be representative of the whole family's use of energy. For example, many of those who stated that they 'always' conducted energy saving habits in 2010 later stated in 2011 and 2013 that they increased this action 'much more', explaining that their partner or children have done more around the house to save energy.

There were difficulties capturing how the user of the IHD used the device as part of their energy use lifestyle and how they connected the energy consumption information to the changes in their energy reduction behaviours. For example, in the 2011 and 2013 interviews, more than half the respondents stated that they did not use the device, although further questioning revealed that the occupants looked at the IHD regularly and later provided examples of how they had seen the red bars on the IHD and turned down heating or convinced others in the home to turn off unused appliances or lights. The users perceived that this form of interaction with the device did not constitute 'using the IHD'.

The findings from this chapter and Chapters 4 and 5 comprise statistical analysed results that argue that the IHD can change energy use behaviours to promote energy efficiency and that this change can be maintained. However, the IHD does not recommend nor directly influence individual energy saving behaviours, which activities the occupants should focus on more, or which energy reduction activities would have the greater impact on their energy consumption. There is no easy method of associating or weighting the energy reduction behaviour listed in this chapter in the context of the quantitative findings of Chapters 4 and 5. The results of this chapter show that the self-reported energy saving behaviour of participants in 2013 was significantly different from that of the control group, but the quantitative findings show that the energy consumption differences were substantial but not statistically significant.

Further research is needed to understand the family dynamics of electricity and gas use and in particular in the area of identifying the specific energy use behaviours that significantly change the electricity and gas consumption profile. More work is needed in the area of consumption related life-styles in which energy use is part of a wider set of behavioural change and quality of life balances in the household. Ethnographic methods could be employed to enhance understanding in this area, adding useful detail to the findings above and exploring whether the behavioural changes are responsive to different types of archetype, demographic, income or other restraint, for example. This study has a considerably longer monitoring period than the vast majority of energy behaviour trials, including real time IHDs, and is still one of the only studies that involves a coloured real time IHD that displays electricity and gas consumption side-by-side. The social science techniques for this type of experiment are limited when attempting to measure the impact of IHDs and energy saving behaviours or learning adopted and adapted by the younger members of the family. Children who were four years old at the start of the trial were seven years old at its end. The cross-germination of energy saving practices from school to the home could have a considerable impact. It is common knowledge that the energy use profile of a home changes with the arrival of new family members; what is less well known is how the energy profile changes as the child develops.

Equally, Hargreaves et al. (2013) recommend that ethnographic techniques could be employed to examine how the impacts of the IHD might be improved or made more durable through their combination with other interventions such as behavioural change campaigns or community-led modes of distribution and installation.

6.5 **Real time energy feedback: The IHD**

The intervention group were asked to rate how useful they found the different methods that the Ewgeco IHD uses to communicate energy consumption information. Table 6.4 presents a list of the Ewgeco methods for communicating energy use information and the percentage of the intervention group who rated that method ‘very or quite useful’.

Features	2010. % stating very or quite useful (n=30)	2011 % stating very or quite useful (n=30)	2013 % stating very or quite useful (n=10)
Coloured bars	90	90	90
Peak energy use	80	30	30
Energy usage in pence per hour	63	60	60
Energy usage in total cost for today	57	54	70
Energy usage in kWh	30	27	10
Energy usage in Total kWh/day	30	20	10
Directly reviewing the history	14	7	10
Household carbon footprint (CO_2 / kg)	10	0	0
Energy use in Ewgeco unit	7	0	0
Audible alarm	4	4	0
Independent appliance monitoring	2	0	0

Table 6.4: User Preference for Displayed Information. Shaded cells denote the majority of users (>50%)

6.5.1 Coloured graphical and numerical display of energy information

The responses to the first interview (2010) show that the occupants professed a high level of favourability towards viewing their electricity and gas consumption as represented by the coloured bars. The majority of interviewees commented on how the traffic light system continuously attracted their attention and in many instances reinforced the need to take action to reduce wasted energy. Over the course of the study, the interviews in 2011 and 2013 found that the vast majority of users maintained a preference for using the non-numerical coloured bar portion of the device which indicates their level of consumption based on a three colour system of green, orange and red.

> *Well we use the traffic lights the most, mostly because it's bright, and I don't know what kilowatts mean. When the monitor is out of the green we pay more attention, when the display is orange or red, I mean, when its showing an unusual number of coloured bars for that part of the day, we go hunting to see what's been left on… if we don't need that on, we switch it off*. (E01)

Additionally, the interviewees described how they augmented the information from the active display with the monetary value expressed by the display.

> *Yeah, my wife uses the colours to see what's going on, but I find the pounds per day figure the most useful. It's true that the coloured bars still attract my attention… I would walk past and see red, and I'd think, 'how much is that costing me?' then I would go over and look closer at the pound figures. After all that's what matters, right? Everything we do is money. I want to see how much this place is costing to heat, after all at the end of the day, it's the pound figure that my supplier is interested in, so, so am I*. (E02)

Notably, interviewees still maintained interest in their current consumption figures, as displayed in pounds and/or pounds per day. Early interaction with the Ewgeco IHD led some users to explore which particular electrical appliances around the home were costing the most to run.

> *See, people always tell you, that this costs that and that's costing that, but it's not until I done this myself, now I am a believer. I don't know about everyone else, but I would like the Ewgeco to show me a list of all my stuff and how much each of them are costing me*. (E03)

Many of the participants who used the device in this way described how they began to understand the costs associated with running household electricity appliances and with running the central heating and hot water. Similar to the comment made by E03, others who used the device this way described a desire to view all of their appliances' energy consumption individually and continuously.

However, of those users, very few had attempted to use the display's independent appliance monitoring facility. Many continued to comment that they were not confident in doing so, did not possess the 'required' level of knowledge to properly operate the monitor and were afraid of 'breaking' the device if they tried any extended form of physical interaction.

A small number of the participants attempted to use the audible alarm or independent appliance monitoring features. This is likely because these features are only accessible by pressing buttons in combination, which is difficult unless one reads the manual.

Overall, few of the households investigated the different functions or special features. It seems that, as in previous studies (Allen & Janda 2006, Anderson & White 2009), the occupants perceived that there was a substantial learning time that prohibited them from fully exploring the functions of the IHD beyond one button interaction.

A small group of those interviewed valued the display of current and total daily consumption expressed in kilowatt hours. Throughout the interviews it became apparent that viewing daily or hourly consumption in kilowatts was favoured by male occupants, and/or those who had, or were working in, an occupation that required them to have an appreciation of the kilowatt hour value. This difference was not statistically significant ($t(28)=1.45$, $p=0.15$). More female than male respondents preferred viewing the £/kWh numerical information. This was not statistically significant ($t(28)=-0.98$, $p=0.33$).

Many interviewees commented that initially that they were unaware of the purpose of having the single lit bar in each column. After they had gained an adequate understanding of the function for the peak bars, however, a large majority found that this feature to be of particular use to help them budget, although by the time the second interview was conducted, interest in this feature had dropped sharply.

> *I didn't even know why this single bar was lit above the rest, first I thought it was broken, when I finally read what it meant and I started looking at that bar more often, after a while it was meaningless again, definitely for the gas side, when I run the hot water in the morning, the gas peak bar flies away off to the top and doesn't come back down, it just stays there all day… how is that fair?* (E04)

The above sentiment was expressed by a majority of interviewees in the 2011 and 2013 interviews. To improve this situation, several interviewees had suggested a peak bar should display the collective average of each utility. This in turn would allow the peak bar to remain a visual descriptor of peak use throughout the day and avoid it being pushed 'out of sight' by early morning energy demand.

2013 results: Smaller sample, similar results

By 2013, it was still reported that the intervention group found viewing energy consumption through the real time moving coloured bars was the 'most useful' method of those available for viewing their consumption. Similar to the findings from the Phase 1 interviews, viewing energy displayed in a cost format was also reported to be ‘very or quite useful’.

None of those in the intervention group were any more confident with using the independent appliance monitoring function or the audible alarm. Those who attempted to use those features in 2010 and 2011 commented again during the 2013 interview that they had tried to explore the benefit of these features, but most had gotten frustrated navigating through the one-directional scroll menu in the settings and given up. Others, who had managed to get the feature to work, noted that they could see the benefit of a feature like an alarm but that having another beeping ‘thing’ in the house was undesirable. Further investigation revealed that it was not so much the perceived annoyance of being told by the device that they had reached their energy budget that was off-putting, but more that they would have to enter the hall to stop it from beeping. Others stated that they would have got annoyed by the alarm, knowing that it would distract them from what they were doing and force them to take measures to stop it from beeping actively.

The historical energy consumption view was the only feature offered by the IHD that required the user to navigate through its menu that was rated as either very or quite useful by the users in 2011 and 2013. These users stated that this feature was interesting and that they reviewed their historical energy use often, usually when they were away from the house for long periods of time or when they had ‘unusual’ activity the previous day or days, e.g. visitors etc. Many commented on the limitation of using this feature on a small screen and compared it to technology that they have become very accustomed to over the past two years:

> *It needs a longer term side by side average. Having it on a calendar would be great, for that overview sorta view. But not on a laptop, then it becomes too much like hard work. Having it on a device that’s not much bigger than my tablet* – (respondent was holding a 7in tablet) (E18)

> *Yeah the historic view thing. Its fine, really I look at it very now and again. Seeing what I used yesterday is fine but I pay my bills monthly, I want to*

> *see my energy consumption monthly. If this thing* (Ewgeco IHD) *provided the information as a calendar as well as the wee jumping bars, then that would be good. I suppose they'd have to redesign it, 'cause the screen is so small.* (E11)

6.5.2 CO_2 and Ewgeco units

A smaller portion of interviewees appeared interested in viewing their consumption as carbon dioxide emissions (CO_2) or in Ewgeco Units. However, this selection of interviewees came to see the CO_2 figures as meaningless and difficult to relate to; at the same time, many of the users criticised the Ewgeco Units reading as being too abstract. As a result, none of those questioned in the second interview felt that the CO_2 and Ewgeco Unit figures were "very" or "quite" useful. In the 2013 interviews, the entire intervention group reported that viewing their energy use in CO_2 or Ewgeco Units was 'not useful'. The primary reason for this was the difficultly the participants had visualising the value of these units.

Several interviewees, who felt that they had developed an adequate appraisal of their own CO_2 and Ewgeco Units consumption, explained that they had no means of comparing their own figures. This led to interest in the figures tailing off due to the lack of an adequate motivator or sense of accomplishment. Some went on to suggest that there was a need to have these figures displayed in a comparative format. One suggestion that received much interest was having the ability to compare the Ewgeco Units and carbon dioxide emissions of their own domestic energy usage to that of other similar nearby households. The interviewees commented that this type of displayed information would better allow them to connect the figures to the everyday aspects of their lifestyles and would personally allow them to define a benchmark of what is socially acceptable.

Those who had not used the CO_2 figure went further, stating that there was a need for more information to help them to visualise how CO_2 fits into particular everyday activities.

Most people in this trial said that they tried to minimise the amount of energy they used. In 2010 (n=52) the reasons for this tended to be financial, rather than environmental: 82% said that they minimised the energy they used because it saved money, while only 51% said they did so because it was “good for the environment”. When the questions were repeated during the 2013 interviews (n=20), a similar percentage of participants (80%) agreed or strongly agreed that they tried to reduce the amount of energy they consumed because it could save them money. The 2013 interviews show an increase (65%) in those who agreed or strongly agreed that they reduced the amount of energy they use because it was good for the environment. This difference was not statically significant ($t(16)=-1.58$, $p>.05$, $r=.40$).

6.6 Using Ewgeco

Most people (81%) reported finding the Ewgeco monitor easy to use in the first survey (2010). This figure was slightly increased in the follow-up survey (83%). A large majority also claimed in the first survey that the Ewgeco made them more aware of how much energy they were using (87%) and of how much money they were spending on energy (74%). These values were similar in the 2011 interviews as well, both at 77%.

Less than half the respondents (39%) said that they had used a lot of the functions of the IHD in the first survey (2010), and even fewer (17%) admitted doing so in the follow-up interview (2011). This may be due to a well-documented interaction with new devices where, over-time, people will focus on only specific functions that they find easy to interact with or which they find most useful.

Most people in the first survey (68%) felt that the Ewgeco had made them reduce the amount of energy they used; only 7% reported that it had not changed the way they used energy. These proportions fell to 53% and 3% in the second survey, conducted in 2011. Interviewees commented that their attitudes towards the Ewgeco had changed over the course of the trial.

I'm still using the monitor, but not as much, the coloured bars were very attractive, it was the first thing that ever attempted to explain energy to us. At first it was only the coloured bars now the coloured bars give us an overview of what's going on, but I'm far more interested to see how much we are and have spent, you can't see the financial impact just by the increase of one green bar (E07)

It gives you a clearer idea on how much money you are spending, even just moving the central heating by a few degrees, the house is still warm, you can quickly see the effects on the monitor, and the money is coming down, but once we knew that that was what we needed to do, that was it. Simply keeping it in the green now is what we constantly try to do (E08)

It was all useful when we moved in, in the beginning, I was always looking at it every day, now I don't need to as much, I don't find half of the stuff useful, but I still rely on it to keep reminding me. (E10)

I am using it less, but don't think I can ever afford to completely stop using it, yeah in the beginning I was all over it, but in the past few months I have learnt that the kettle costs this and my heating costing so much depending on the temperature level, I don't need to constantly look at it anymore, but I think it still needs to be here to keep on reminding me to be good, especially for the heating. (E11)

These, comments and similar ones that came from the 2011 interviews, seem to suggest that the participants have started to use the device in a reduced and more focused capacity. Many used the monitor more intensively during the first months of the trial, and began to implement the information they gained into certain aspects of their lifestyle. Many participants felt that they needed the presence of the monitor to refer to periodically, but it appears that those people who tried out the monitor's features quickly decided which functions they wanted to use and rarely attempted to re-engage with functions that they initially had felt were of limited use.

