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TECHNICAL ARTICLE

Impact of Emerging Interaction Techniques on Energy Use in the UK Social Housing

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End use energy efficiency and fuel poverty is one of the major issues in the UK social housing sector. It is estimated that about 10% of English households live in fuel poverty. During 2015 UK greenhouse gas emission final figures show that the net CO_2 emission was reduced by 4.1% between 2014 and 2015. This shows that the UK is on course to attain its second carbon budget with annual 2013–2015 emissions that are each below the estimated level for the period. However, the housing sector lags with a 4% increase in emissions over the same period. More work needs to be done in this sector. Householders can adopt more efficient energy use approaches and make better lifestyle choices to save money and have a safer environment.

This research addresses government priorities to reduce energy demand, meet CO_2 reduction targets, and reduce domestic reliance on fossil fuels, offering protection from price risks and fuel poverty as well as providing more affordable and comfortable domestic environments.

The proposed research paper deals with novel interaction methods on energy use in social housing and how the aforesaid issues can be reflected on. A detailed background study on existing interaction methods and ongoing development of a serious game trialled in 19 households has been carried out. It has been noted that displaying real-time utility use and indoor environmental conditions to householders increased awareness and impacted how energy is being consumed. Furthermore, the proposed paper will investigate end use energy profile pattern changes due to novel interaction methods.

Keywords: Social Housing; Fuel Poverty; Human Behaviour Transition; Serious Games; Human Energy Interaction

1 Introduction

During 2015 UK greenhouse gas emission final figures report that net CO_2 emission was reduced by 4.1% between 2014 and 2015. This shows that the UK is on course to attain its second carbon budget with annual 2013–2015 emissions that are each below the estimated level for the period (DBEIS, 2017a). This outcome re-echoes the need for more effort by the housing sector towards achieving the emission reduction target of 34% and 80% below base year (1990) level by 2020 and 2050 respectively (Parliament of the UK, 2008). Further reduction in the housing sector is expected to have a twofold effect. Firstly, it will reduce emission from the residential sector via carbon intensive activities such as cooking and heating. Secondly, it will result in a further reduction in emission from the power supply sector, since buildings account for about 40% of non- transport energy consumption in the UK and EU (Vassileva, 2012).

It is not possible to achieve the 2050 target without the alteration of home energy consumption levels (Palmer & Cooper, 2012). Consciously adopting efficient, low carbon and sustainable approaches to energy consumption is vital to achieving this goal. Much of the houses in the UK today were built at a time when the relationship between energy consumption and carbon emission was yet to be discovered and the expectation for thermal comfort was quite different (Palmer & Cooper, 2013). In the UK, steps are being taken by companies, agencies and governments to make energy more visible and intuitive to consumers and to curb the effects of inefficient energy consumption in all sectors of the economy, with the housing sector being one of the most promising. One of such steps is the rollout and installation of smart meters

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for all buildings in the UK. This rollout is part of efforts to deploy technologies that will be needed to halve emission in the 2020's (HM Government, 2011), thereby putting the UK on the path to achieving 80% cut in emission by 2050.

The smart meter technology is amongst the tools essential for providing householders with real-time information about their energy consumption rate. Previous studies have shown that display of real-time utility consumption and indoor environment conditions can result in increased awareness and better consumption habits. This paper first looks at energy performance in the UK housing sector. Subsequently, it investigates intuitive approaches that can make householders more aware of their energy use patterns and indoor conditions. Some of the project research data is also analysed to see if household actions can be related to their energy consumption and indoor environment conditions.

2 Energy Use and the UK Housing Sector

The United Kingdom's housing stock is older than that of most European countries. Many houses date back to the Victorian era (1837–1901 AD) (DBEIS, 2017b). **Figure 1** shows that as at 1990, 39% of homes in England were built before the Second World War. These houses were poorly insulated when they were built, but these was not a cause for concern because the anticipation of what indoor thermal well-being meant at that time is totally different from what it means in present times. In 1970 for instance, families lived in homes with temperatures as cool as 12 degrees centigrade. Such a temperature would be considered as cold in contemporary times (Palmer & Cooper, 2013). The rise in acceptable mean indoor temperature can be attributed to lifestyle choices (Druckman & Jackson, 2008). In the past, it was necessary for everyone to wear thick clothing even at home during the winter period. This practice is observed to have changed with people preferring to wear T-shirts rather than jumpers in the winter (Palmer & Cooper, 2013) (Druckman & Jackson, 2008).

Some literature has argued that the poor thermal efficiency of the British housing stock can delay the actualizing of its carbon emission plan (Milne & Boardman, 2000). Such opinions might have been motivated by low annual building completion and demolition rate. The annual new building completion rate in England decreased by 1% between 2015 and 2016. The figure is estimated at 35,980 which is 26% below the peak of March quarter 2007 (DCLG, 2017). The slow rate of introducing high energy performance new buildings can be remedied through refurbishment using retrofit practices (Crawford, et al., 2014).

