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An innovative energy efficiency application development: through the evaluation of occupants' behavioural issues and its impact on domestic energy consumption in the UK

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Abstract: The research investigates the reason why low-carbon retrofit programmes always may not meet expectations. It is explored by focusing on a series of 'hard-to-quantify' factors, especially the energy-related behaviours and their impact on energy performance. The research assumes that the abovementioned parameters have not been thoroughly taken into consideration for optimising domestic energy performance. This is also the cause of the phenomena of 'Building Performance Gap (BPG)'. To cope with this issue, the correlations between occupants' behaviours and energy performance are investigated by adopting a mixed research methodology where questionnaire survey and the review of energy efficiency tools were carried concurrently to collect and analyse quantitative and qualitative data. The data collected is mainly quantitative but supplemented by qualitative data from a few open questions and in-depth interviews. This paper primarily focuses on the research survey design and how the required data was collected and analysed to help achieve the research aim. The preliminary data analysis was also presented in order to draw a general picture of the conditions of social housing in London. The issues encountered during the distribution of the questionnaire were also discussed in order to inform relevant future studies. At the end, the found correlations could help to form an innovative smart phone application in order to adjust occupants' energy-related behaviours and provide incentives in taking up the low-carbon retrofit projects. Thus, reducing the BPG and increase energy efficiency in the UK housing sector.

Keywords: domestic building, home energy performance, occupants' behaviour, questionnaire survey, energy efficiency application

Introduction

The reasons of climate change are diverse and over-consumption of energy generated from burning fossil fuels is considered one of the major causes (Liu et al, 2016). The importance of reducing CO2 emissions has been realised for a few decades. Governments establish energy policies and protocols to regulate energy consumptions in different sectors. In Kyoto Protocol, UK agreed to achieve 12.5 per cent CO_2 reduction by 2010 comparing to its emissions in 1990 (United Nations, 1992). In the domestic level, UK also sets out a 15 per cent energy reduction rate by implementing renewable technologies by 2020. Besides, a further CO_2 reduction of 80 per cent compared with 1990's level was also vowed by the UK government by 2050 (UK Renewable Energy Roadmap, 2013).

Residential sector, as one of the primary energy consumers (almost 30 per cent of the total energy), is in focus by the UK government. A recent report (Environmental Change Institute, 2005) demonstrates that the growth of energy demands in the residential sector has been much higher than other sectors between 1990 and 2003. In addition, housing energy demands have increased by 32 per cent since 1970 mainly deriving from heating which makes up 60 per cent of overall energy consumptions.

The research focuses on increasing the efficiency of low-carbon retrofit in existing UK homes. A number of case studies were examined in this paper Besides, occupants' socio-economic characteristics, energy consumption behaviours and their impacts on energy performance were also investigated. In a further step, the study attempts to consolidate the role of smart metering devices, and technology towards occupants' energy-related behaviours, thus regulate these behaviours by designing an innovative smart phone application at energy end-users' level.

Research context: Low-carbon retrofit and occupants' behaviour

In order to meet the CO_2 emission reduction target (80 per cent) by 2050 (Climate Change Act, 2008), the UK government has tightened its energy regulations to pace up the progress (DCLG, 2013a). As stated by Dowson et al (2012), policies were also released to increase the incentive of taking up low-carbon retrofit programmes such as the Feed-in Tariff (Fit), the Green Deal, the Renewable Heat Incentive (RHI), the Decent Homes, etc. The past and current retrofit projects have been assessed with their success and falls. Several research studies suggest that retrofit projects need to be widely spread to be efficient and effective (Webber et al., 2015; Smith and Swan, 2012). Besides, occupants' socio-economic factors need to be taken into consideration (Ma et al, 2012). In a few cases, the retrofit works were criticised for the lack of quality which may lead to the failure of the project (Gilbertson et al., 2008; Long et al., 2014; LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2014). The case studies adopted in this research are either currently under retrofit constructions or expected to be retrofitted in the future. The review of the previous retrofit case studies will help to well understand the government's 'top-down' retrofit approach. Abovementioned issues are also focused and investigated in this case study during the research.