For the majority of the IHD users, the visual features of the monitor stood out as its most successful aspect. The main screen communicates the real time energy levels to the observer; this was enough to stop a number of the households from physically interacting any further with the monitor.

During the periodic meter reading schedule, a small number of households with the Ewgeco requested a tutorial on how to use the device. Although each of the participants with an Ewgeco had received a user manual and instructional DVD, they had not taken the time to read the manual, but were willing to spend some time learning the monitor's functions when someone described them. To this sample of users, the IHD was not intuitive enough to be easily understood or that they could interact with the majority of its functions. However, in its simplest terms, the IHD was effective enough to attract and motivate the users to increase their energy saving behaviour and reduce their energy consumption.

2013 observations:

31 months later, 50% of the reduced sample stated that the IHD was easy to use. However, much confusion was observed when trying to describe exactly how they used the device. A follow-up question enquiring about the frequency with which they looked at the monitor found that almost all of those with a monitor looked at it more than once a day. 70% stated it had made them more aware of the energy they were using and a large majority (80%) stated that the IHD had made them more aware of the money they were spending on energy.70% said that the IHD made them reduce the amount of energy they used and 70% said that it had changed how they use energy.

The intensity or length of time spend interrogating the device has dropped since the first interviews were held in 2010. Commentary from those participants suggest that they understood that the monitor has 'much more' functionality than perhaps they had used or could even describe. During the 2010 interviews, the users quickly chose the level of interaction with which they were comfortable and were still comfortable with that level of engagement in the follow-up interviews. The self-reported evidence suggests that they maintained the minimum amount of engagement required to receive the information that could affect their actions. This minimum amount of engagement was described as ‘viewing the level of coloured bars and associated number’. Typically these numbers were display of the cost in (£) pounds.

Even after 31 months only 10% said they have tried a lot of its functions, but the majority had become skilled at deciphering what sort of appliances may have been left on by looking at the coloured bars. Many had described the way they expected the bars to be arranged at different times of the day

> *At first I was mad turning everything off and telling him* (partner) *to do the same. When things got really hectic with the kids school stuff and work and that, I couldn’t keep track of what I had or hadn’t left on. But we are still very safety minded, we wouldn’t leave anything dangerous on. I think that that is just built in to you, you know. But I know at 5 o’clock the Ewgeco bars should be here, at 7 it should be here and at 10 it should be here. And that’s when I look at it, if the bars aren’t where I think they should be, then the hunt is on (laughs).* (E05)

6.7 Ewgeco in the homes, age and gender

The monitor was utilised in different ways according to age and responsibility across the different households. Several interviewees commented on the monitor’s ability to communicate with younger members of the family. The bright coloured bars which formed the graphic ‘traffic light’ were easily understood, predominately due to the use of vivid colours which were already familiar from other common situations.

> *Sometimes I think the kids use it more than I do. When I first told the youngest about it how it worked, she would stare at it, and scream the house down every time it went red. My eldest is in the eco council at school, oh she takes it very seriously, they learn all about this at school, so it’s good for them to have this*. (E05)

Many respondents felt that the monitor encouraged the whole household to save energy, and therefore money. There was a small positive correlation between age and how easy the respondents felt the Ewgeco was to use (a tendency for people to find it easier to use the older they got), although this correlation was not statistical significant.

There was no significant relationship between the respondent's age and how much he or she thought about his or her energy use or whether he or she tried to minimise the amount consumed for financial or environmental reasons.

Different behaviour was observed from similar-sized families. It was often observed that one spouse would express energy saving behaviour, while the other often saw less value in engaging with the IHD or conducting energy saving habits. Neither of these roles were strictly gendered. In these instances, a few interviewees spoke of disagreements that arose from one trying to enforce the information displayed by the device.

This type of device may be desired and used predominantly by an individual; however the device is then operated under a regime of very complex sets of social relationships. These issues clearly indicate that the IHD can become limited by the existence of unsupportive family members.

There was no difference in how easy respondents felt the Ewgeco was to use depending on whether they were support tenants (independent-samples t-test, mean scores 4.25 vs. 4.14, $df=28$, $p=0.86$) or how interested they were in using it. Also, there was no difference between male and female respondents (independent-samples t-test, mean scores 4.14 vs. 4.19, $df=28$, $p=0.94$).

Support tenants were as likely as non-support tenants to think about and try to minimise their energy use. Support tenants were more likely than non-support tenants to consider environmental reasons for minimising energy use (rather than financial ones), but difference did not achieve statistical significance.

Interaction with Ewgeco only encouraged a small number of participants to look more frequently at their meters or to re-evaluate their contract with their existing utility provider. This may suggest that people are content using Ewgeco simply to help them understand and be aware of their consumption and to alter their consumption behaviour. However, the study suggests that energy display devices may not stimulate users to think about changing tariff or supplier or even to collect meter readings for accurate billing.

Two conflicting comments were made by the occupants of three and four person dwellings with the Ewgeco which had children between late primary school and early secondary school age. Some of these participants commented that the children became a catalyst for the household to engage with the Ewgeco and that they were motivated to use the monitor to teach their children about energy conservation and reinforce what they had learnt at school. Conversely, other families with children stated that their roles and responsibilities in the family left them with less time to devote to monitoring their usage.

This finding reinforces the earlier observation of the complexity of social norms and lifestyle patterns which may hinder or compel individuals to use energy more efficiently. Individuals may act independently or in social roles, such as members of a family, where a person conforms to their responsibilities and priorities within the family unit.

6.8 Consumer findings and suggestions for improvement

As mentioned in previous chapters, the level of engagement with the Ewgeco tended to decrease over time, although a large majority of users continued to profess that they still used the IHD to stay aware of how much money they were spending on energy. This may be a result of a learning process which takes place at the very early stages of using the monitor, thus focusing attention on a smaller group of functions. Interviews with respondents also yielded further insights into why people tended to use the monitor less after having it in their homes for three months.

6.8.1 Tariff

Many of those interviewed during the second questionnaire stated that the single tariff structure of the device served to devalue the significance of the monitor's monetary display.

Over the course of the three interviews, the majority of the participants received many paper or digital utility bills, and some demonstrated a new-found interest in scrutinising their bill. Those who conducted the comparison recognised that the cost figures on the bill and those of the Ewgeco IHD were not entirely the same:

> *Yeah, the one tariff thing, that was a surprise, I guess if it wasn't for the monitor I never would of knew about the tariff, then I was told that I have two tariffs, I was like, were does my second figure go, which figure do I use. I ended up using the bigger number, better it giving me an over price than an under-price*. (E15)

This quotation represents a common theme that arose during the second questionnaire/interviews. However, viewing the energy consumption in monetary value still increased users' attraction compared to the other numerical values offered by the device.

Several users emphasised the need for an additional tariff input option on the monitor's set up menu. Others favoured a more automatic tariff selection system which set up the occupants' tariff structure based on selecting from a list of drop-down menus of existing suppliers and their tariffs.

> *Overall, I think this was a good product, I mean it was great that telling me when stuff was left on and stuff, but it doesn't real manage your energy does it? maybe if it managed your account with the gas company, like you paid them through this thing* (IHD) *like I used to do in my last flat with the meter*

> *key* (pre-paid meter). *Maybe it could manage your energy by turning things off before you reached the limit, so your limit would last for longer.* (E07)

6.8.2 Temperature

A number of interviewees professed a desire to have the indoor temperature displayed on the monitor so that it could be compared with the heating being used and how it reflected on cost could be seen:

> *I was hoping to have some sort of figure for the inside temperature… I think this would be so handy to be able to see how the use of gas compares to the temperature going up and down. It would definitely of help over Christmas. And I guess when it starts getting really hot, it would let me see what a couple of degree difference could make*. (E12)

Temperature data from the properties was recorded by the monitor but was not displayed to the occupants. However, the collection of this data from within the device and its location in the dwelling showed no significant correlation between those properties with large differences in gas consumption over similar dwellings sizes, occupancy types etc. The use of this function and its implementation as part of the monitoring regime requires further consideration and analysis.

If available, the presence of accurate temperature data might indicate the levels of occupant comfort in each dwelling and a comparative normalisation variable.

6.8.3 Installation location

The Ewgeco monitor was installed as part of the building's internal fabric and was in-place before any of the occupants took up residence. The positioning of the IHD was much debated at the start of the project because it needed to be hard-wired to the mains electricity supply. This limited the device location to within a metre of a plug socket. The author is not aware of any research that suggests the optimal location for technology of this nature. The majority of past studies with a similar research focus have not detailed the position or location of the IHD. Many of the IHDs involved in previous studies have been of a standalone, table-top design.

It was decided not to install the IHD in the kitchen or living room if possible because the device would not operate well in hot or humid locations, and also because the ability of the device to attract the attention of the user might be compromised if it were surrounded by larger, brighter and arguably more distracting pieces of technology. Therefore the hallway or a location close to the front door was considered best.

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 living room. Installers were advised to install the IHD above a light switch, near the system thermostat in the hallway, or close to the front door.

Several participants noted that the monitor was installed in unsuitable and unsightly locations in the property. Most commonly, the device was installed in the centre of a large wall; the occupants valued the level of engagement required to benefit from the device, but two of the users intentionally covered the device with a picture or similar wall art.

Occupants with this set-up emphasised that they wished to interact with the device more frequently, commenting that the device would better serve them if it were installed somewhere more prominent but also more sympathetic to the dwelling’s internal decoration.

It should be noted that the Ewgeco device can be a fixed installation or mounted in a cradle, thus allowing it to be portable within the house. The results of this survey suggest that any real time display should be in a clearly accessible location to allow for repeated interaction and also should be portable to allow home occupants to assess the effects of devices’ energy usage in different locations.

6.9 **MyEwgeco**

The wireless technology that enables the transfer of household energy consumption data from the Ewgeco monitor to the online “myEwgeco” web portal was installed after the interviews had been conducted. This section summarises the participants’ perceptions of the “myEwgeco” web portal and the self-reported likelihood they would engage with its features.

The number of residents interacting with the myEwgeco application was lower than anticipated (only 4% by November 2010 and 12% by March 2011). However, the handful of residents who did explore the application tended to be very positive, particularly regarding the monetary information display.

- Only 4% of the respondents had used the MyEwgeco portal by November 2010. The two respondents who had used it agreed that they found it easy to use and useful and stated that they liked being able to access their information over the web.
- By the second survey, the number of people who stated that they had used the MyEwgeco portal increased to 8 (12%). Again, all these respondents felt that it was useful and easy to use, and agreed that they liked being able to access their information over the web.

Similar to the behaviour demonstrated by the users’ interaction with the Ewgeco monitor installed in their homes, the (£) icon was the first feature on the “myEwgeco” web portal that each of the tenants wished to explore. As a result, the users soon highlighted an obvious limitation of the way the existing myEwgeco application analyses and displays their consumption.

Their comments and suggestions were as follows:

- The need to input a value for two tariffs, both for those with tariffs that change depending on the first kWhs used and with tariffs governed by times of the day.

- The need of those with a standing charge associated with their tariff to input and display information.

A number of factors influenced this result, including:

- All three sites were new-build developments: although the occupants had the facility to obtain a broadband service, the vast majority had not acquired the service at this stage in the trial.
- For various reasons, obtaining broadband or a computer was not one of their priorities.
- The desired broadband supplier was not yet available to them.
- A number of the residents did not possess a desire to explore the online portal; they were content with the functionality and information provided to them by the dedicated graphic traffic light display.
- Few attempted to explore the features of the online portal.

None of those interviewed in 2013 (n=10) had accessed or revisited the Myewgeco web app since the 2011 interview. However, many of those who mentioned the IHD's limitations pointed to their smart tablet or phone and suggested that an energy app for that device would be 'interesting'. Given that none of these participants used or explored the web app, it is uncertain how many would have actually used or benefited from using a tablet or phone app. Given the general method by which this sample engaged and interpreted energy consumption, it would appear very likely that the tablet app would be little more than 'interesting'.

On the same topic, embedding the data in a social media platform, providing control over appliances and allowing users to easily action budget activities were the comments that arose from those who discussed the future of the device.

6.10 Conclusion

Combining the evidence collected from the quantitative and qualitative analyses, the participants in the intervention group have maintained a reduction in energy consumption compared to the control group. This reduction appears to have been achieved using the very basic features of the Ewgeco IHD. This finding does not coincide with those of many authors in this area. The common consensus is that energy monitors do much to encourage considerable interest in a consumers' energy use but fail to secure long term savings. Past research suggests that visualising energy to the user is of mere novelty value, with the result being that the energy monitor turns from interesting to annoying to being ignored at varying rates depending on the user. Many in the utility sector have used the term 'time to kitchen drawer' to define how long it takes the user to disconnect the energy monitor and banish it to a cupboard.