The UK building demolition rate is 0.1% per annum. Boardman et al. (Boardman, et al., 2005) estimate that at this rate, it will take about 1,300 years for the housing stock to turnover in the UK. They also proposed a fourfold increase of the yearly demolition rate from 20,000 to 80,000.

Building structures can be improved by internal/external insulation and double/triple glazing window replacement. Furthermore, householders can enhance building performance by improving the heating system, microgeneration and replacing non-energy efficient equipment and appliances (boilers, refrigerators). Timely decisions to change inefficient home equipment can save money and reduce carbon emission from homes in the long run (Crawford, et al., 2014). Householders should also have proper understanding of their home appliances (Love 2013). Moreover, in the 1970's few families possessed all the household appliances we use in homes today (DBEIS, 2017b).

In addition, other factors that influence energy consumption in homes include: household characteristics, how much householders can afford to spend on energy, energy price and number of households. Between 1970 and 2015, the number of households have increased by 46%, while population has grown by 17%. These figures show a reduction in the number of residents per

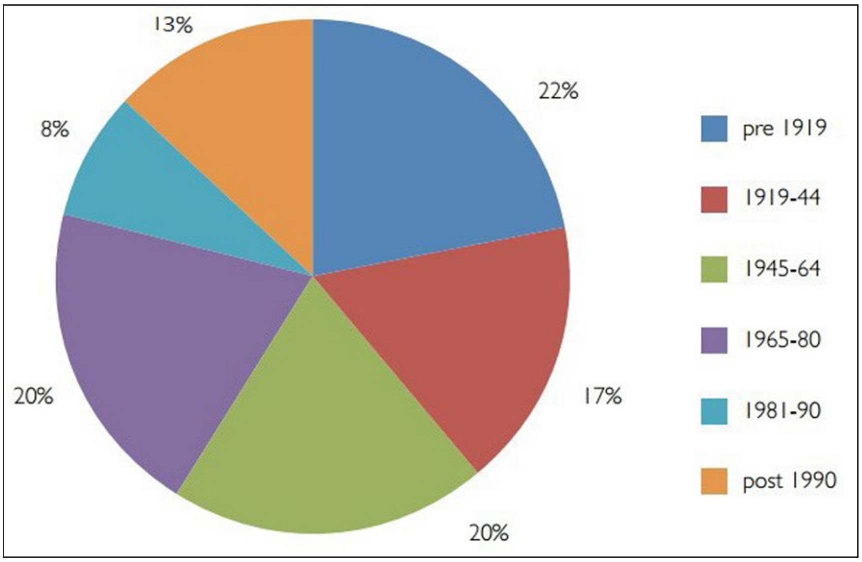

Figure 1: Age Profile of Homes in England: 2010 (DECC, 2012).

household. Hence, a reduction in consumption per household, but the rising number of households still means that consumption will stay high. Between 2014 and 2015, the consumption per household and consumption per householder increased by 2.6% and 2.8% respectively. The reason for these are rising number of lone-parent families, smaller family sizes and increase in one person households (DCLG, 2007; DBEIS, 2017b). Different tasks in the home account for varying amounts of CO_2 emission to the environment. 43% of emissions from homes are caused by space heating, this is followed by lighting and appliances which results in 42% emission, cooking and water heating produces 4% and 11% of the CO_2 emission respectively (Crawford, et al., 2014). The consumption level for lighting and appliances are high compared to others because they consume electricity from the power grid. Power grids have higher carbon discharges per unit energy produced compared to other forms of energy supply. Natural gas also contributes 70% of energy used by householders (Pyrko & Darby, 2011).

In recent years, space heating has become an area of interest for the UK government. This is evident by the amount of policies and enticement schemes, energy efficiency obligations, and the carbon emission reduction targets geared towards cutting down the amount of energy required to keep buildings warm. The government's plan is to reduce consumption through energy efficiency programmes and building regulations. They also look forward to a lower carbon regime through a transition to decentralized energy generation approaches and decarbonizing the power supply grid (Crawford, et al., 2014).

These drivers set in motion by the government have accelerated the deployment of cavity wall and loft insulations. Between March 2014 and March 2015, 410,000 homes had cavity wall insulation installed. 320,000 and 49,000 houses also had loft and solid wall insulation respectively within the same period. These additions brought the percentage of homes with insulation to 70%, 73% and 4% for loft, cavity walls, and solid wall insulation respectively (DECC, 2015). These insulations have resulted in an annual savings of over one billion pounds on national heating bills in the UK (HM Government, 2011).