Notably, domestic energy performance is also subject to how occupants operate their homes, especially the heating control systems. So a wider range of 'hard-to-quantify' variables will affect energy performances such as occupants' socio-economic and behavioural aspects (Greening et al., 2000; Khazzoom, 1980; Saunders, 1992). The Building Performance Gap (BPG) stands for the differences of domestic energy performance between design and as-built. The detailed explanation was also demonstrated by Sunikka-Blank and Galvin (2016) that the BPG includes two types: the 'prebound effect' where designed energy performances is more than as-built performances and the 'rebound effect' where occupants use more energy than expectations. In order to avoid the 'rebound effect', the 'hard-to-quantify' factors need to be taken into consideration in diverse approaches to try and draw helpful correlations for reducing energy consumption (Sorrell and Dimitropoulus, 2008; Hadjri and Crozier, 2009; Preiser et al., 1988; Zimring and Reizenstein, 1980; Chiu et al., 2004). Suggestions are also given in some recent reports (LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2012 and 2014) on how to regulate occupants' behaviour for more efficient energy consumptions, such as the introduction of smart meters/IHDs and stronger interaction between construction team, professionals and the occupants.

Energy efficiency tools and applications in the domestic sector

In the UK, the transition of energy network is currently taking place where Advanced Metering Infrastructure (AMI) is widely adopted. Smart meters and In-House Displays (IHDs) in each home help energy end-users effectively understand, appreciate and manage their energy consumptions (The Cabinet Office et al, 2011). Through different case studies, researchers who affirm the positive role of AMI and smart meters include Gans et al (2013), Stromback et al (2011), Wesley Schultz et al (2015) and Zhang et al (2016). The installation of pre-payment meters helped to reduce 11 to 17 per cent of electricity consumption in an experimental large scale case study (Gans et al, 2013). Recent report (Stormback et al, 2011) also indicates a 5.13 to 8.68 per cent energy consumption reduction among 100 pilots in Europe. However, it was also proven inefficient in some of the case studies (Rajagopalan et al., 2011; Schultz et al., 2015; Carroll et al., 2014; Hargreaves et al., 2017) due to privacy invasion and the extra energy consumptions on AMI and smart meters. In detail, occupants' personal energy data, and even their habits and energy use signatures will be unintendedly published (McDaniel, 2009). Furthermore, a number of scholars (Schultz et al, 2015; Carroll et al, 2014; Hargreaves et al, 2017) suggested not only rely on smart meters and IHDs but also carrying out occupant trainings and close interactions with them as the combined approaches to achieve energy effeciency.

Although some of the occupants' socio-economic and behavioural aspects are unquantifiable parameters (Sunikka-Blank and Galvin, 2016), the correlations of these factors and energy performance can be analysed and demonstrated in equations. The found implications could be one of the important components of the future energy management system and act as an energy efficiency application in the smart phones. In addition, energy efficiency applications are developed based on the smart metering devices to help occupants understand their energy consumption patterns and save energy effectively (Zhang et al, 2016). As energy companies are responsible for the roll-out of smart meters, they developed energy efficiency apps for their own customers such as British Gas app, EDF Energy app and E.ON app (British Gas, 2017; EDF Energy, 2017, E.ON UK, 2017, Npower, 2017, and Scottish Power, 2017). Energy providers' applications all tend to provide easy and convenient customer experiences, thus have similar functions and aspects. Apart from that, applications developed by European and International specialised companies also include efergy engage, OVO and Homeselfe (OVO Energy, 2017; apkpure, 2017; efergy engage, 2017 and Homeselfe, 2017). A comprehensive comparison of abovementioned applications was carried out by Shi et al (2017) that applications developed by specialised companies are more innovative than the ones developed by major energy providers in the UK as more interesting aspects are found from them, such as 'retrofit comparison scenarios', 'behavioural suggestions' and 'energy performance mock-ups'. Although the more innovative and advanced aspects in applications are significantly recognized (Barrett, 2016), they have not been widely implemented and incorporated into the existing energy management systems.