It should be stated that much of what the public and industry know about energy monitor use behaviour has originated from the EDRP (2011) trials, which gather the self-reported findings of the energy monitor research programmes of four of the major utility companies. The findings relating to savings made by the intervention groups with an IHD were considerably less than those observed by this study. The authors of the AECOM (2011) report frequently commented on the level of bias in results that may have arisen due to the recruitment methods employed by the utility companies. The selection process for dwelling participation was called into question for a number of trials. For many of the results, the gas results for those with an IHD were either non-existent or heavily skewed by selection methods. It was consistently easier for the utility company to report domestic electricity than gas use in real time. The AECOM (2011) review reported how gas monitor installation was more likely than the electricity IHD to be cancelled by the utility company, meaning that the IHD would not show the consumers their gas consumption. Many more complications relating to gas consumption logging by the utility company meant that the EDRP review did not report as robustly on gas consumption reduction as was it did on electricity consumption.

The EDRP review gave insufficient details on the design specifications of the IHD used in the utility company trials. However, given the authors' knowledge of utility company IHDs at the time of the EDRP trials, it is likely that the IHDs being trialled were an early design that presented electricity use information in a monochrome and/or numerical format. The little detail that is provided in the EDRP report on IHD design states that the IHD displayed gas consumption when the user cycled through a series of menus. This cannot be compared to the display configuration of the IHD used in this project.

From the little information available on the how the IHDs showed gas consumption, it was reported that those with an IHD connected to a smart meter responded more positively to the information and to the device than those with the IHD connected to 'dumb meters' (the term given to differentiate between the new smart meters and existing utility meters). One reason given for this disparity was the increase in IHD functionality that came with the more sophisticated smart meter IHDs. Again, no information is presented that defines what constitutes a 'sophisticated' IHD. However, the analysis presented in this project shows that the users consciously refrained from using the additional features and functions of the coloured dual fuel IHD (Ewgeco), stating that the 'coloured bars' and £/day information for gas and electricity was enough to manage their understanding of energy use in the house. It could equally be argued that the Ewgeco IHD has a cumbersome menu interface for accessing these additional features, and this contributes to why they were not utilised.

The difference in demographics also could impact on the disparity in gas saving results between the findings of this trial and those of the EDRP review. It could be argued that the tenure of this study; which focused specifically on housing association social housing tenants, have a much lower desire or willingness to investigate this type of technology. This is in comparison to the much wider tenure type demographic who were likely used in the utility company trials.

Additionally, the methods by which the sample populations were recruited in the EDRP study could potential have impacted on the results. The participants in this trial were volunteered by the housing association(s) and later confirmed their willingness to participate. The common recruitment method employed by the utility company means that the participants must have made a conscious decision to actively seek to be involved in the trial. It could be argued that such a recruitment approach, although allowing for a more diverse demographic, would skew the sample towards those who already have a vested interest in energy consumption or energy reduction. In contrast, the recruitment method for this trial meant that the sample was conceivably made up of a spectrum of people within a similar demographic but with varying degrees of interest in energy saving and energy reduction.

Equally as important in terms of its impact on the results are the methods by which the participants in the trials received the IHD. The properties investigated by the author had the IHD installed during their construction, so they were in-place before the occupants moved in. The utility company trials installed the IHD in the homes of the participants after they had been recruited. This made it more difficult for the utility companies to install an IHD with the ability to display gas consumption. Many of the recruited properties were unsuitable for the installation of gas data loggers and transmitters. As part of the installation during construction, the Ewgeco IHD was part of the building fabric, meaning that the most suitable gas meter could be specified before the building was completed and the required wiring of the logger could be in place with little disruption.

Moreover, the utility company trials excluded occupants from participating if the dwelling was less than two years old and the properties in this Ewgeco trial were constructed 9-10 months before the trial began. In this respect, the EDRP review makes a critical point. It seems that the gas smart meter is paramount to the successful installation of an IHD with gas consumption display functionality. The gas smart meter streamlines the retrofitted installation of IHDs, where the IHD synchronises with the smart meter using the meter’s GSM capability so that it no longer requires complex third party transmitters or data transmission probes and cables. The single smart meter specification means that an IHD, theoretically, can receive accurate gas consumption information from the meter. Currently, if the Ewgeco IHD or other consequent IHD claiming to record and display gas consumption is to be retrofitted, then the property’s gas meter must have a pulsed output. If this is not the case, then the gas meter needs to be changed to one that does have a pulsed output. This procedure of replacing a gas meter with a pulse-enabled one is technically straightforward, but could be perceived as a considerable disruption and cost to occupants, although arguably no more of an inconvenience that the subsequently mandated smart meter roll out.

The Ewgeco electricity and gas IHD became an influential presence and source of behavioural change information for the households in which it was installed. The users did not want the IHD to be removed at the end of the study because they felt that it was responsible for their increased energy use awareness in their new homes. Many of the occupants felt it would be more challenging to retain their newfound awareness of gas consumption if the IHD were removed and the majority of users predicted that they would lose awareness over time if the IHD were removed. Therefore, a real time coloured dual fuel IHD such as the Ewgeco 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 by this sample led to reductions in their energy consumption and improvements their energy saving patterns.

A small portion of the interviewees indicated that the monitor was complex, overwhelming and even intimidating. As a direct result, these participants expressed negative feelings about using the IHD, but subconsciously interpreted its basic principles.

> *We don't use it, we don't know how to, the only thing we do is try to keep the thing out of the red and in the green, but we haven't used it*. (E16)

A minority of the intervention group, who stated that they did not use the Ewgeco IHD, commented that using the IHD had a low priority in their daily routine because energy use and utility bills were also a low priority An element of uncertainty surrounding the unit's presence, plus ambiguity relating to its functions, intensions and potential advantages, combined with the lack of engaging documentation, served to intensify its perceived complexity, which resulted in the IHDs neglect. This suggests that the end user requires a certain level of engagement from a medium or information source they can relate to before they attempt to use the IHDs full functionality.

Investigating the users' preference for receiving information from the IHD, the user quickly explored and selected the communication method that they could use to best understand what the IHD was telling them, then quickly decided whether they wanted to maintain an engagement with the device.

Cross analysis of the findings between 2010 and 2013 shows that the IHD quickly became embedded in the households' routine, and formed part of the users' cost budgeting decisions. The users described how the IHD quickly transformed from a device that dominated their consciousness to one that fell into the background. This transition is not an uncommon path of usage for modern digital technology. However, the IHD became an integrated part of the users' energy use routine, but in a subconscious manner. The IHD did not suffer from being ignored or deemed annoying. The participants in this study appeared to define what levels of electricity and gas consumption were within acceptable levels for their house for different times of day quickly. This level of interaction with the device appears to be enough to change behaviour and reduce energy consumption for this sample.

Earlier understanding of IHDs credits them with bridging the 'information-deficit' and closing the performance gap by directly tackling occupant energy use behaviour, particularly by promoting pro-energy behaviours. This research suggests that by simply making energy visible, and managing to keep it visible, was effective for this sample, but the device cannot be defined as 'smart technology'.

The simple display and the push information style of this generation of IHD has achieved what is arguably the most it can achieve in the way of behavioural change. It is, in essence, a passive piece of technology that requires its user to act on the information it provides. Without such action the device is little more than a data logger or a 'colourful clock', as described by one user in this trial. The evidence from the interviews suggests that the next step for the IHD is to be better connected to the home, moving closer to the definition of a smart home. The IHD is best placed to collect information from the appliances. These trials show that the IHD in its current form has been accepted by users. The longer the IHD is on display, coupled with advancements in similar domestic internet connected technology, the greater will be the desire for the IHD to regulate energy consumption in the home actively. A first step towards accomplishing this would be a ‘soft approach’ that allowed the Smart IHD to identify and promote options to the user to ‘eliminate’ the energy that is being wasted or forgotten about or energy that is not needed.

Chapter 7

7 Conclusions

7.1 Domestic in-home displays

Depending on the model, IHDs provide instantaneous and real or near to real time data on energy consumption (kW and cost), and usually also give other information such as CO_2 emissions and energy consumption over specified periods. A literature review of the past research that used energy monitoring technology as an intervention mechanism found that mostly it used early generations of the IHD that were of relatively simple design and displayed electricity consumption data in a numerical or monochrome graphical format. The use of these styles of IHD has given rise to the commonly quoted figures for the electricity savings to be expected from this type of technology. These savings are quoted as being in the region of 5% to 15% (Darby 2010a, Mountain 2006, Van Houwelingen & Van Raaij 1989, McClelland & Cook 1979).

Few trials exist which have used an energy monitor connected to existing or ‘dumb’ meters to display household gas consumption. Examples of successful gas consumption trials have been found in North America, the Netherlands and Australia. Authors who researched the difference in gas consumption through the use of an IHD reported a wide variation in levels of consumption compared to control groups.

Results from the limited number of published academic trials involving standalone energy monitors displaying the domestic gas consumption suggest that reductions in gas consumption fall within the typical range of that observed for reductions for electricity consumption. Research by Hutton et al. (1986), Van Houwelingen and Van Raaij (1989) and SenterNovem, UC Partners (2009) show that reductions in gas consumption are not always certain. Reductions in gas consumption can be as high as 12%. However, trials conducted by Black et al. (2009) and Hutton et al. (1986) involving IHDs in Australia and British Columbia respectively show that the intervention group increased their gas consumption by 2.3% to 10%. Black et al. (2009) state that the increase in gas consumption may have been attributable to faulty equipment.

These have all occurred in countries other than the UK, and have taken place in regions where large variations in temperature are experienced, e.g. Wagga Wagga in Australia, California, Quebec and British Columbia. These locations experience different heating and cooling temperatures and weather seasons to the UK. The EDRP UK utility IHD trials tried to incorporate gas consumption information. They reported an inability to connect successfully to existing gas ‘dumb meters’ because of the different types of pulse and non-pulse enabled gas meters currently in use.

Past research which used coloured energy monitors has typically originated from countries which have ‘time of use’ (TOU) energy tariffs. These IHDs use flashing or bright lights to remind users to turn off certain appliances. Similar technologies have used this technique and a colour range to alert the user to a change in the time of use (TOU) tariff (Martinez & Geltz 2005, Seligman et al. 1978, Sexton 1987). Black et al. (2009) report a positive response from end users to the display of coloured squares changing on their energy monitor as their energy consumption increased. Hargreaves et al. (2010) conduce qualitative research into occupants’ use of a coloured energy monitor displaying electricity consumption in the UK. However, the IHD did not use colours to represent different levels of consumption. Hargreaves et al (2010) report a positive response from participants, and a correlation between the coloured display and a positive change in consumption level.

The research presented in this dissertation shows that electricity and gas consumption are not affected in the same way. Research from this study suggests that the participants, regardless of experimental condition, had a considerably high level of electricity saving habits. This appears have been instilled through a combination of the messages they received from the generation above them and from media campaigns to reduce electricity. The most prevalent theme of this sample is that high levels of reduced electricity consumption were encouraged by a fear of electrical fires and concern about electrocution from faulty electrical appliances. Analysis of the sample energy consumption averages shows that the electricity consumption for every property type in each experimental condition in this study is much lower than the UK average domestic electricity consumption (4,192 kWh/year DECC 2014c).

It is worth noting that the property types in this study may not be statistically representative of the majority of the house types that comprise the DECC figures in terms of age, size and tenure etc. Therefore it could be argued that the houses in this group are likely to use less electricity than the UK average. However, the point remains valid: electricity saving behaviour from those in this trial seems to be less influenced by the presence of an IHD and more the result of ingrained habits relating to safety and parental influence.

Electricity was seen as a luxury for maintaining a sense of quality of life. Those with younger dependents felt that it was necessary to give them as much electronic luxury as they could. In contrast, space heating was perceived as a sacrificial commodity. The participants who compared both utilities stated that they would have ‘no problem’ shutting off the heating (space heating) if they felt that they were using it ‘too much’, but stated that they would find it difficult to do the same for electricity. This relates back to the fragmented nature of electricity use in the house and its perceived ‘invisibility’, as described by Darby (2010b) and Burgess and Nye (2008). Therefore, eliminating a lot of excessive electricity usage in a gas heated home is more difficult than turning off the heating at one point, which impacts the heating of the whole house.

The behaviours around the consumption of gas were by far the most revealing in terms of explaining the quantitative findings. At the start of the project, the collective response from the majority of the sample was one of disregard or ignorance of the actions required to reduce excessive gas use. Many of participants stated that they would ignore the many heating controls present in the home, and simply turn the heating on and off at the boiler as required.

It was observed during the later interview sessions that those who had significantly reduced their gas consumption were now justifying the use of additional clothing and blankets to keep warm rather than 'instantly reaching for the (space) heating'. The most revealing insight to changes in gas use behaviour was the increased uptake of using heating controls by the intervention group. This change in behaviour was not displayed by the control group. However, those who used the heating controls commented on how many different heating control they had access to and how the IHD assisted in learning which were most effective. Most of the properties were fitted with temperature regulator values on each radiator (TRV), a main system thermostat often placed in the hallway and a timer system on the boiler. The TRV and system thermostat were the most quoted controls used by the intervention groups.