3 Social Housing and Fuel Poverty in the UK

In the UK, most social housing is provided by local authorities and housing associations. Buildings in this sector are mostly controlled by government guidelines (Reeves, et al., 2010). These homes are usually meant for those in need, the unemployed or low income earners. As at 2015, 17.2% of homes in England were social abodes; 8% and 37% of these stocks were built after 1980 by the local authorities and housing associations respectively (DCLG, 2017). This houses do not meet contemporary building energy performance regulations given the time they were built. However, the social housing stock are more energy efficient than the private housing stock. (DCLG, 2017). The latest building construction guidelines expects all new buildings from 2016 to be carbon neutral; this implies that the operational energy of the buildings should stay low and be generated mostly with renewable sources (Crawford, et al., 2014).

Many social housing occupants are susceptible to fuel poverty due to the age-inflicted poor energy performance of their homes and their weak earning power. The advances by the government as mentioned in the previous section is expected to alleviate the circumstances of about 2.38 million -estimation in 2014- English households living in fuel poverty. A household can be said to be fuel poor if their dwelling cannot be kept warm at a rational price (HM Government, 2000). Fuel poverty in households is dependent on the energy performance of the home, energy cost and household income (DTI, 2006). Low income earners have been observed to pay more per unit energy consumed than higher income households because they are often incapable or reluctant to choose energy payment plans that evoke lower tariffs such as direct debit (Druckman & Jackson, 2008). In most cases, they cannot enjoy the benefits of acquiring new technologies because they cannot afford them (Jaber, et al., 2008). Furthermore, low income homes are more vulnerable to rebound effects because their energy consumption is insatiable due to high demand for heat (Milne & Boardman, 2000).

It is also worth noting that improved housing stock can lessen health disparity amongst householders in the UK. It can also save the government over 1 billion pounds spent by the NHS on people who live in poor housing conditions (Marmot, 2010; Nicol, et al., 2015).

4 Household Energy Interaction Techniques

Low carbon and safe energy regimes can be attained through innovation and behaviour change (Darby, 2006; Fischer, 2008; Abrahamse, et al., 2005). Structural and non-structural intervention approaches were used by Ting et al. (Ting, et al., 2011) to represent this regime transition. They went ahead to posit that the structural approach uses technology, instruments, tools and alternative sources of energy for conservation while the non-structural approach targets user perception, cognition, knowledge and behaviour. These two methods complement each other and cannot be effective in isolation. Behaviour change is vital because humans are the primary consumers of energy while technological innovations are meant to provide these humans with information and awareness that will bring about the change in habits. More importantly, an understanding of human energy behaviour is imperative for the design of energy conservation tools. Studies have shown that technology consumers do not utilize ready-made technologies inactively, but are active decision makers in what roles technologies play (Skjølsvold, et al., 2017).

Mixed feelings trail the intervention studies carried out so far by researchers. The outcomes show that interventions geared towards informing and prompting energy consumers to change their behaviour can promote energy conservation. Savings of between 0% and 20% were recorded. These studies used single intervention methods or a combination of several of them to achieve their results (Abrahamse, et al., 2005; Darby, 2006; Fischer, 2008). Abrahamse and colleagues grouped the various intervention approaches into antecedent and consequent intervention. The antecedent approach tries to influence the underlying behavioural determinants (e.g. knowledge) of humans, and by doing so ends up also influencing the behaviour of the subjects. Commitment, goal setting, information and modelling are some of the methods that fall under the antecedent approach (Abrahamse, et al., 2005). Consequent interventions could imply behavioural change prompted by an individual's receipt of information on their level of performance based on an expectation, e.g. feedback. It could also be a show of appreciation or discontentment to individual because of a pleasant or unpleasant behaviour, e.g. rewards, penalties (Abrahamse, et al., 2005).

Computerized feedback system provide consumers with interactive and intuitive information about their consumption, helps them set consumption targets and in some cases, offer them tips on how to reduce consumption. Feedback can be offered to householders using smart meters, dashboards, in-home displays, energy consumption displays or energy management systems (Abrahamse, et al., 2005). In general, these devices fuse all vital information about end-user consumption on a screen. The information allows users to monitor and scrutinise activities that will bring about better energy use decisions. Contemporary displays have been observed to contain real-time electricity use, estimated electricity cost, carbon emission commensurate to the electricity consumed, historical and social comparative data (comparison of a user's present consumption against previous and other householder's consumption). These technologies were successful because the feedback was given frequently over a long time, had multiple options; some of them provided appliance specific breakdowns and presented the information in a clear and intuitive manner (Darby, 2006). Other design dimensions as highlighted by Fischer include accuracy; content and metrics; presentation medium and mode; historic and normative comparison and provision of additional information, comparison and instruments (Fischer, 2008; Darby, 2006).