Research methodology and survey design

The research asserts that a series of 'hard-to-quantify' factors, especially occupants' behavioural issues, have not been thoroughly considered for home energy performance. Thus, the correlations between those factors and home energy performance need to be investigated by employing a mixed research design where questionnaire survey and review of energy efficiency tools were carried out concurrently. Data collected will be mainly quantitative but supplemented by qualitative data from several open questions and in-depth interviews. Then Statistical Package for the Social Sciences (SPSS) is employed to find the potential correlations. On the other hand, the review of the energy efficiency tools has been performed to inform the design of the innovative smart phone application. The purpose of designing the questionnaire is to effectively extract data from respondents (Hague, 2006). It aims to prevent the questions being asked in a random way by keeping a structured, systematic order of questions. The design of the questionnaire also needs to ensure that the data is processable and with minimal or no errors (Dornyei, 2003).

The questionnaire aimed to collect participants' attitudes towards low-carbon retrofits, as well as household profiles and their lifestyle patterns. It also aimed to gather a wide range of necessary information from the participants for the later data analysis, such as their housing conditions, energy use patterns, energy-related behaviours, energy conservation awareness, and occupants' attitude on energy efficiency application. The majority of the questions were designed with dichotomous, multiple choices and rank order scaling questions. In the condition of acquiring sufficient information, these questions are easy to be processed in the next stage of data analysis. However, in order to get more comprehensive data, open-ended questions were also asked so as to probe into more details (Mathers et al, 2009). The questionnaire is divided into four sections in order to capture different types of required information. To understand the housing conditions, structured questions was designed to record and understand basic conditions of the dwellings including room numbers, room types, building services, walls, roofs, materials of openings and any damaged and issues occupants have experienced. Household profiles were also asked in the questionnaire with structured questions to collect demographical data. In addition, the semi-structured questionnaires were developed in order to understand the occupants' attitude and awareness towards low-carbon retrofit and their behavioural preferences. For example, occupants were asked to explain if they have changed their energy suppliers or energy plans. They were also asked to write the reason if they do not open extractor fans when take the shower which is an effective way to improve indoor environment quality. Besides, occupants were asked if they think they have used more energy than they should and why.

Data collection and analysis

The data collection was carried out in the manner of door-to-door questionnaire distribution. The collected data were then analysed to investigate the potential correlations between socio-economic/behavioural factors and home energy performances. Questionnaire distribution has been completed by August, 2017 targeting two social housing estates in the Borough of Newham. The data analysis is currently ongoing. The consequent sections explain the recent data analysis and demonstrate a few initial key inferences.

Distribution of questionnaires

Both of the target estates was built as an affordable housing with low rents for the people who are struggling with their housing costs. The first estate is currently under refurbishment that was carried out by the appointed contractor. The project is aimed to deliver energy-efficient insulations internally and externally in two phases. The first phase of the refurbishment focusing on the interior has been completed by the end of 2016. The second phase of the work focusing on exterior insulations has been started and expected to be completed by the end of 2017. The block does not have a basement floor but a roof terrace. The occupants in the tower block are suffering certain degrees of issues such as damp, cold, draught and condensation. The second estate was built by 1967 with 23 storeys. Externally, the estate is clad in asbestos cement panels painted various shades of blue. For healthy and safety purposes, the external panels of the tower block were jet washed in 2012 which has taken away the original paint finishes and part of the construction sealing. The problems occurred has been aware by the Council and the planned improvement work is on schedule.

The data collection process started in April, 2017 and was completed in August, 2017. Two housing estates in the Borough of Newham were taken as the research samples for the roll-out of questionnaires. The research started with the first estate with forty-four flats during the first 2 months of the investigation and then continued with the second one with one hundred and nine flats during the following months. From the first housing estate, 18 flats have completed and returned the questionnaires while 32 flats have completed and returned questionnaires from the second estate. The research findings based on the collected data are presented as below.

Based on the records presented above, the response rates of the questionnaires between the two estates are different. A few internal and external factors affecting occupants' willingness of collaboration were identified and discussed as below. Besides, lessons learnt and potential improvement for future questionnaire distribution approaches are also noted.