7.1.1 Changing energy consumption

Overall, the flats consumed less electricity and gas than the houses in the trial, which may be expected due to their size and number of occupants. This may be attributable to the heating approach and behaviours around gas use adopted by the occupants between the property types. However, the results illustrated that the flats without an IHD consumed close to the same levels of energy as the houses with the energy monitor.

Gas Consumption

- Once normalised using the SAP figures, after the initial 6 month period, across the 52 properties in the trial, the homes with an Ewgeco energy monitor on display consumed 17% less gas (normalised figures) and the flats with it on display consumed 23% less gas (normalised figures) than the control groups. These reductions were found to be statistically significant, therefore, alternative hypotheses 1 and 3 are supported.

- The groups with an Ewgeco maintained a substantially lower consumption pattern over the six month trial period. This was observed for both dwelling types.
- Across most levels of property occupancy, those with an Ewgeco yielded improved figures, with the largest reductions in consumption compared to the control properties peaking at 23% in the 2 person houses and decreasing as occupancy increased.
- Interviewees with a Ewgeco monitor from larger occupancy dwellings commented on the difficulty of regulating the use of gas due to the number of people who had access to the heating controls.
- The results for the complete longitudinal study (37 months) show that the intervention group consumed 27% less gas (normalised data) than the control group; this difference was statistically different.
- The exact difference in energy consumption between experimental groups is dependent on the type of normalisation condition applied to the recorded energy consumption.

Electricity Consumption

- On average during the initial 6 month trial there was a 10% reduction in the houses with an Ewgeco and a 2% reduction in the flats with an Ewgeco. These differences were not statistically significant, and therefore alternative hypotheses 2 and 4 are rejected.
- Differences in electricity consumption amongst those properties with an Ewgeco were spread out, with a trend showing that large occupancy homes with an Ewgeco consumed less electricity than the control group.
- During the study it became apparent that the occupants in the control group and those in the intervention group were equally confident in regulating their own electrical energy use.
- Occupants utilised the Ewgeco as an instrument for reinforcing their existing level of electricity awareness and consumption. It was also used to detect electronic devices that were left on and helped to satisfy the occupants' safety concerns regarding electrical fires.

- For the full 37 month research period, the electricity results show that the intervention group reduced their electricity consumption by 21%. Although this difference was not statistically significant (the alternative hypothesis is not accepted), it is a considerable difference, suggesting that the IHD has an effect on domestic electricity consumption. This finding is considerable, because it shows that the savings made by the intervention group continued 31 months after most other trials have ended. Such other trials have suggested that any difference in electricity consumption would return to negligible levels.
- Again, the exact difference in electricity consumption between experimental groups varied based on the dependent normalisation condition.

The real-time energy display Ewgeco IHD was shown to be a necessary enabling platform for behaviour changing measures. While the savings were sometimes small in percentage terms, the absolute savings when scaled up to the national level would be substantial. The provision of a standalone in-home energy monitor was particularly important in achieving savings in gas consumption.

7.1.2 Changing energy use behaviour

The Hawthorne effect is well documented; its validity and potential impact on research involving monitoring and quantifying changes in human behaviour appear widely in academic literature. Although all reasonably practical steps were taken by the researcher to reduce this effect, it remains plausible that a number of the occupants in this study have reported their behaviour towards the Ewgeco IHD in a way that was influenced by the presence of the researcher.

A further influencing feature on the results reported here was the inability to systematically account for, correct or calibrate the qualitative feedback such that human awareness could affect the outcomes of this part of the research. The combination of user behaviour and energy data analysis provides some validity in this respect to the findings reported by the users about their energy consumption and thus their interaction with the IHD.

The analysis of the qualitative feedback, coupled with the consumption figures, shows that the presence of the Ewgeco energy monitor had a positively influence on gas usage reduction habits and served to reinforce and solidify electricity reduction behaviours amongst the intervention sample.

At the start of the 37 month monitoring period, many of the participating households described how existing billing and methods of payment have distanced them from controlling their electricity and gas consumption. From the start of the reach project, the Ewgeco IHD was very well received by a high proportion of the participants. Early interaction with the Ewgeco helped the users to generate a certain level of awareness of their electricity and gas use. This type of awareness allowed users to reinforce existing energy-efficient behaviour and also gave instantaneous cost information relating to their actions. This in turn allowed for conscious and rational decisions to be made about energy use patterns and how they might be changed in the future.

At the end of the first phase of monitoring, the analysis of the interview data found that the level of interaction with the monitor had been reduced and that people tended to be less positive about many of the IHD's additional functions. The initial excitement was reduced and users felt that they had learnt from the device and optimised or changed their behaviour accordingly. However, they still maintained a level of dependency on the IHD and periodically referred to the device to reinforce the lessons that had already been learnt. This suggests that the IHD had a material effect on longer term sustained behaviour changes.

The coloured traffic light display appeared to be the preferred medium by which many of the users chose to engage with the monitor. Numerically, features showing energy use in terms of money were the most frequently reported as being useful or very useful. For most of the users, the IHD's additional functions, like showing CO2 levels and the energy use alarm system, were perceived as being uninformative. Users felt that these features overcomplicated the device and they were unable to see the feature's relevance in their daily routine. Users were unable to contextual the CO_2 figure into a meaningful scale and quickly ignored the figures. Participants who experimented with more of the Ewgeco's features usually described themselves as being 'very computer literate' and had little trouble setting up and interacting with their home's heating system and using advanced features of other electronic domestic appliances. However, this was not specific to any one gender or age.

Several of the participants described the device as a learning tool because it helped them to identify which habits and appliances were costing them the most money, thereby enabling them to make informed decisions and to take actions they saw as necessary to reduce energy waste. This form of interaction with the IHD makes energy consumption increasingly relevant to everyday lifestyles.

At the end of the 37 month monitoring period, the gas usage activity scores showed that those in the intervention group had a higher gas reduction behaviour score than those in the control group. This difference was also observed for electricity consumption. The differences were statistically significant, with large effect sizes. These findings correspond with and help to explain the quantitative findings collected from the Ewgeco logger, which showed that the intervention group consumed considerable less electricity and gas than the control group.

The visualisation of the gas consumption translated into new behaviours and longer term habits being formed and maintained. The visualisation of electricity appeared to have failed to incite new electricity reduction behaviours, but it was used as a tool to help maintain and reduce the time taken to repeat the already existing electricity reduction habits.

7.2 IHD benefit to the low and zero carbon homes strategy

This research has shown the potential of smart energy monitoring technology, in the form of the IHD, to create and maintain reductions in domestic energy consumption behaviour. Reducing energy consumption in the domestic sector is a fundamental component of meeting national carbon reduction commitments, but it is not the only component. Adding thermal insulation and improving air-tightness to reduce heat loss and reduce the demand for heating fuel is another component and is not a new concept. A third component is the inclusion of micro renewable generation technology that provides on-site electricity and heat directly to the source of demand.

The publication of this research adds to a growing body of work showing that the deployment of effective and evidence based technology can engage and change occupant behaviour to reduce energy consumption. Furthermore, this technology is an integral part of the strategy to reduce and maintain low energy demand from carbon sources. Fabric improvements, occupant behaviour modification technology and renewable energy generation technology (F.O.R.) have a great potential together to reduce the operating energy demand of new and existing homes.

This concluding Section explores the importance of F.O.R in isolation and combination and explains the importance of these components to new and existing homes.

Fabric first

Through the implementation of a domestic energy and environmental rating scheme for homes, a fabric first approach is often adopted for new build and retrofit construction projects in an attempt to reduce energy demands, particularly for heating. The fabric first approach shows that considerable energy savings can be achieved with significant improvements to the predicted energy performance certificate (EPC).

A fabric first approach to enhancing the energy efficiency of buildings can be potentially circumvented through inefficient energy consumption behaviour such as heating controls and window opening behaviour, although these can be mitigated to a certain extent by home owner user manuals like those detailed in Scottish Building Standards Section 7 and housing association home user guide and information packs.

When considering new homes with advanced heating and ventilation systems, the visual presence of the IHD allows the occupants to gain a better appreciation of the energy being consumed for space heating and possesses the potential to assist in the closing of the performance gap.

Renewable energy technology

On-site low and zero carbon energy generation technologies are considered an essential part of the low carbon energy mix and of low energy homes. However, they have been met with opposition, and many are uncertain as to their role in mass produced housing. The retrofitting of micro renewable technology for on-site generation is becoming more widespread, although the number of installations is linked to the funding mechanism, performance requirements and financial incentives attached to the type of on-site generation. The addition of renewable energy technology to the design of new housing allows for a considerably higher (better) energy performance certificate value (EPC).

The addition of renewables requires a certain amount of maintenance, and many of the renewable energy technology payback calculators evaluate the rate of return (ROI) by subtracting the calculated annual energy generated by the current annual energy consumption. For domestic purposes, this equation may not accurately represent reality. The visual presence of the colour IHD has the potential to allow users to better appreciate and balance their energy demands and the on-site energy being generated. Examples in the USA have shown the success of ambient coloured IHD which alert users to temporal changes in energy tariff.

The future of IHDs may reside in their playing a more integrated and active role in managing and balancing energy consumption appliances and energy generation appliances. Such an integrated home is known as smart technology and the internet of things protocol.

Occupant behaviour change

Encouraging consumers to use less grid electricity and gas is an essential element of sustainable living and longer term fuel security. With the implementation of smart metering technology, this project has shown the capacity of user focused technology to generate and maintain changes in occupant energy consumption behaviour. On its own, this component has shown its potential to address the increase in electricity and gas demand, capping wastage and reducing reliance on fossil fuel operated power stations.

Changing consumer behaviour so that it is more energy conscious, with an increased awareness of how to use energy and the home more efficiently through the use of IHD information, is potentially more significant than the roll out of utility smart metering.

New housing/existing housing

New housing and the refurbishment of existing housing is the main vehicle for change, and building regulations and government funding incentives are the most convenient method for driving energy reductions.

Existing housing

Less than 1% of the UK's existing building stock is replaced every year, and it has been estimated that 85% of the current housing stock will still be operational and lived in by 2050 (Palmer et al. 2006). It is well recognised that, to achieve low and zero carbon and energy homes, the existing housing must be much more energy efficient. This can be achieved through the F.O.R strategy.

Much progress has been made in material innovation and expanding knowledge in the research field of retrofitting older dwellings to reduce consumption of thermal energies (Currie et al. 2013, 2014). Solutions that reduce thermal energy consumption tend to complex to install, have a considerable expense and be difficult to scale up to the national level. The Energy Efficiency Standard for Social Housing (EESSH) has been developed to help to improve the energy efficiency of the existing social housing stock in Scotland.

In the context of existing buildings, architects and designers have much less opportunity to change most fabric components. Improvement to the thermal performance of the existing envelope is typically the chosen prerequisite for energy conservation in buildings, focusing on improved thermal performance levels and reducing air filtration. However, aspects of significant building improvements and renovations that are required to reduce the energy consumption of the mature housing stock begin to arise when considering the inclusion of an effective user focused colour IHD. This IHD has a significant role to play as the relatively low-cost, non-intrusive and easy to install first step of reducing energy consumption in existing homes, especially the ‘hard-to-treat’ variety, or as part of a combination of retrofit measures that assist in reducing the circumventing of predicted energy savings through fabric first and/or renewable installation (the rebound effect).

New housing

Much of the work in the new build sector follows a physical, technical and economic model of the built environment (Lutzenhiser 1993). Architects, engineers and similar professionals are the major players, making technical improvements to existing buildings and designing new ones to higher standards. Building regulation, coupled with voluntary eco-design standards like Eco-homes and Scottish Building Standards Section 7, accomplishes much in reducing the energy requirement of new houses. All of these agents advocate a combination of F.O.R to achieve and maintain low and zero carbon homes.

7.2.1 F.O.R. cost trade-off

This Section continues to evaluate of F.O.R’s contribution and importance to low and zero carbon homes by investigating the costs associated with the F.O.R components for both retrofitted and new build housing. The data for renewables and fabric improvements has been taken from two reports (Sweett 2014, Zero Carbon Hub 2014).

Additional costs to enhance new build

The additional costs required to construct new homes in order to meet the Zero Carbon Standard have reduced considerably since they were first estimated in 2006. At that time, costs were estimated to lie between £15,000 and £40,000 per home (this was dependent on house type and the combination of fabric, renewables and carbon trade-off compliance). This was, in-part, due to changes in the definition of ‘zero carbon’ and the exclusion of any requirement to address carbon emissions from unregulated energy uses. A significant influence on the lower cost estimates was continuing reductions in the cost of materials and technologies that have the most potential to reduce predicted energy requirements at the design stage. Examples include the price of solar photovoltaics (PV), solar water heaters (SWH), air source heat pumps (ASHP) and more efficient double and triple glazing.

Based on Zero Carbon Hub (2014), research suggests an additional cost of £2,200-£2,400 for low-rise apartments (average 56.6m²) and £3,700-£4,700 for semi-detached properties (average 76m²). These values have been calculated to achieve Zero Carbon standards above those specified in Part LA of the 2010 English Building Standards and include costs to meet Carbon Compliance (see Zero Carbon Hub 2014 for more details on Carbon Compliance). Table 7.1 is reproduced from the Zero Carbon Hub (2014) research report. It lists the average cost and cost/m² of materials and technologies commonly used to achieve low and zero carbon homes. Noticeably, the cost associated with fabric first enhancements for flatted accommodation is zero because of the very small changes required to floor U-value, air-tightness and thermal bridging values.