The benefit of portable displays is being able to place them in a location most useful to the householder, but it also increases the possibility that the display will be put in a drawer or a room that is only used by one person (Hargreaves, et al., 2010; Snow, et al., 2013).

The design background for these technologies is vital because participants could easily disengage from active studies or interventions due to poor display (Nilsson, et al., 2014). Poor displays are inevitable when users are not involved in the interface design process (Fischer, 2008). Human energy interaction design is not a one size fits all. Appeals could differ across demographics. For example, what is preferred by aged persons might not be for younger people, same also goes for different genders. Therefore, there is a need for interface designs to be people-oriented.

Serious games and gamification is becoming a new focus for researchers in human energy interaction. The use of games for learning is not a new idea. Traditional board games and role playing have proved to be useful for formal learning in the classroom environment (Egenfeldt-Nielsen, et al., 2008). Learning through games offer humans the opportunity to imbibe knowledge by doing, as a substitute for learning by reading or listening. Game-based learning stands a chance in human energy behaviour transition because most behaviours that people exhibit are consciously or unconsciously inspired by examples (Bandura, 1971). Serious games use gaming technologies to fulfil educational or training purposes. Stone (2008) defines serious games as 'games with a purpose. They move beyond entertainment per se to deliver engaging interactive media to support learning in its broadest sense'. Serious games are expected to have a learning objective, interactive engagement and a gaming element. They should also possess basic motivational components such as challenge, curiosity, fantasy and control (Rieber, 1996). Serious games have been used for learning in real-world contexts such as work productivity and product quality (Williams & Smith, 2009), cultural training (Froschauer, et al., 2010), medical prevention (Read & Shortell, 2011), scientific research (Bainsbridge, 2007), farming (Fisher, et al., 2012), K-12 education (Mayo, 2009), and national security and foreign relations (Subrahmanian & Dickerson, 2009).

Knol and De Vries (Knol & De Vries, 2011) carried out a study amongst secondary school students using a serious game called Enercities. The study was aimed at making the students more environmentally aware and to conserve more energy at home. This study proved to increase awareness and more positive attitude towards everyday life energy related behaviour. This result is backed by the fact that young people are more receptive to visual as opposed textual information (Bennett, et al., 2008).

A similar study by Reeves et al. (Reeves, et al., 2015) using social games also corroborated Knol and De Vries's work. Social games are games that are tied to social media platforms such as Facebook. In their study, Reeves et al., were optimistic that social games offer a novel context that could make home energy information simple and interesting. They stated that games draw more attention because of their prevalence, accessibility, emotional engagement and entertainment. The outcome of the 60 days' study showed a decrease in energy consumption amongst the participants.

5 Study Participants

Clusters of properties in the Midlands of England were targeted for this trial. 19 households took part in the trial. **Figure 2** is a map showing the towns and the number of households partaking in the study. **Figures 3** highlight householders' information while **Figure 4** is a summary of participants' housing typology. Householders' employment status as seen on **Figure 3b** clearly indicates that more of the participants are low income earners, since 52% of them are either unemployed or retired. The retired are likely to be on pensions with the unemployed on social support. 15 out of the 19 households use gas as their source of heating while 4 households use solely electricity as their source of heating.

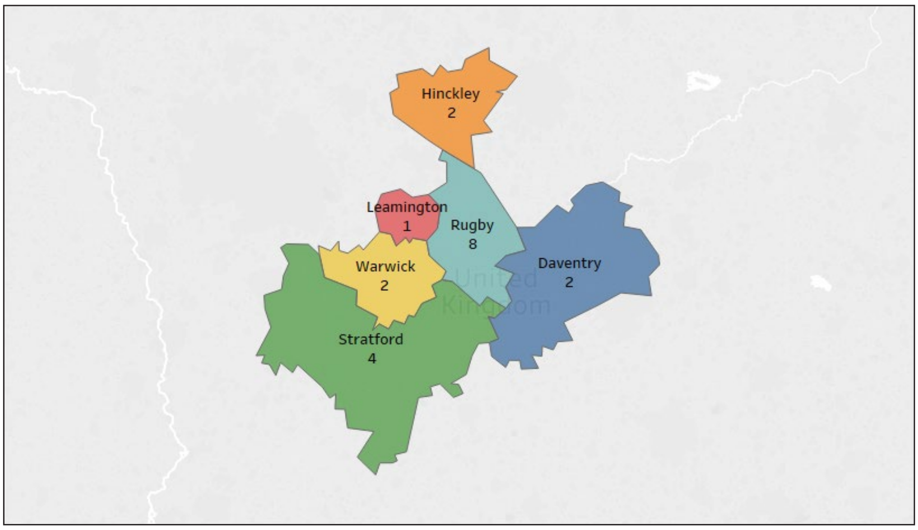

Figure 2: A map showing number of participants per town.