The response rate at the first estate is 40.9 per cent which is much higher than the second estate (29.4 per cent). There are a few aspects proving that occupants at the first estate are more cooperative than the second estate: their social, economic and personal issues determine whether or not the researcher can have an opportunity to speak to them and also determine the difficulties of convincing them taking up the survey. In detail, households with more full-time employed family members tend to spend less time at home, especially in the day time. So the researcher has less opportunity to meet them in person. Besides, occupants with different cultures and religions may not like to open their door and speak to the strangers, especially male researchers. In addition, according to the conversations with households and local staffs, there are many disabled and occupants in need of care living at the second estate. That also increases the difficulties of completing the questionnaires. The external factor that impact on the response rate is the cooperation of on-site contractor. It is a driving factor that leads to a high responding rate at the first estate. As mentioned previously, the refurbishment work was being undertaken on-site at the time of questionnaire distribution so the contractor has been able to keep a close relationship with all local occupants. Coffee meetings were held regularly to receive feedback from occupants and provide them with updates concerning the latest construction progress. Besides, as the research was carried out in parallel with the construction work, occupants tended to be more cooperative due to the word-of-mouth dissemination about the research undertaken.

The one-way data analysis

The questionnaire is separated into four sections exploring the issues affecting home energy performance, such as housing conditions, energy use patterns and behaviours, energy efficiency applications, and occupants' socio-economic characteristics. A review of the initial data analysis is hereby presented with the details of some key findings.

Quarterly electricity and gas bills

Occupants are also asked to provide their quarterly electricity and gas bills in the questionnaires. It is found that each household uses almost the same amount of electric and gas. In general, households' gas bills may slightly higher due to high gas demands in the winter.

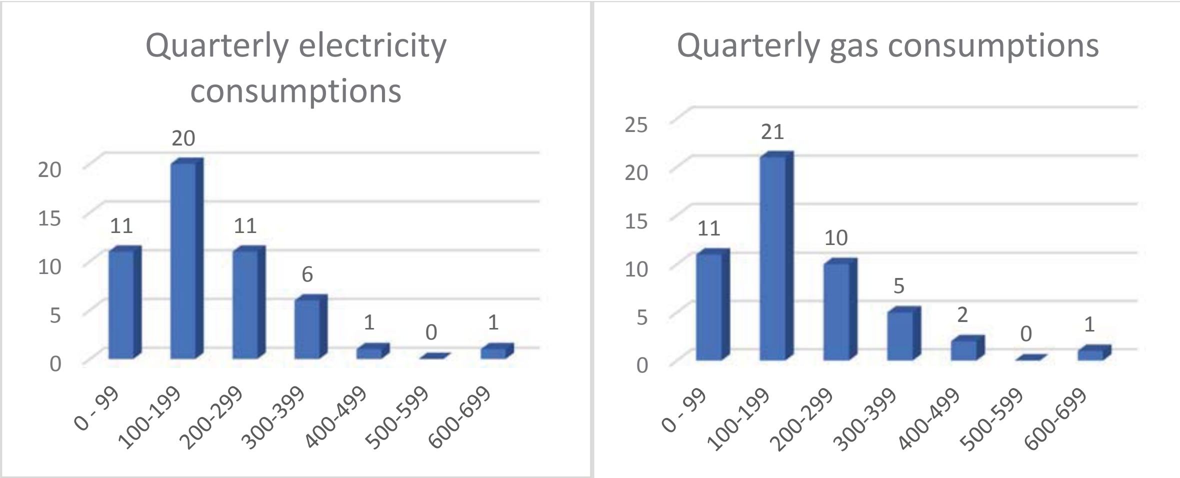


Figure 1. quarterly electricity bills Figure 2. quarterly gas bills

Among the participants, 22 per cent of them have their quarterly electricity bills within £0-£99; 40 per cent of the households pay their quarterly electricity bills within £100-£199; 22 per cent of the households' quarterly electricity bills are within £200-£299; 12 per cent of them spend £300-£399 on their quarterly electricity bills; 2 per cent of their quarterly electricity bill are within £400-£499; and another 2 per cent of them pay their quarterly electricity bills between £600-£699. From the results, 62 per cent of the participants tend to spend less than £199 for their quarterly electricity bills and only 16 per cent of them tend to spend more than £300 for their electricity bills.

Have the occupants changed their energy supplier/energy plans?