	Semi-detached house		Low-rise apartment (flat)	
Low carbon home component	**Average cost (£)**	**Cost /m²**	**Average cost (£)**	**Cost /m²**
Fabric first (F) (46 kWh/m2/year=semi-detached house), (39 kWh/m2/year=low-rise apartment - flat)	439.00	5.78	0.00	0.00
Renewable energy technology (R) 2 kWp photovoltaic	2849.00	37.49	2849.00	50.34
Renewable energy technology (R) Air Source Heat Pump	6406.00	84.29	7125.00	125.88
Renewable energy technology (R) efficient gas boiler with solar water heater	9693.00	127.54	9741.00	172.10

Table 7.1: New build, additional cost to enhance a designed dwelling to meet low energy zero carbon levels, Zero Carbon Hub (2014).

Additional costs to retrofit existing homes

Sweett (2014) published industry research that catalogued the cost associated with enhancing existing dwellings to reduce primary energy to less than 115kWh/m²/year. The fabric improvements and renewable technologies listed in Table 7.2 were generated from actual quotes and work carried out by the authors. No definition is made of dwelling archetype or of the average floor area of the dwellings that were treated. The increase cost for the materials and technologies compared to the figures in Table 7.2 is noticeable. This increase is associated with the increased time and complexity of enhancing fabric and fitting electrical and servicing equipment in existing buildings.

Low carbon home component	Average cost (£)
Fabric first (F) double glazing	261/m²
Fabric first (F) triple glazing	567/m²
Fabric first (F) internal wall insulation	123 to 368/m²
Fabric first (F) external wall insulation	150 to 161/m²
Fabric first (F) floor insulation	65 to 130/m²
Fabric first (F) roof insulation	14 to 82/m²
Renewable energy technology (R) Mechanical Ventilation with Heat Recovery	6,117/system
Renewable energy technology (R) Photovoltaics	5,627/kW
Renewable energy technology (R) Air Source Heat Pump	1,310/kW
Renewable energy technology (R) Solar Water Heater	1,739/m²

Table 7.2: Existing dwellings, additional cost to retrofit dwellings to meet low energy requirements, Sweett (2014).

Cost and energy savings from occupant behaviour changing technology

The research results and findings presented in this dissertation have shown that the limited ‘push’ only information style of this IHD can provoke and maintain longer changes in people’s energy use habits and behaviour. The research has shown that reductions in gas and electricity were achieved by a group of social housing tenants in different dwelling archetypes. Table 7.3 displays the results presented in Chapters 5 and 6, with the added figures showing the savings per dwelling in each archetype group on the utility bill and carbon dioxide emissions.

The carbon dioxide figures were based on the kg CO_2/kWh values provided in carbon conversion tables by the Carbon Trust (2011); the electricity multiplier was 0.5245kg/kWh and the gas multiplier 0.1836kg/kWh. The finance figures were based on the £/kWh figures provided by the DECC (2014c) Average Domestic Energy Bills for the UK; the electricity multiplier was 0.1463£/kWh and the gas multiplier 0.0476£/kWh.

The gas results in Chapter 4 where presented as kWh/kWh based on the calculated SAP gas requirements and selected as a suitable normalisation condition because of the coefficient of variation calculations. The gas results in Table 7.3 are presented in kWh because this value is widely recognised for conversion to £/kWh and kg CO_2/kWh. The dwellings in this research had an average floor area of 64.2 m^2 for the flats and 84m^2 for the semi-detached house.

As reported and discussed earlier, the IHD users in both dwelling types consumed considerably less gas than electricity than the control group. The difference in fuel bill and carbon dioxide emissions between the fuel types decreases base on national multipliers. Table 7.3 shows that the energy, utility bill and carbon dioxide savings continue for those in the research three years after the first installation.

		Phase 1 (6 months)	Phase 1 (6 months)	Phase 2 (31 months)	Phase 1+2 (37 months)
		Semi-detached house (n=21)	Flat (n=31)	Flat (n=20)	Flat (n=20)
Energy (kWh)	Electricity	191	29	1492	1543
	Gas	1545	644	3789	5350
Finance (£)	Electricity	27.94	4.24	218.28	225.74
	Gas	73.54	30.65	180.36	254.66
Carbon dioxide (kg CO_2)	Electricity	100.20	15.21	782.70	809.46
	Gas	283.66	118.24	695.66	982.26

Table 7.3: Resource savings on average per dwelling with IHD compared to control dwelling

Table 7.4 shows the price of the Ewgeco IHD loggers and displays as they were installed in 2010, including VAT and commission in the form of the initial set up of the device. In comparison to the costs presented by Zero Carbon Hub for new build enhancement and by Sweett for retrofitting improvements, the cost/m^2 of the Ewgeco IHD falls within the expected range. However, considering the cost of the Ewgeco IHD and the money saved through utilities bills, on average those living in the flats have not saved enough money on their utility bills over the past three years to pay for the price of this device.

However, the users of the Ewgeco IHD where not made aware of the cost of the device and did not have to purchase the IHD themselves. It is not known to what extend the purchasing behaviour and energy saving behaviour of the users might have changed if they knew how much energy they would have to save to pay for the price of the logger and the display.

Low carbon home component	**Average cost (£)**	**Cost /m^2 semi-detached house**	**Cost /m^2 flats**
Occupant behaviour change (O) based on cost of Ewgeco IHD logger, display, installation and commissioning	796	9.48	12.40

Table 7.4: Cost and cost/m^2 for Ewgeco IHD

The cost/m^2 values presented in Table 7.4 are indicative of the costs to the housing association who installed the devices, and are designed for comparison to Tables 7.1 and 7.2. Practically, the unit cost of the Ewgeco IHD would not change based on floor area: the unit cost is dependent on the distance between the IHD and the utility meters, which is not always directly linked to the dwelling’s floor area. An additional £150 + VAT is added to the cost if the electricity and gas meters are more than 10 metres apart; this additional cost was not applicable to any of the properties involved in this study.

The price of the Ewgeco IHD is much elevated compared to other more common IHDs because of its additional front and back end features. On average, the commercially available IHDs similar to the ones presented in Figure 2.1 cost around £100 to buy on the high street and self-install. These are the same IHDs which, when trialled, returned energy savings on electricity consumption between 5 and 15%, although many of these were not statistically significant.

The Ewgeco IHD claims to have enhanced features over these electricity-only IHDs, including the ability to log and display gas consumption in real time and in colour and the ability to transmit energy data from the logger to the display using a secure and low energy protocol.

This style of occupant behaviour changing technology has value to the low energy and zero carbon home, both retrofit and new build. However, this particular device in the retrofit market is perhaps more suited to being part of other low energy components (fabric refurbishments, renewable technology installation, boiler upgrades) to allow the payback period to be more attractive. This particular IHD and its enhanced features are of particular interest to new build designers and specifiers because it possess many more of the abilities required to satisfy the voluntary requirements of the Code for Sustainable Homes ENE3, BREEAM ENE 02 and Scottish Building Standards Section 7 Aspect Gold 5.

The relative ease of installation of the IHD in comparison to the energy efficiency components listed in Tables 7.1 and 7.2 means that this version of the IHD also has an uncosted benefit which makes an important contribution to limiting the effects of the performance gap, witnessed in energy efficient new builds, and t limiting the rebound effect observed in retrofitted existing dwellings.

7.3 Future of the IHD

The future of the device appears to be in a state of flux. The results from this study shows that the push-style IHD was still effective at helping occupants to maintain lower levels of gas and electricity consumption compared to a control group. In this respect the IHD has achieved its goal. Arguably, however, the push IHD method of energy reduction through behaviour does not provide consistent results. The results from this study have not been replicated by other authors using other designs of IHD. The success of this IHD could be attributed to one or a combination of its three relatively unique qualities: its coloured 'traffic light' display, its permanent installation in a heavy traffic part of the home before the occupants moved in and its ability to display electricity and gas side-by-side.

These three features make this IHD unique among the IHDs trialled by past authors. The coloured traffic light display was listed as the most effective method used by the IHD to attract the attention of the user and to communicate its message about temporal consumption quickly. The presence of the gas information on screen had a large effect on the users' gas use behaviour and long term habits.

Arguably, it may have been the provoking presence of the gas information on the IHD that encouraged the user to maintain visual engagement with the electricity display portion of the IHD.

The electricity consumption comparison shows that, on average, over the initial 6 month period the intervention group consumed 7% less electricity than the control group, and that this difference was not statistically significant. When monthly averages were analysed, it was noted that the intervention groups often consumed more electricity than the control group. Had this research project investigated changes only in electricity behaviour, and concluded after the first 6 months of data collection, then the conclusions would have widely concurred with the findings of other researchers, with the 7% difference in-keeping with the 5% to 15% 'electricity savings' often quoted.

However, this longer-term research study has shown that the push-only IHD utilised here has changed and maintained long-term energy saving behaviour compared to a control group. The users identified the red, amber, green display design linked to consumption levels as the main reason for their attraction to and prolonged engagement with the IHD. The Ewgeco IHD seems to be much more effective at changing energy use behaviour and reducing domestic energy consumption than the similar, mass-produced monochrome electricity-only IHDs initially supported by UK utility companies.

The study shows that such inferior devices are found in large numbers, and that previous studies using these type of devices report that long-term energy savings are rarely, if ever, achieved. This research advocates a step change in the collection and presentation of energy consumption data to the user, especially in terms of the IHD technology being rolled out with the smart meters.

Since originally undertaking this research in 2010, collecting the Phase 1 data in 2011 and collecting the Phase 2 data in 2013, utility company IHDs have evolved into devices with much the same abilities and features as the 2010-2013 Ewgeco IHD. With the roll out of the smart gas meter and, by extension, easier wireless data connections between meters and IHDs, the inclusion of gas consumption data in smart meter IHDs is now set to be a common feature of all relevant smart meter installs. Several of the larger UK utility companies have changed their flagship IHD to one with a coloured consumption display very similar to that of the 2010-2013 Ewgeco IHD.

Since the inception of smart meter roll out in the UK, utility companies have monopolised IHD design and directly empowered the organisation and completion of the roll out. They have also promoted the energy saving benefits of the IHD. Their dominant position in the IHD market has been reinforced by the addition of certain accreditation standards, which state that the IHD must display accurate tariff and billing information.

A major concern with this strategy is the conflict of interests between the sale of energy and campaigns to help domestic users use less energy. The coordination of the IHD campaign may not be best supported, or done so in the most competitive or objective way, by UK utility companies. However, this strategy is not uncommon, with UK utility companies indirectly influencing renewable technology incentives and home insulation grants. Similar to the government supported implementation of feed-in-tariffs and other utility-led energy efficiency incentives, the roll out of smart meters and IHDs should be tracked by targeted drops in domestic energy consumption; this would help ensure that the UK utility companies opt for the most effective IHD and not merely for the cheapest.

User feedback highlighted the comparisons between this technology and tablets, the recently popular handheld smart devices. The interviews conducted for this research suggest that the IHD technology has suffered from an identity crisis. The device is categorised by users and sellers as part of the ‘clean technology’ group of ecological or energy efficiency technologies even though it neither generates nor saves energy without the explicit time investment by the user. It cannot be classified as a ‘fit and forget’ energy saving items like photovoltaic panels, high energy efficient rated boilers, low energy light bulbs or cavity wall insulation.

From a user’s perspective, this technology falls into something of a grey zone in terms of household electronic devices. The device is sometimes described as an integral part of the building fabric, a device as fundamental to the home as traditional ‘lifestyle assistance’ technology like cooking or washing appliances, and therefore should be as simple and intuitive to use. However, the IHD is also described as ‘lifestyle luxury’ technology, like entertainment or hobby equipment. The IHD lies somewhere between these definitions: it is neither of these types of household equipment, but it must perform like the first and engage like the latter.

The conflicting identity of the IHD is one of the reasons that both past research and industry professionals have condemned it as an ineffective and inconsistent energy saving device. The IHD is too dependent on the user to act, and not dependent enough on being integrated with other parts of the home.

More recently examples of this have been successfully brought to market in the form of the ‘smart’ thermostats, which are conceivably a variation and evolution of the IHD concept. The ‘smart thermostat’ monitors, learns about and acts to resolve excessive or unnecessary use of heat energy. The IHD will struggle to compete with the recent advance in domestic handheld devices, and arguably the issue of energy saving is still too low among occupants’ priorities for the IHD to make the successful transition to being a smartphone app. The danger with transforming a standalone IHD into a smartphone app is again its inability to engage remotely with other household appliances and equipment. The IHD smartphone app would become less visual and less effective at attracting and provoking users to act on its information. This theory is supported by the findings of this thesis.

Many commentators and critics of the IHD have devalued its contribution, arguing that the standalone IHD became obsolete before smart meters could be rolled out nationally. This research supports the theory that the quality and format of information presented to the user is of paramount importance in fostering a long term relationship between the IHD and user(s). This is evidenced by the variations in energy savings seen in past IHD trials and the myriad of IHD designs used across those different research trials.