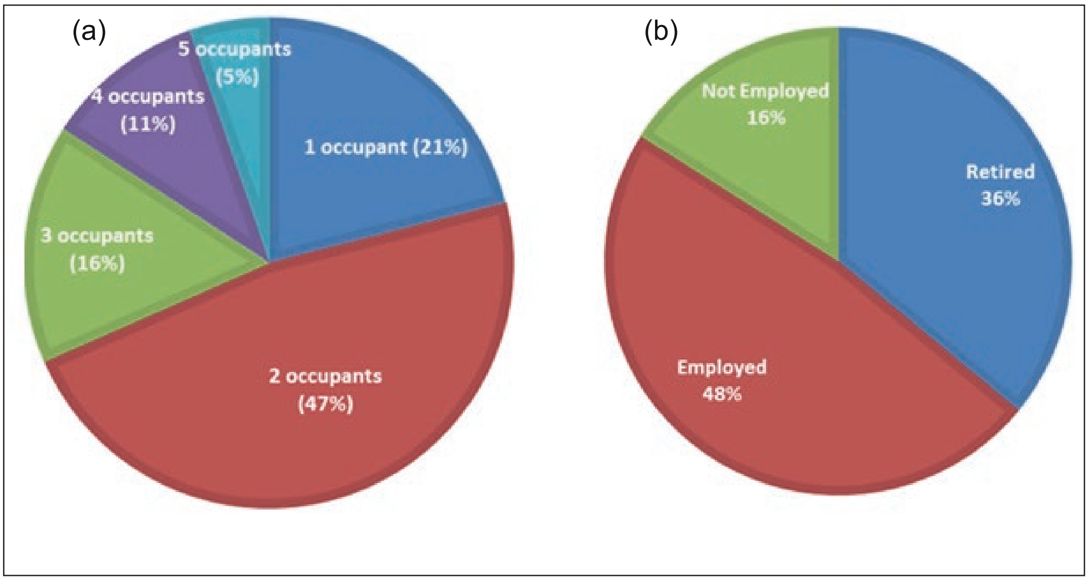

Figure 3: Demographics of selected housholds **(a)** number of occupants and **(b)** employment status.

5.1 Study Method

The purpose of the project is to establish a correlation between everyday routines and behaviours, utility consumption expenses and indoor environment conditions. To achieve this aim, an assessment of Human Energy Interaction trends and best practices was carried out. This was followed by the design, development and acquisition of the tools required for the adopted technique (**Figure 5**). The designed and developed technologies (dashboard and serious game) went through a usability test before adoption. Susequently, householders were provided with dashboards that displayed real-time energy consumption and estimated energy use cost. The dashboard also provided information on carbon dioxide, humidity and temperature levels within the indoor environment and compare consumption rate between two consecutive weeks. Energy use information (electricity and gas) were captured from the homes using meters installed by the utility providers, while sensors were used to monitor the indoor condition of the homes. Participants were provided with a 3D serious game to provide them with tips on better household management and energy use opitimization approaches. The interfaces of the dashboard and 3D serious game can be seen on **Figures 6** and **7** respectively. At the beginning of the intervention, the research target group were contacted by a partner social housing provider through emails and text. Interested households completed an expression of interest form.

This was followed by a home visit to ensure that the meters in the proposed participants' homes were compatible with the monitoring equipment. During this visit, a survey was also conducted. Householders were provided

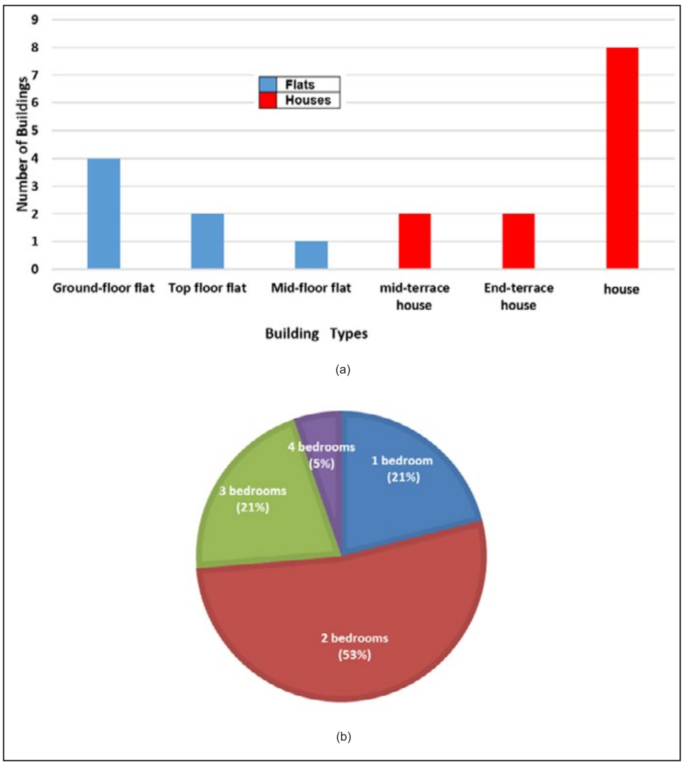

Figure 4: Types of building used for the trial **(a)** build type **(b)** number of bedrooms.