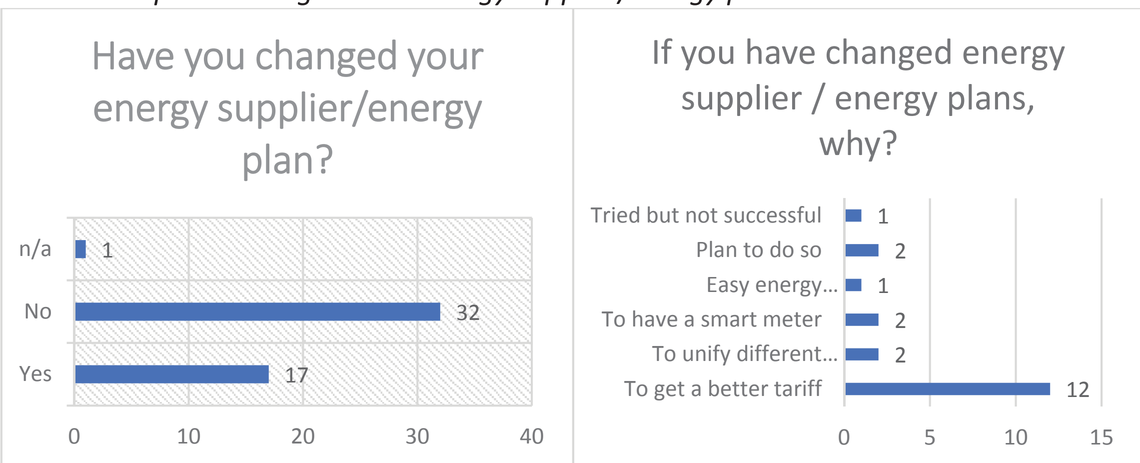
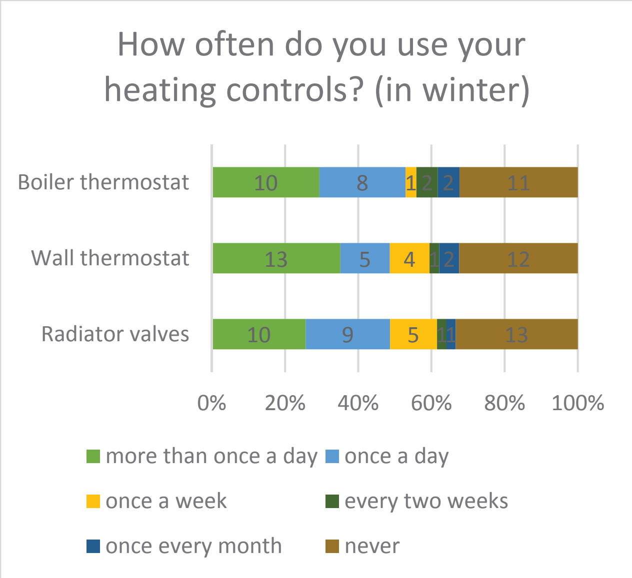


Figure 3. Have you changed your energy supplier/energy plan? If yes, why?

According to Figure 3, the 64 per cent of the respondents have not considered changing energy suppliers or plans. 4 per cent of them expressed that they are wishing to do it but have not started yet. Among the respondents who have changed their energy plans or energy suppliers, 60 per cent of them changed their energy plans or energy suppliers for better tariffs; 34 per cent of them did it for easy energy management or installation of smart meters; 6 per cent of the occupants were either plan to do it or have tried but not successful. Undoubtedly, financial savings is the dominating reason for occupants to make changes. This means that any financial savings in energy bills will probably be considered and appreciated.

The heating controls



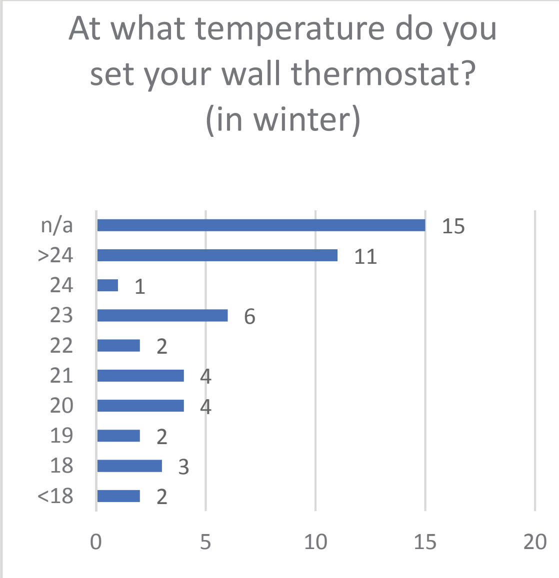


Figure 4. how often do you use your heating controls? Figure 5. What temperature do you set thermostat?