Undoubtedly the IHD is receiving less attention and it has lost its place as the foremost technology aimed at reducing domestic energy consumption. Although the IHD features prominently in voluntary ecological design standards such as Scottish Building Standards Section 7 and England and Wales Code for Sustainable Homes, it is often perceived as been largely dependent on the occupant and therefore to vary largely in the energy reduction it can secure.

As suggested by some of the participants involved in this study, a possible solution to further enhance position of this technology is to connect it to a social network. This would tune the IHD closer to its ‘lifestyle luxury’ attributes, and strengthening its ‘entertainment for engagement’ strategy to provoke behavioural change from its users. This could be realised by promoting national and/or local benchmarks of electricity and gas consumption and generating competition between communities to maintain lower levels of energy consumption. This approach was adopted by research studies in Australia, which show that encompassing a social community aspect helps to encourage behavioural change from energy consumption to recycling and reducing carbon intensive transport. This social media type forum and gamification of reduction behaviour have had success in the past for exercise and outdoor apps like the Endomondo personal trainer app, which supports activity. However, the infrastructure necessary to collect, store and update this type of neighbourhood style energy comparison would require significant investment on the part of utility companies. The smart meter programme has already highlight that involving utility companies in achieving a national target is costly, often ‘policy diluted’ and often resisted by the companies involved. Arguably, the new smart meter infrastructure and the

DSS centres could allow neighbourhood gamification of energy reduction to happen more readily.

Perhaps the most logical future of the IHD, based on the findings from this study and the review of many similar studies, is that an IHD be designed that focuses less on its ‘lifestyle luxury’ characteristics and more on its ‘lifestyle assistance’ characteristics. The IHD has shown its effectiveness at connecting to, monitoring, storing and displaying energy consumption data. If this data was handled and analysed to produce a set of computer rules, then through the advent of the IOT (internet of things), the IHD could connect to and regulate the use of certain household appliances. The smart home has been much written about and tested, and public opinion is still wary of the cost associated with and issues relating to modern controls on their electrical appliances. What is being advocated here is the use of the IHD as a home hub for energy consumption related decisions. An IHD with a learning algorithm that tracks household electricity and gas use profiles is not unrealistic. To be truly integrated as a home energy hub, the IHD would need to bridge the gap between onsite energy generation and household energy demand, and to overlay that onto a temporal profile. The IHD would need to display the energy consumption of the utility to the user and then present a list of options for the user to select, thereby giving it the ability to switch on and off or adjust the demand of many appliances and heating demands in the home remotely.

This theory comes with a host of challenges, not least of which is the interoperability and computer communication protocols required between difference household appliances and difference standards within the same types of appliances. Closing the gap between the presentation of information and the provision of actionable energy reduction options to the user would create more confidence in the IHD’s ability to define and secure energy reduction in homes.

It seems that the advent of the IOT, home access networks and abundance of WiFi technology is bringing this concept closer to reality, but the investment and agreements required by an IHD manufacturer to connect to and engage with the myriad of household appliances is significant. In the immediate term and in the build-up to the completion of the smart meter roll out, the IHD looks likely to remain a simple ‘push’ style device. Its aesthetic design may change to improve how it presents and communicates energy consumption data, but the ability of the user to use the IHD to interrogate their consumption and control their home remains a relatively futuristic feature.

7.4 Recommendations for future study

Energy consumption feedback has a strong theoretical basis which supports its effectiveness in changing levels of consumer energy knowledge and changing consumer energy use behaviour. This study was undertaken to gain additional insight into the potential effects of a specific type of direct feedback under research conditions relevant for future policy and marketplace decisions for energy and resource conservation. Feedback has typically been associated with motivational and behavioural impact measures in previous research. This study shows the potential for feedback to have a learning (i.e., knowledge) effect, which is a necessary prerequisite for behavioural change in many situations.

Tayeco LTD, the company that manufactures the Ewgeco, has released newer versions of its product which automatically transfer the consumption data from the display to an online user account. These versions of the IHD allow customers to view historical data in a graphical format. Further research and monitoring could be undertaken in a random sample of homes where the homeowners are either given access to the graphical computer data or the coloured dual fuel IHD. A control sample could also be included.

One potential problem with this experiment would be that the sub-sample of occupants with access to a graphical representation of their energy use would be limited to households with a personal computer and internet access. Additional factors would also be involved in such a study, such as the social priorities of participants and the frequency with which they chose to view their online energy monitor account. Smart devices like tablets and phones would be the most suitable medium to display this platform.

At the time of writing, no other commercially available device could monitor and display domestic gas and electricity consumption simultaneously and in real time. However, with the increase in clean tech devices and the onset of the UK government’s mandate to provide an in-home display with every electricity and gas smart meter, commercial incentives exist to encourage the arrival of further domestic gas energy monitors. The varied style of pulse availability of gas meters has been a barrier to the development of gas IHDs.

Many of the very early energy monitors showed end users a numerical display, whereas the Ewgeco IHD used in this research has a graphical display which uses a traffic light coloured system to provide a visual representation of the level of energy consumption. Research could be undertaken to compare coloured and monochrome monitors to identify whether colour displays influence the level of energy reductions, and/or support the longevity of behavioural change. In subsequent studies, researchers should compare non-graphical and graphical real-time feedback in a larger sample with controls. This research would measure the effect of IHDs with many features and function to that of a research defined ‘standard’ smart meter IHD.

The Ewgeco energy monitor has a transmission rate of two seconds, whereas other documented energy monitors transmit consumption information to the display in six or more seconds. Further research should seek to establish a standardised approach for the term ‘real time’ and investigate whether the rate at which the energy monitor receives and displays energy consumption has any influence on pro-environmental or energy reduction behaviour.

Could energy consumption information be successfully displayed on a device without the need for an independent dedicated display? With the growing number of consumer products per household, is it necessary to add another electronic item to the electricity demand? With the recent development and widespread cultural penetration of portable compact tablet computers and advanced mobile phones, perhaps the next step for in-home energy display and analysis is destined to be integration into computer application (‘apps’). With an increasing number of standalone energy displays possessing downloading capabilities and being accompanied by analytical software tools that require a computer to harness the full potential of securitising historical energy patterns, then perhaps the next step in the electronic evolution of domestic energy consumption monitoring is to become fully integrated and displayed on multipurpose, constantly on computerised devices.

Perhaps the dangers identified by Ihde (1990), Borgmann (2000) and Van Dam et al. (2010) – that the merging of many household appliances creates a disburdening effect, with appliances and equipment being designed not to impact adversely on the daily routine of people – will come into play. Therefore, if a dedicated energy monitoring display were integrated into a multifunctional device whose primary function were not to display energy consumption, it could be argued that losing the ever present instantaneous, dedicated, stand-alone energy monitor display may in fact discourage any of the behavioural change effects it may possess. At this stage in our electronic and energy conservation evolution, it may be increasingly pertinent for energy consumption levels in the home to be as prominent as possible, thereby provoking users into engaging with their own energy consumption routines and challenging their own habitual routines.

The UK domestic sector relies heavily on gas more than any other primary energy source to provide energy for space and water heating. In all, 39% of the UK's primary energy comes from gas, compared with 35% from oil, 15% from coal, 9% from nuclear and 2% from other sources. Gas-fired power plants are also the main method of power generation, generating 38% of the UK's electricity requirement.

Since 2004 and in every year since, the UK has been a net importer of gas, with imports in 2009 of gas 319 TWh higher than exports (and approximately 32% of the total gas supply). This was an increase of 12% on 2008's level of 284 TWh (26% of the total supply) and 48% on 2007's level of 215 TWh. As UK gas production continues to decline, the shift from domestic gas surplus to import dependency may leave the UK more vulnerable to supply interruptions and gas price fluctuations.

The energy pattern profiling information collected by Ewgeco will lend itself to allowing future researchers to orchestrate an understanding of tariff optimisation, which may assist in moving the UK away from imported gas as its primary fuel for heating towards alternative sustainable heat sources. It may also cause electric heating to become more affordable. This would further provide an insight into demand load patterns and how feedback could impact on the operation of low and zero carbon technologies (LZCT).

To optimise and reduce carbon emissions within a quota based system, it is necessary for an individual to observe, record and quantify their carbon emissions, in order to then forecast their future use. Optimisation is achieved through having the system co-operate with other users, recommending cooperative actions which will result in reduced emissions and encouraging activities such as trading emissions.

Future technologies, information data streams and links between appliances and monitoring suggest that the future of real time information about energy usage will potentially provide a platform for future generations to be much more aware of their energy usage and for this awareness to become a more natural part of their daily routines.

The move towards smart homes and the interconnection between household appliances, entertainment equipment, travel and security has become more of widespread topic in recent years. As previously mentioned, the IHD, with its links to direct energy consumption and generation, is well placed within the home to monitor and balance these systems. The role of WiFi, home access networks (HAN) and other communication protocols should be investigated in order to understand the role and achievability of such future smart homes. IHDs and HANs have the opportunity to increase the control of energy levels with a view of enhancing occupants’ knowledge, providing a catalyst for energy use reduction engagement and for delivering behavioural changes with a legacy.

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9 Appendix 1

First questionnaire and semi structured interview sheet, conducted with 52 occupants at the beginning of the trial, October 2010. The qualitative feedback gathered through the use of this questionnaire is presented in Chapter 6.

TSB ENERGY SURVEY

Edinburgh Napier UNIVERSITY

October 2010

REF:

[A] OVERVIEW (open ended interview section, for Ewgeco households only)

1) **Can you give me an idea of how you feel about the Ewgeco unit?**

   Prompts

   - How much have you used it?
   - What do you like about it? - advantages
   - What don't you like about it? - disadvantages
   - How easy is it to use?
   - How do you think it affects the way you use energy?
   - What do you think would make it better?
   - What other piece of equipment would you compare/associate it with
   - What kind of people do you think it's aimed at?
     - Age group

2) **What do you think the unit tells you? And why?**

Key points raised:
Difference between smart meters and energy monitor?

[B] YOUR ENERGY USE

Q1. Who is your current energy provider?

Scottish Hydro	❑	**1**	British Gas	❑	**2**
Scottish Power	❑	**3**	N-Power	❑	**4**
Green Energy UK	❑	**5**	E-on	❑	**6**
Scottish Southern Energy	❑	**7**	EDF	❑	**8**
Other: ________________	❑	**9**	*don't know*	❑	**10**

Q2. Did you switch energy supplier when you moved in?

Yes	❑	**1**	No	❑	**0**
			don't know	❑	**2**

Q3. If you answered yes, why did you switch?

Cheaper	❑	**1**	Easier	❑	**2**
Other: ________________	❑	**3**	*don't know*	❑	**4**

Q4. How do you pay your energy bills?

Direct Debit	❑	**1**	Standing Order	❑	**2**
Online, via internet bank	❑	**3**	Online, via provider's site	❑	**4**
Post (cheque / postal order)	❑	**5**	Post office	❑	**6**
Key card	❑	**7**	*don't know*	❑	**8**

Q5. How often do you usually check your gas / electricity readings?

Once a month	❑	**7**	Once a quarter (3 months)	❑	**6**
Twice a year	❑	**5**	Once a year	❑	**4**
Less often than once a year	❑	**3**	When a bill comes in	❑	**2**
Never	❑	**1**	*don't know*	❑	**0**

Q6. **How much do you pay for you energy? Fill in price for each in £ pounds and pence**

Electricity _________________ **Gas**_________________

Both _________________ *don't know* ❑ **-9**

Q7. **Do you provide accurate meter readings to your utility company?**

Before every bill	❑ **4**	Occasionally	❑ **3**
Rarely	❑ **2**	Once – when I first moved in	❑ **1**
Never	❑ **0**		

Q8. **Can you tell me how much you agree or disagree with the following statements?**

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree
a.	I understand my energy bill.	❑	❑	❑	❑	❑
b.	It is important to me to understand my energy bill.	❑	❑	❑	❑	❑
c.	I know what I pay for my energy (i.e. the tariff).	❑	❑	❑	❑	❑
d.	I like to know how much energy I use.	❑	❑	❑	❑	❑
e.	I like to know how much money I spend on energy bills.	❑	❑	❑	❑	❑
f.	I don't think too much about the energy I use.	❑	❑	❑	❑	❑
g.	I try to minimize the amount of energy I use because it saves me money.	❑	❑	❑	❑	❑
h.	I try to minimize the amount of energy I use because it is good for the environment.	❑	❑	❑	❑	❑
i.	I feel I am paying too much for my energy.	❑	❑	❑	❑	❑

Q9. [Before you got the "Ewgeco" monitor], how often do you tend to do the following?

		4 always	3 some- times	2 rarely	1 never	0 *don't* *know*
a.	Use energy-saving light bulbs.	❑	❑	❑	❑	❑
b.	Use TRV to keep radiator temp low.	❑	❑	❑	❑	❑
c	Use system thermostat to reduce temperature in the home	❑	❑	❑	❑	❑
d	Use the boiler timer to regulate when heating is used	❑	❑	❑	❑	❑
e	Close windows / put on more clothing before putting the heating on.	❑	❑	❑	❑	❑
f	Keep time in the shower to a minimum.	❑	❑	❑	❑	❑
g	Put little water in the bath.	❑	❑	❑	❑	❑
h	Boil and cook using the minimum amount of water.	❑	❑	❑	❑	❑
i	Hang clothes out to dry rather than use the tumble drier.	❑	❑	❑	❑	❑
j	Turn the temperature down on the washing machine.	❑	❑	❑	❑	❑
k	Switch off electrical appliances rather than stand-by.	❑	❑	❑	❑	❑
l	Switch off the light(s) when leaving a room.	❑	❑	❑	❑	❑
m	Other:	❑	❑	❑	❑	❑

Q10. Comparing your new home to your pervious home, can you tell me how much you agree or disagree with the following statements?