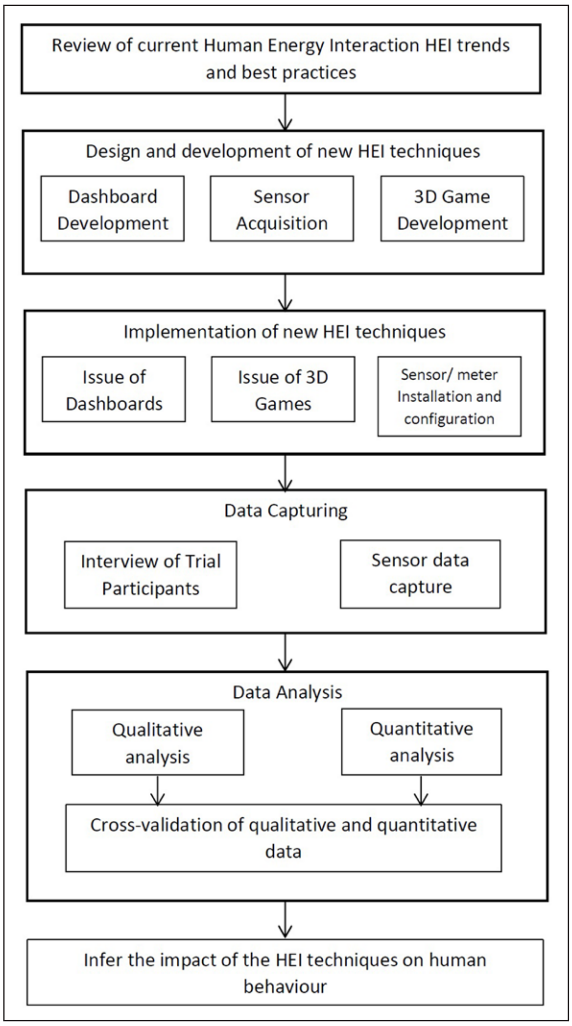

Figure 5: Summary of study processes.

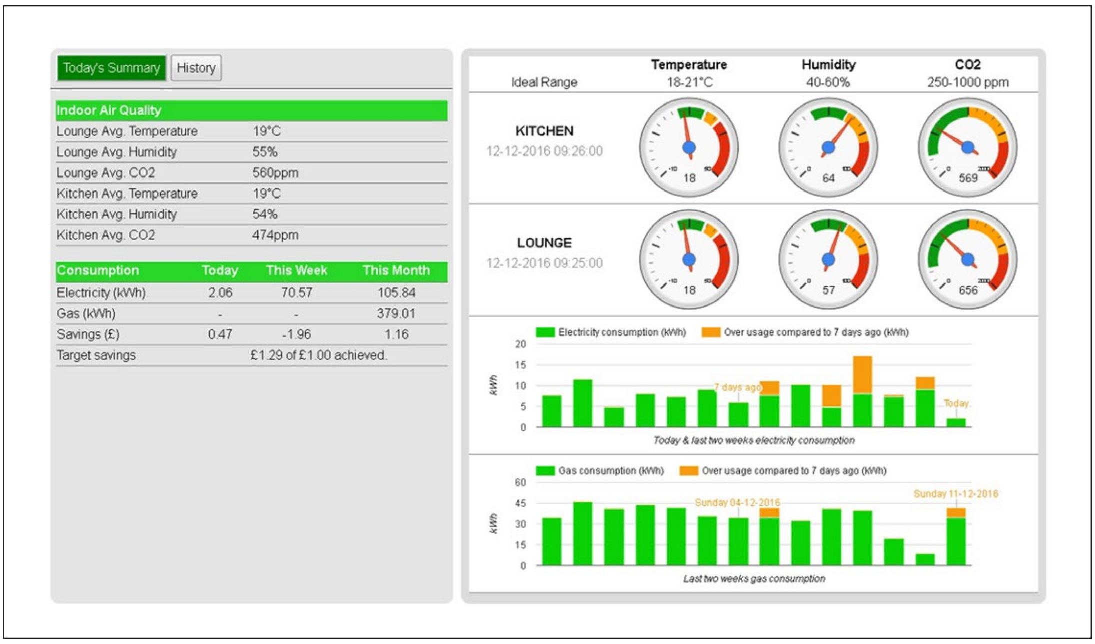

Figure 6: Dashboard interface for end user.