Occupants were also asked to provide the information of how frequently they use the heating controls at their homes. As a result, 52.9 per cent of the households use their boiler thermostat at least 'once a day'; 48.6 per cent of the participant will use their wall thermostat at least 'once a day'; and 48.7 per cent of them use radiator valves at least 'once a day'. On the other hand, 51.4 per cent of the participants will only use wall thermostat at most 'once a week'; 51.3 per cent of them will use radiator valves at most 'once a week'; and 47.1 per cent of the households use boiler thermostat at most 'once a week'. In general, around 50 per cent of respondents use their controls at least once a day, which may imply that they appreciate the significance of those controls perhaps for comfort reasons or to keep their bills down.

According to Figure 5, the temperature occupants set their wall thermostat demonstrates that occupants tend to set their wall thermostat higher in order to have a more comfortable living environment. The majority of the occupants (78.0 per cent) tended to set their wall thermostat more than 21 °C which may not be necessary and encounter the cardiovascular risk when the indoor temperature is more than 24 °C (OVO Energy, 2017). Recent reports (Gram-Hanssen, 2014) also states that the main causes of high heat consumption are indoor temperatures, extensive ventilation and hot water over-consumption.

Energy related behaviours and preferred smart application aspects

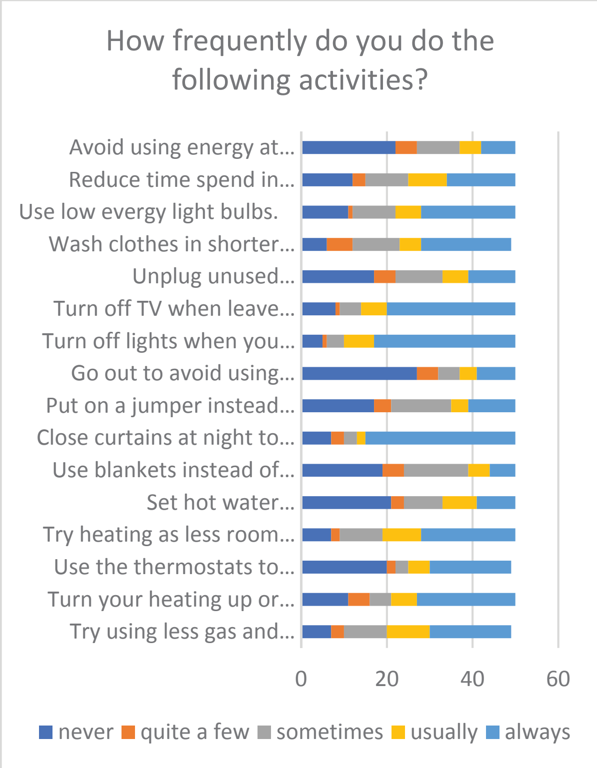


Figure 6. preferred energy related behaviours

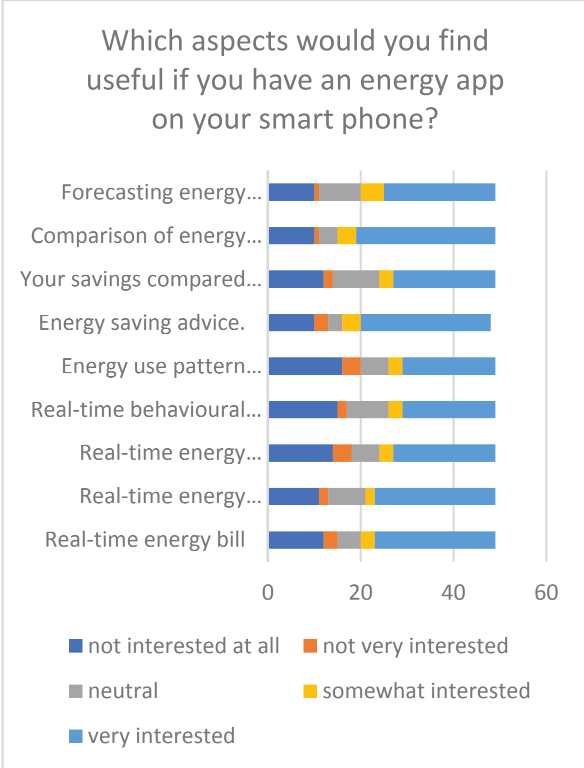


Figure 7. Preferred smart application aspects

According to Figure 6, occupants 'always' save their energy through more conventional ways, such as 'close the curtain' (70 per cent), 'turn off TVs' (60 per cent) and 'turn off the lights' (66 per cent). However, the energy saving behaviours that requires more knowledge and skills were not performed well among the participants: 42 per cent of the occupants will never 'adjust their wall and hot water thermostat', and 44 per cent of them will never 'avoid using energy at peak time'. Besides, people does not want to saving energy by compromising their comfort, that is why 54 per cent of the participants do not like to 'go out avoid using heating' and 36 per cent of them will never 'put on a jumper instead of heating'.