		5 strongly agree	4 agree	3neither agree nor disagree	2 disagree	1 strongly disagree
a.	My new home is easier to heat	❑	❑	❑	❑	❑
b.	My new home stays warmer for longer	❑	❑	❑	❑	❑
c.	My new home is brighter without using artificial lighting	❑	❑	❑	❑	❑
d.	My new heating system is easier to understand	❑	❑	❑	❑	❑
e.	My fuel bills are cheaper in my new home	❑	❑	❑	❑	❑
f.	My new home is more energy efficient	❑	❑	❑	❑	❑

Q11. Which of the following appliances do you have in your home? (tick all that apply) **for each item, score 1 if they have one, and 0 if they don't**.

Food orientated appliances

Fridge / freezer combined	❑	cooker (electric)	❑
Fridge separate freezer	❑	cooker (gas)	❑
Kettle	❑	Hob (gas)	❑
Toaster	❑	Hob (electric)	❑
Microwave	❑	Blender/juicer	❑
		Other: ________________	❑

Household equipment

Washing machine / Tumble Drier Combined	❑		
Washing machine separate Tumble drier	❑		
Only Washing machine	❑	Iron	❑
Vacuum cleaner	❑	Hair dryer	❑
Hair straighteners	❑	Electric tooth brush	❑
Electric heater / fan	❑		
		Other: ________________	❑

Entertainment [if yes - insert the number of each]

for each item, score how many they have (0, 1, 2, etc.)

LCD TV	❑	Plasma TV	❑
CRT TV	❑	DVD player	❑
Satellite receiver / cable box	❑	Stereo / radio	❑
Games consoles	❑	Computer / laptop	❑
Smart phone		do you use the programmer	
		Other: ________________	❑

[C] YOUR "EWGECO" ENERGY MONITOR

Q12. Have you used an energy monitor before?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q13. Have you ever used your "Ewgeco" energy monitor?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q14. If yes, how often do you tend to check it?

More than once a day	❑ **7**	Once a day	❑ **6**
Several times a week	❑ **5**	Once a week	❑ **4**
Once a month	❑ **3**	Less than once a month	❑ **2**
Only looked once	❑ **1**	*don't know*	❑ **0**

Q15. How do you feel about the monitor? Please indicate how strongly you agree or disagree with each of the following statements:

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	It is easy to use.	❑	❑	❑	❑	❑	❑
b.	I have tried a lot of the functions.	❑	❑	❑	❑	❑	❑
c.	It has made me more aware of how much energy I'm using.	❑	❑	❑	❑	❑	❑
d.	It has made me more aware of how much money I'm spending on energy.	❑	❑	❑	❑	❑	❑
e.	It hasn't changed how I use energy.	❑	❑	❑	❑	❑	❑
f.	I'm not interested in using it.	❑	❑	❑	❑	❑	❑
g.	It has made me reduce the amount of energy I use.	❑	❑	❑	❑	❑	❑

Q16. Thinking about the monitor's display, how useful have you found each of the following:

		5 very useful	4 quite useful	3 neither	2 not very useful	1 not at all useful	0 *don't know*
a.	Coloured bars.	❑	❑	❑	❑	❑	❑
b.	Energy usage in pence per hour.	❑	❑	❑	❑	❑	❑
c.	Total cost for today.	❑	❑	❑	❑	❑	❑
d.	Energy usage in "Ewgeco Unit".	❑	❑	❑	❑	❑	❑
e.	Energy usage in kWh.	❑	❑	❑	❑	❑	❑
f.	Energy usage in T kWh.	❑	❑	❑	❑	❑	❑
g.	Household carbon footprint (CO_2 / kg).	❑	❑	❑	❑	❑	❑
h.	Peak energy usage (lighting up single bar).	❑	❑	❑	❑	❑	❑

Q17. Thinking about the monitor's functions, how useful have you found each of the following:

		5 very useful	4 quite useful	3 neither	2 not very useful	1 not at all useful	0 *don't know*
a.	Independent appliance monitoring [pause function].	❑	❑	❑	❑	❑	❑
b.	Audible alarm.	❑	❑	❑	❑	❑	❑
c.	Directly reviewing the history.	❑	❑	❑	❑	❑	❑

Q18. Can you tell me if you do any of these things more, less, or about the same since you got your "Ewgeco" monitor?

		5 much more	4 a bit more	3 about the same	2 a bit less	1 much less
a.	Use energy-saving light bulbs.	❑	❑	❑	❑	❑
b.	Use TRV to keep radiator temp low.	❑	❑	❑	❑	❑
c	Use system thermostat to reduce temperature in the home	❑	❑	❑	❑	❑
d	Use the boiler timer to regulate when heating is used	❑	❑	❑	❑	❑
c.	Close windows / put on more clothing before putting the heating on.	❑	❑	❑	❑	❑
d.	Keep time in the shower to a minimum.	❑	❑	❑	❑	❑
e.	Put little water in the bath.	❑	❑	❑	❑	❑
f.	Boil and cook using the minimum amount of water.	❑	❑	❑	❑	❑
g.	Hang clothes out to dry rather than use the tumble drier.	❑	❑	❑	❑	❑
h.	Turn the temperature down on the washing machine.	❑	❑	❑	❑	❑
i.	Switch off electrical appliances rather than stand-by.	❑	❑	❑	❑	❑
j.	Switch off the light(s) when leaving a room.	❑	❑	❑	❑	❑
k.	Other:	❑	❑	❑	❑	❑

Q19. Since using your "Ewgeco" monitor, have you been influenced to change your utility provider?

Yes	❑	**1**	No	❑	**2**
Considering it	❑	**3**	Haven't thought about it	❑	**4**
I have changed Tariff	❑	**5**			

[D] MyEwgeco WEB PORTAL

Q20. Have you ever used the "MyEwgeco" web portal?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q21. If yes, how often do you tend to check it?

More than once a day	❑ **7**	Once a day	❑ **6**
Several times a week	❑ **5**	Once a week	❑ **4**
Once a month	❑ **3**	Less than once a month	❑ **2**
Only looked once	❑ **1**	*don't know*	❑ **0**

Q22. How do you feel about the "MyEwgeco" web portal? Please indicate how strongly you agree or disagree with each of the following statements:

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	It is easy to use.	❑	❑	❑	❑	❑	❑
b.	It is useful.	❑	❑	❑	❑	❑	❑
C.	I like being able to access my information over the web.	❑	❑	❑	❑	❑	❑

Q23. What did you like <u>best</u> about the "MyEwgeco" web portal? And <u>least</u>?

Key points raised:

[E] FUTURE DEVELOPMENTS

Q24. Do you have any suggestions for how to improve the "Ewgeco" energy monitor? How about in terms of how easy it is to use, and how useful it is?

Key points raised:

Q25. How likely is it that you would use the following applications in the future:

		4 very likely	**3** quite likely	**2** quite unlikel y	**1** very unlikel y	**0** *don't know*
a.	Display of your household energy consumption compared with the national average.	❑	❑	❑	❑	❑
b.	Display of your household energy consumption compared with your own "personal best".	❑	❑	❑	❑	❑
c.	Wireless communication between the monitor and PC / laptop, with continuous data storage (so no need for manual upload / download).	❑	❑	❑	❑	❑
d.	Automatic transfer of energy readings from monitor to energy provider, instead of receiving estimate bills, or providing own readings.	❑	❑	❑	❑	❑
e.	Web site accessible by mobile phone to update you on your energy consumption.	❑	❑	❑	❑	❑
f.	Ewgeco phone app to update you on your energy consumption.	❑	❑	❑	❑	❑

g.	Text messaging service to update you on your energy consumption.	❑	❑	❑	❑	❑
h.	Messaging service (text / email) to inform you that your energy consumption has passed a predetermined limit.	❑	❑	❑	❑	❑
i.	Regular email reports showing details of individual appliances' energy consumption, from worst to best.	❑	❑	❑	❑	❑
j.	Manual, remotely switching off of appliance(s) during peak energy times.	❑	❑	❑	❑	❑
k.	Manual co-ordination of household appliances to operate at certain times of day; set your own timings and appliances.	❑	❑	❑	❑	❑
l.	Automatic switching off of appliance(s) during peak energy times.	❑	❑	❑	❑	❑
m.	Automatic co-ordination of household appliances to operate at certain times of day (not allowing too many appliances to operate at once).	❑	❑	❑	❑	❑

Q26. Is there anything else you'd like to tell us about, that we haven't covered today?

Key points raised:

10 **Appendix 2**

Second questionnaire and semi structured interview sheet, conducted with 52 occupants at the end of phase 1, March 2010. The qualitative feedback gathered through the use of this questionnaire is presented in Chapter 6.

TSB ENERGY SURVEY

Edinburgh Napier UNIVERSITY

February 2011

REF:

[A] **OVERVIEW** (open-ended interview section, for Ewgeco households only)

How do you feel about the Ewgeco monitor, now that you've had it in your home for a while?

Prompts

- Used it more? – or **for the first time?**
  - **Why have you not used it?**
- Have more family members engaged with it?
- Have you used more of its functions?
- Has ewgeco become part of daily routine?
- **Using its full features, compared to using and programming the setting for DTV, heating system, other equipment**

Key points raised

[B] YOUR ENERGY USE

Q1. Since my last visit, have you switched energy supplier?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q2. If you answered yes, who is your new energy provider?

Scottish Hydro	❑ **1**	British Gas	❑ **2**
Scottish Power	❑ **3**	N-Power	❑ **4**
Green Energy UK	❑ **5**	E-on	❑ **6**
SSE	❑ **7**	EDF	❑ **8**
Other: ________________	❑ **9**	*don't know*	❑ **10**

Q3. If you answered yes, why did you switch?

Cheaper	❑	Easier	❑
Other: ________________	❑	*don't know*	❑

Q4. Have you changed how you pay your energy bills?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q5. If you answered yes, how do you pay your energy bills now?

Direct Debit	❑ **1**	Standing Order	❑ **2**
Online, via internet bank	❑ **3**	Online, via provider's site	❑ **4**
Post (cheque / postal order)	❑ **5**	Post office	❑ **6**
Key card	❑ **7**	*don't know*	❑ **8**

Q6. Have you changed how often you pay for energy?
IF YES -

Quarterly	❑ **1**	Monthly	❑ **2**
Weekly	❑ **3**	Daily	❑ **4**

Q7. Have you changed how much do you pay for you energy?
IF YES

Electricity __£_______________ **Gas**__£_______________

Or Both __£_______________ *don't know* ❑ **-9**

[C] YOUR "EWGECO" ENERGY MONITOR

Q8. Have you used your "Ewgeco" energy monitor?

Yes ❑ No ❑

don't know ❑

Q9. If yes, how often do you tend to check it?

More than once a day ❑ Once a day ❑

Several times a week ❑ Once a week ❑

Once a month ❑ Less than once a month ❑

Only looked once ❑ *don't know* ❑

Q10. How do you feel about the monitor? Please indicate how strongly you agree or disagree with each of the following statements:

		strongly agree	agree	neither agree nor disagree	disagree	strongly disagree	*don't know*
a.	It is easy to use.	❑	❑	❑	❑	❑	❑
b.	I have tried a lot of the functions.	❑	❑	❑	❑	❑	❑
c.	It has made me more aware of how much energy I'm using.	❑	❑	❑	❑	❑	❑
d.	It has made me more aware of how much money I'm spending on energy.	❑	❑	❑	❑	❑	❑
e.	It hasn't changed how I use energy.	❑	❑	❑	❑	❑	❑
f.	I'm not interested in using it.	❑	❑	❑	❑	❑	❑
g.	It has made me reduce the amount of energy I use.	❑	❑	❑	❑	❑	❑

Q11. Thinking about the monitor's <u>display</u>, how useful have you found each of the following:

		very useful	quite useful	neither	not very useful	not at all useful	*don't know*
a.	Coloured bars.	❑	❑	❑	❑	❑	❑
b.	Energy usage in pence per hour.	❑	❑	❑	❑	❑	❑
c.	Total cost for today.	❑	❑	❑	❑	❑	❑
d.	Energy usage in "Ewgeco Unit".	❑	❑	❑	❑	❑	❑
e.	Energy usage in kWh.	❑	❑	❑	❑	❑	❑
f.	Energy usage in T kWh.	❑	❑	❑	❑	❑	❑
g.	Household carbon footprint (CO_2 / kg).	❑	❑	❑	❑	❑	❑
h.	Peak energy usage (lighting up single bar).	❑	❑	❑	❑	❑	❑

Q12. Thinking about the monitor's functions, how useful have you found each of the following:

		very useful	quite useful	neither	not very useful	not at all useful	*don't know*
a.	Independent appliance monitoring (pause function).	❑	❑	❑	❑	❑	❑
b.	Audible alarm.	❑	❑	❑	❑	❑	❑
c.	Directly reviewing the history.	❑	❑	❑	❑	❑	❑

Q13. Can you tell me if you do any of these things more, less, or about the same since my last visit?

		much more	a bit more	about the same	a bit less	much less
a.	Use energy-saving light bulbs.	❑	❑	❑	❑	❑
b.	Use TRV to keep radiator temp low.	❑	❑	❑	❑	❑
c	Use system thermostat to reduce temperature in the home	❑	❑	❑	❑	❑
d	Use the boiler timer to regulate when heating is used	❑	❑	❑	❑	❑
c.	Close windows / put on more clothing before putting the heating on.	❑	❑	❑	❑	❑
d.	Keep time in the shower to a minimum.	❑	❑	❑	❑	❑
e.	Put little water in the bath.	❑	❑	❑	❑	❑
f.	Boil and cook using the minimum amount of water.	❑	❑	❑	❑	❑
g.	Hang clothes out to dry rather than use the tumble drier.	❑	❑	❑	❑	❑
h.	Turn the temperature down on the washing machine.	❑	❑	❑	❑	❑
i.	Switch off electrical appliances rather than stand-by.	❑	❑	❑	❑	❑
j.	Switch off the light(s) when leaving a room.	❑	❑	❑	❑	❑
k.	Other:	❑	❑	❑	❑	❑

Q14. Since using your "Ewgeco" monitor, have you been influenced to change your utility provider?