Figure 7: 3D serious game interface.

with information packs and asked to sign an agreement if they wanted to take part in the trials.

The study is designed to capture qualitative and quantitative data. Qualitative data is being gathered with the use of semi-structured interviews and activity diaries. Meters and sensors are used for acquiring quantitative data. Sensors were set up in the lounge and kitchen areas of the homes to capture temperature, humidity and CO_2 levels in these parts of the homes. Observation is also being made on the engagement of participants with the dashboard and serious game. Nevertheless, this paper only presents the analysis of some quantitative data.

5.2 Data Analysis

Readings from the sensors are received several times every hour. The raw data is stored on a remote database. It is subsequently cleaned, analysed and visualized. For the purpose of this paper, some preliminary data from a typical trial household is visualised below. This house is a four bedroom (one converted garage inclusive) semi-detached house with four occupants (two adults and two children) and a fifth adult occupant who joins the family during the university holiday. The householders had been provided with a dashboard and 3D serious game at the time the data was collected. These tech-

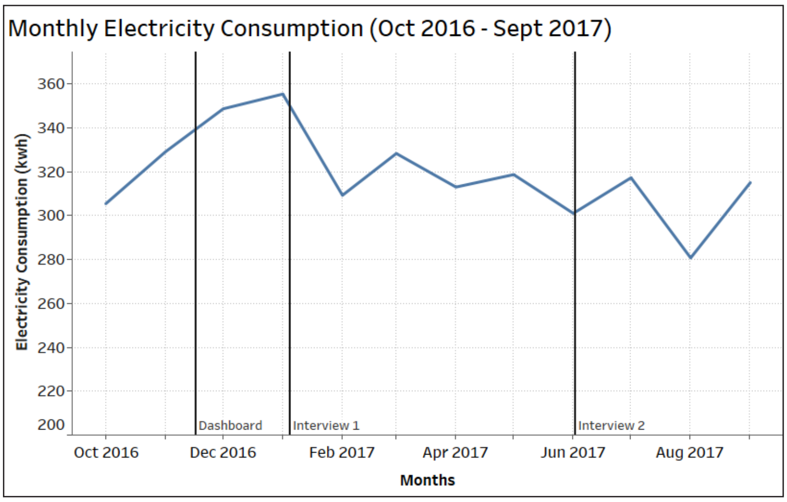

Figure 8: Monthly electricity consumption profile within a typical house.

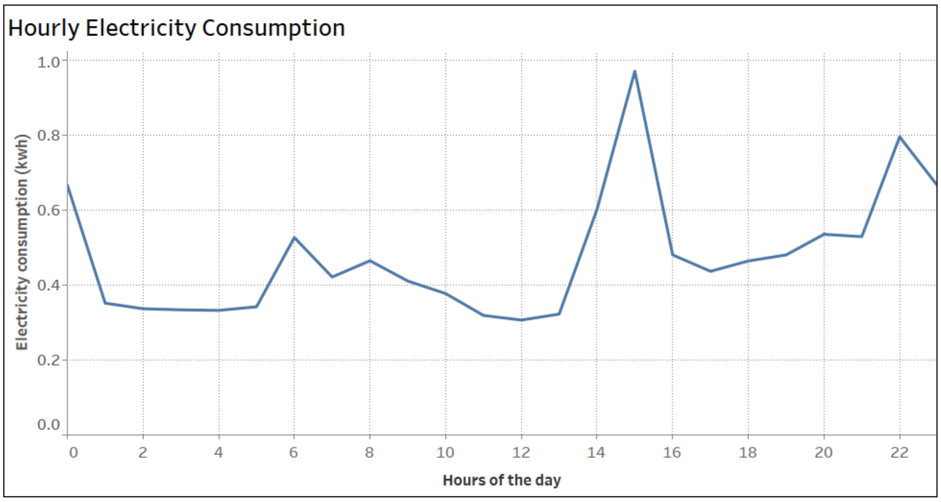

Figure 9: Hourly electricity consumption pattern within a typical house.

nologies are expected to make them more aware of their environment.

Figures 8 and **9** are visualizations of electricity consumption for periods of one year and one day respectively. The average hourly temperature within the kitchen of a household during a typical day can also be seen on **Figure 10**. **Figure 8** further indicates the times that several interventions were introduced to the householders. **Figure 8** suggests that there is a relationship between the electricity consumption and the seasons, given that electricity use increased steadily from the month of October and peaked in January which is known to be one of the coldest months in the year. February saw a dip in electricity use. This reduction in consumption could be attributed to the interview session held in January 2017 as indicated on the chart.