Occupants also rated aspects that they felt would help them reduce their home energy consumption such as 'comparison of energy prices' (61.2 per cent) and 'energy saving advice' (58.3 per cent). However, some approaches have not been fully implemented and facilitated thus they do not draw widely attention, such as 'energy savings compared to your neighbours' (44.9 per cent) and 'real-time behavioural suggestions' (40.8 per cent) In order to draw a picture of those innovative energy saving aspects to the occupants, energy suppliers and the council need to initiate more pilots within their boroughs. Through the case studies, Ehrhardt-Martinez et al (2010) and Hargreaves et al (2013) both indicated that households with comparative feedback displayed in their IHDs tend to use less energy as people may think about the reason why others can achieve low energy consumption than themselves. This can be taken as a social norm feedback which is normally carried out in the communities' level.

Households economic status

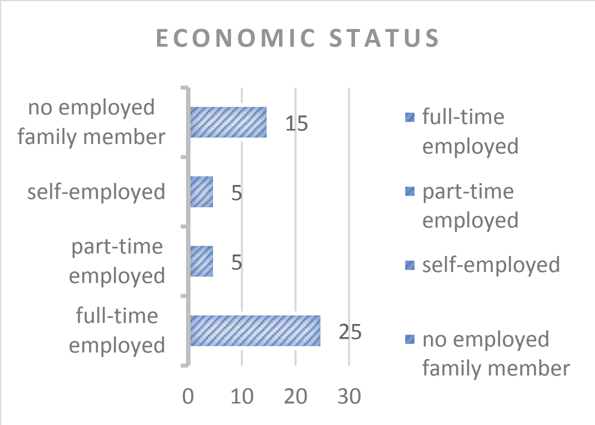


Figure 8. economic status of the family members

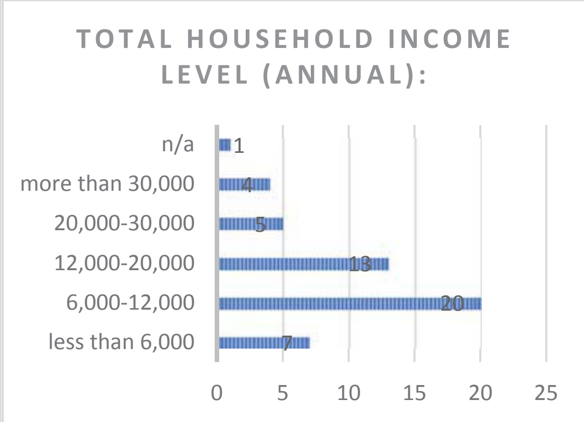


Figure 9. annual household income

Apart from asking occupants' sustainability awareness and their energy related behaviours, their socio-economic factors were also investigated in the questionnaire. According to the Figure 8, households with full-time employed family members take 50 per cent of overall participants; 10 per cent of them have part-time employed family members; 10 per cent of them have self-employed family members, and 30 per cent of them indicated that all of their family members are not able to work. According to the Figure 9, majority (80 per cent) of the households earn less than £20,000 per year. Among these households, 17.5 per cent of them have less than £6,000 annual incomes.