Yes	❑	No	❑
Considering it	❑	Haven't thought about it	❑
I have changed Tariff	❑		

Q15. Have you read the User Manual we gave you last time?

Yes, all of it	❑	Yes, some of it	❑
No	❑	*don't know*	❑

Q16. How do you feel about the User Manual? Please indicate how strongly you agree or disagree with each of the following statements:

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	It is easy to understand.	❑	❑	❑	❑	❑	❑
b.	It contains enough information.	❑	❑	❑	❑	❑	❑
c.	It has encouraged me to try out the functions. [such as alarm, pause, history]	❑	❑	❑	❑	❑	❑
d.	The energy saving tips are helpful.	❑	❑	❑	❑	❑	❑
e.	It explains what to do when I get an error message.	❑	❑	❑	❑	❑	❑

Q17. Do you feel the "Ewgeco" monitor has influenced your behaviour at all? Please indicate how strongly you agree or disagree with the following:

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	Has influenced me to reduce the amount of energy I use.	❑	❑	❑	❑	❑	❑
b.	Has influenced me to switch to a cheaper energy supplier.	❑	❑	❑	❑	❑	❑
c.	Has influenced me to change the method I use to pay my energy bills.	❑	❑	❑	❑	❑	❑
d.	Has influenced me to look at the electricity meter more often.	❑	❑	❑	❑	❑	❑
e.	Has influenced me to look at the gas meter more often.	❑	❑	❑	❑	❑	❑
f.	Has influenced me to send my meter readings to my utility company more often.	❑	❑	❑	❑	❑	❑
g.	Has not influenced my behaviour at all.	❑	❑	❑	❑	❑	❑

Q18. Do you have a smart phone, with internet access, and downloadable app's?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

[D] MyEwgeco WEB PORTAL

Q19. Have you ever used the "MyEwgeco" web portal?

Yes	❑	**1**	No	❑	**0**
			don't know	❑	**2**

Q20. If yes, how often do you tend to check it?

More than once a day	❑	**7**	Once a day	❑	**6**
Several times a week	❑	**5**	Once a week	❑	**4**
Once a month	❑	**3**	Less than once a month	❑	**2**
Only looked once	❑	**1**	*don't know*	❑	**0**

Q21. How do you feel about the "MyEwgeco" web portal? Please indicate how strongly you agree or disagree with each of the following statements:

		5 strongly agree	**4** agree	**3** neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	It is easy to use.	❑	❑	❑	❑	❑	❑
b.	It is useful.	❑	❑	❑	❑	❑	❑
C.	I like being able to access my information over the web.	❑	❑	❑	❑	❑	❑

Q22. What did you like <u>best</u> about the "MyEwgeco" web portal? And <u>least</u>?
Prompt

- **If no – why not?**
- What has influenced you to not use it?
- Do you know the advantages?
- Would you have likes to use it?

Key points raised:

[E] FUTURE DEVELOPMENTS

Q23. Do you have any suggestions for how to improve the "Ewgeco" energy monitor? How about in terms of how easy it is to use, and how useful it is?

Key points raised:

Q24. Is there anything else you'd like to tell us about, that we haven't covered today?

Key points raised:

11 Appendix 3

Third questionnaire and semi structured interview sheet, conducted with 20 occupants at the end of phase 2, October 2013. The qualitative feedback gathered through the use of this questionnaire is presented in Chapter 6.

SMART HOMES ENERGY

SURVEY

Edinburgh Napier UNIVERSITY

October 2013

REF:

(open ended interview section, for Ewgeco households only)

[A] YOUR "EWGECO" ENERGY MONITOR

Q1. Have you ever used your "Ewgeco" energy monitor?

Yes	❑	**1**	No	❑	**0**
			don't know	❑	**2**

Q2. How often would you look at the display?

More than once a day	❑	**7**	Once a day	❑	**6**
Several times a week	❑	**5**	Once a week	❑	**4**
Once a month	❑	**3**	Less than once a month	❑	**2**
Only looked once	❑	**1**	*don't know*	❑	**0**

Q3. Can you give me an idea of how you feel about the Ewgeco unit?

Prompts

- What do you like about it? – advantages
- What don't you like about it? – disadvantages

- How often does it go into the red?
    - What are your thoughts when the display shows red/green?
    - Is there anything you do differently when you see red/green?

- What do you think would make it better?

- What other piece of equipment would you compare/associate it with

- What kind of people do you think it's aimed at?
    - Age group

- If it was removed would you miss it?

Notes:

Q4.How do you feel about the monitor? Please indicate how strongly you agree or disagree with each of the following statements:

		5 strongly agree	**4** agree	**3**neither agree nor disagree	**2** disagree	**1** strongly disagree	**0** *don't know*
a.	It is easy to use.	❑	❑	❑	❑	❑	❑
b.	I have tried a lot of the functions.	❑	❑	❑	❑	❑	❑
c.	It has made me more aware of how much energy I'm using.	❑	❑	❑	❑	❑	❑
d.	It has made me more aware of how much money I'm spending on energy.	❑	❑	❑	❑	❑	❑
e.	It hasn't changed how I use energy.	❑	❑	❑	❑	❑	❑
f.	I'm not interested in using it.	❑	❑	❑	❑	❑	❑
g.	It has made me reduce the amount of energy I use.	❑	❑	❑	❑	❑	❑

Q5.Thinking about the monitor's <u>display</u>, how useful have you found each of the following:

		5	**4**	**3**	**2**	**1**	**0**

		very useful	quite useful	neither	not very useful	not at all useful	*don't know*
a.	Coloured bars.	❑	❑	❑	❑	❑	❑
b.	Energy usage in pence per hour.	❑	❑	❑	❑	❑	❑
c.	Total cost for today.	❑	❑	❑	❑	❑	❑
d.	Energy usage in “Ewgeco Unit”.	❑	❑	❑	❑	❑	❑
e.	Energy usage in kWh.	❑	❑	❑	❑	❑	❑
f.	Energy usage in T kWh.	❑	❑	❑	❑	❑	❑
g.	Household carbon footprint (CO_2 / kg).	❑	❑	❑	❑	❑	❑
h.	Peak energy usage (lighting up single bar).	❑	❑	❑	❑	❑	❑

Q6.Can you tell me if you do any of these things more, less, or about the same since you got your “Ewgeco” monitor?

		5 much more	**4** a bit more	**3** about the same	**2** a bit less	**1** much less
a.	Switch off the light(s) when leaving a room.	❑	❑	❑	❑	❑
b.	Use TRV to keep radiator temp low.	❑	❑	❑	❑	❑
c.	Use system thermostat to reduce temperature in the home	❑	❑	❑	❑	❑
d.	Use the boiler timer to regulate when heating is used	❑	❑	❑	❑	❑
e.	Close windows / put on more clothing before putting the heating on.	❑	❑	❑	❑	❑
f.	Keep time in the shower to a minimum.	❑	❑	❑	❑	❑
g.	Put little water in the bath.	❑	❑	❑	❑	❑
h.	Boil and cook using the minimum amount of water.	❑	❑	❑	❑	❑
i.	Hang clothes out to dry rather than use the tumble drier.	❑	❑	❑	❑	❑
j.	Turn the temperature down on the washing machine.	❑	❑	❑	❑	❑
k.	Switch off electrical appliances rather than stand-by.	❑	❑	❑	❑	❑
l.	Consider more energy efficient rating when purchasing new appliances	❑	❑	❑	❑	❑
m.	Other:	❑	❑	❑	❑	❑

Q7. Has ewgeco influenced you to?

		4 Yes	3 No	2 Haven't thought about it	1 Considering it
a.	Change energy provider	❑	❑	❑	❑
b.	Change Tariff	❑	❑	❑	❑
c.	Change the frequency of paying the energy bill	❑	❑	❑	❑
d.	Change the method used to pay the energy bill	❑	❑	❑	❑

Q8. Has ewgeco influenced you to?

		5 much more	4 a bit more	3 about the same	2 a bit less	1 much less
a.	Look at the electricity meter more often	❑	❑	❑	❑	❑
b.	Look at the gas meter more often	❑	❑	❑	❑	❑
c.	Send your meter readings to your utility company	❑	❑	❑	❑	❑

Q9.Thinking about the monitor's <u>functions</u>, how useful have you found each of the following:

		5 very useful	4 quite useful	3 neither	2 not very useful	1 not at all useful	0 *don't know*
a.	Independent appliance monitoring [pause function].	❑	❑	❑	❑	❑	❑
b.	Audible alarm.	❑	❑	❑	❑	❑	❑
c.	Directly reviewing the history.	❑	❑	❑	❑	❑	❑

[B] Ewgeco support information

Q10. **Have you ever used the "MyEwgeco" web portal?**

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

<u>IF YES can you tell me how!</u>

Q11. Have you had a chance to watch or read the user manual or DVD

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

<u>IF YES can you tell me how!</u>

Q12. Is there anything else you'd like to tell us about, that we haven't covered today?

[C] YOUR ENERGY BILL AND USE

Q13. Since the last visit have you switched energy supplier?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q14. <u>If you answered yes</u>, who is your new energy provider?

Scottish Hydro	❑ **1**	British Gas	❑ **2**
Scottish Power	❑ **3**	N-Power	❑ **4**
Green Energy UK	❑ **5**	E-on	❑ **6**
SSE	❑ **7**	EDF	❑ **8**
Other: ________________	❑ **9**	*don't know*	❑ **10**

Q15. <u>If you answered yes</u>, why did you switch?

Cheaper	❑ **1**	Easier	❑ **2**
Influence from ewgeco	❑ **3**	*don't know*	❑ **4**
Other: ________________	❑ **5**		

Q16. Have you changed how you pay your energy bills?

Yes	❑ **1**	No	❑ **0**
		don't know	❑ **2**

Q17. <u>If you answered yes</u>, how do you pay your energy bills?

Direct Debit	❑ **1**	Standing Order	❑ **2**
Online, via internet bank	❑ **3**	Online, via provider's site	❑ **4**
Post (cheque / postal order)	❑ **5**	Post office	❑ **6**
Key card	❑ **7**	*don't know*	❑ **8**

Q18. Have you changed how often you pay for energy?
<u>IF YES</u> -

Quarterly	❑ **1**	Monthly	❑ **2**
Weekly	❑ **3**	Daily	❑ **4**

Q19. Have you changed how much do you pay for you energy?
IF YES

Electricity £________________ **Gas** £________________

Or Both £________________ *don't know* ❑ **-9**

Q20. Can you tell me how much you agree or disagree with the following statements?

		5 strongly agree	4 agree	3 neither agree nor disagree	2 disagree	1 strongly disagree
a.	I understand my energy bill.	❑	❑	❑	❑	❑
b.	It is important to me to understand my energy bill.	❑	❑	❑	❑	❑
g.	I try to minimize the amount of energy I use because it saves me money.	❑	❑	❑	❑	❑
h.	I try to minimize the amount of energy I use because it is good for the environment.	❑	❑	❑	❑	❑
i.	I feel I am paying too much for my energy.	❑	❑	❑	❑	❑

Q21. Can you score the following statements 1 to 5

		5 Most comfortable/efficient)	4	3	2	1 Least
a.	How comfortable the house is during the summer	❑	❑	❑	❑	❑
b.	How comfortable the house is during the winter	❑	❑	❑	❑	❑
c.	Rate the energy efficiency of the home	❑	❑	❑	❑	❑
d.	Rate your own families energy efficiency	❑	❑	❑	❑	❑

Q22. In the past 12 months, have you changed the way in which you normally heat your home or use electricity to reduce your energy consumption

Yes ❑ **1**

No ❑ **0**

don't know ❑ **2**

Q23. If you answered yes, what was the influence

Advertisements ❑ **1**

rising fuel bills ❑ **2**

Fear of fuel poverty ❑ **3**

advice from friends or family ❑ **4**

Concern over climate change ❑ **5**

other ❑ **6**