In addition, **Figures 9** and **10** can be said to have provided some insight as to how sensor data can be linked to the lifestyle of householders. The graphs can be said to indicate the following.

Sleeping time: as shown in both graphs, this period is likely to be indicated by the continuous drop in electricity consumption from about midnight to about 06:00. Electricity use was observed to drop after 22:00 which is most likely when appliance were switched off and householders went to bed. In a similar vain, the temperature in the kitchen dipped after midnight until 07:00, this could have been sleeping time for the occupants. Householders can also be said to have rounded up their activities in the kitchen and retired to the sitting room or bedroom at about 19:00 as shown on **Figure 10**.

Waking time: **Figures 9** and **10** indicates that activities resumed in the house at about 06:00. The rise in electricity use could indicate wake up time while the rise in temperature could be householders preparing their meal for breakfast.

Daytime activities: the rise in electricity use was minimal until about 14:00 and 15:00. Temperatures also rose at about 16:00, this temperature increase could be as a result of the energy intensive activity carried out earlier. An activity such as cooking could have resulted in such spikes in electricity use and temperature. Another factor that can affect indoor temperature is the outdoor temperature and the likelihood that occupants left the kitchen windows open to let fresher air in. The spikes in temperature at 17:00 and 18:00 could indicate meal preparation times. The frequent activities during the day as indicated

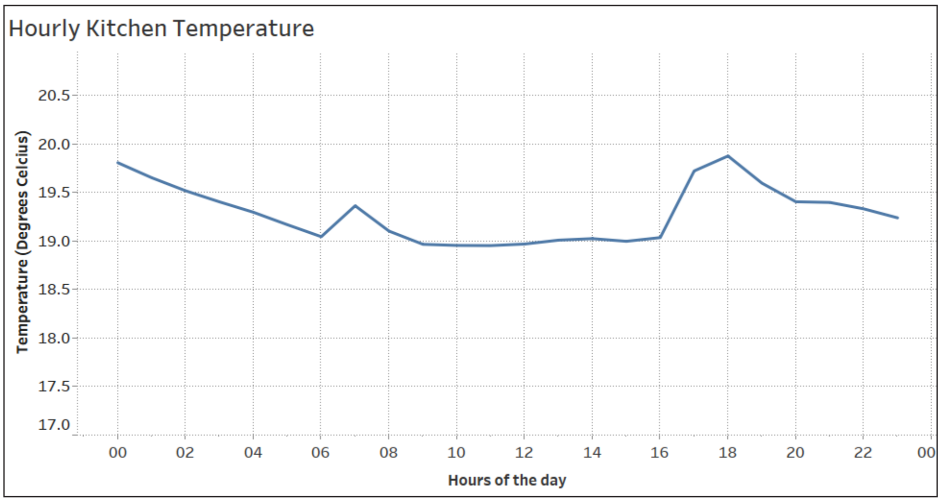

Figure 10: Hourly kitchen temperature within a typical house.

by **Figure 9** shows that the house was occupied most of the day. The fall in values between 11:00 and 13:00 could indicate naptime; it could also imply that the house was vacated for the period.

6 Conclusion

This paper presents preliminary results from a research study that aims to relate presumed daily human activities to energy consumption and indoor environmental conditions. For this study, feedback is provided to householders on a dashboard while a 3D serious game was used to provide tips and guide to better home management behaviours. It is premature to pronounce the effect of these tools since the trial is ongoing and the entire data is yet to be analysed.

However, we can see from the analysis shown on **Figures 9** and **10** that our daily actions and inactions have some effect on our electricity consumption and the condition of our indoor environment. Although activities such as cooking, dish washing, clothes washing and drying, bathing and floor cleaning are all necessary; they can also influence the temperature, moisture and CO_2 balance within the indoor environment. Extreme imbalances can result in discomfort and several other negative health consequences.

The average suitable indoor temperature, CO_2 and humidity stand at 18–21 degrees Celsius (Hartley, 2006), 250–1000 ppm, 40–70% (CIBSE, 2006) respectively. For instance, a fall in humidity can expose home occupants to static electricity while when in excess can result in condensation and mould growth, and several building related illnesses. Building fabrics can also lose their thermal insulation because of high moisture. Similar consequences can also be experienced with temperature and CO_2. In the long run, all these do have huge financial implications.

The place of better energy use approaches and awareness amongst householders cannot be over emphasized. Simple practices such as using the sun as a source of heat (instead of a heater) on a sunny afternoon, opening windows to allow fresher air into the house (instead of an electric fan or air conditioner), unblocking of radiators and drying clothes outside the house can afford us better indoor conditions at no financial cost. The use of more appliances for these simple tasks cost money and also increases annual energy expenditure. These approaches can help householders to spend less on energy and still have comfortable lives.

Disclaimer

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Competing Interests

The authors have no competing interests to declare.

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