Discussion

The above-mentioned initial results help to understand the occupants' living conditions, energy use patterns, behaviours, socio-economic backgrounds and their awareness of energy efficiency in social housings. It is noted that there are variety of similarities between the case studies and other social housing tower blocks in London Boroughs such as the construction details, housing conditions and occupants' compositions. With its representativeness of a larger scale of social housings in London, the research aims to reveal the problems that may have not been thoroughly investigated and provide suggestions to councils and the policy makers for more efficient retrofit schemes.

According to the findings, 80 per cent of the households have less than £20,000 total annual incomes. The majority of them are residing in their rented properties for more than 10 years. Although the occupants are experiencing various of housing issues, their energy consumptions are generally not remarkably low or high than each other. Only a few of them will pay attention and try to manage their energy consumption carefully. Most energy usages are in the range between £99 - £300, however, a few of the respondents showed dramatically high heating usages for different reasons such as children's comforts or illnesses. Besides, efforts made from the energy company and government in order to increase occupants' environmental awareness and improve energy efficiency have been found in the survey regarding to the questions of receiving energy advices and changing energy plans/tariffs. However, more efforts are still needed: only less than half of the occupants expressed they have received energy advice and only 34 per cent of the participants have changed their energy plans or energy tariffs mainly for cheaper prices.

More than half the respondents appeared to be able to use their heating systems reasonably according to their own life patterns. Besides, although the majority of the participants have similar heating controls at homes, only less than half of them will frequently use them in the winter. The temperature set on their wall thermostat is also too high. The majority of the people do focus on opening windows and extractor fans in the winter to get better ventilations. But extractor fans are not equipped at the first estate which needs to be addressed by the local council. Trickle vents are mostly ignored by the occupants as only 34 per cent of the participants will adjust it for ventilation purposes. 86 per cent of the participated households are either leave it open or close forever regardless of the weather. In addition, although great interests have been shown by occupants regarding to energy conservation, the approaches adopted are limited. There are still a lot of efforts can be made on regulating their energy related behaviours. The ones that people were not doing well but proved efficient include set hot water thermostat lower, avoid using energy at peak time, and use blanket instead of heating (Aydin et al, 2017). Participants did not prefer to go out to avoid using heating and put on a jumper instead of heating which mean that occupants do not like saving energy by compromising their living comforts regardless of the household income levels.

Furthermore, the majority of the occupants have sufficient understanding of their energy bills and feel comfortable to read it. The roll-out of smart meters at both estates are not optimistic as it only covers 20 per cent of the sample size in the research. Even for the homes that smart meters are installed, only 50 per cent of the respondents are likely to read it and adjust energy usages accordingly. Only 10 per cent of the respondents expressed that they have energy monitoring applications installed on their smart phones and only one of them will 'sometimes' read it and adjust energy consumption accordingly. Thus, more supports are needed to educate occupants on how to use the energy efficiency applications.

Concerning tackling the BPG, the study focuses on increasing home energy efficiency by taking into consideration of occupants' energy-related behaviours and other socio-economic factors. The study attempts to provide possible solutions for regulating how occupants operate their homes in a more innovative and effective way. In this case, smart metering devices and energy efficiency applications, as part of the smart grid, increase interactions between energy end users and the management level, and thus become the ideal working direction for the future domestic energy conservation. The suggestions are to provide real-time behavioural suggestions to the occupants. The correlations between energy performance and occupant's behaviour need to be thoroughly investigated based on the collected data.

The innovative smart phone application aims to influence at end-users' level by improving energy efficiency by regulating occupants' behaviours through prompts and real-time advice (Shi et al., 2017). As occupants with different demographic and socio-economic status will operate their homes in different ways, the application will require basic input of audience's social and economic backgrounds and quantify these factors based on the found correlations. Then the application is able to identify the proper energy consumption range accordingly and notify the users with alarms/alerts when improper energy uses are detected. Furthermore, it also helps to improve the efficiency of low-carbon retrofit projects by providing the most efficient energy use patterns and behaviours.

Conclusion

The paper firstly identified that the way of meeting UK's CO_2 reduction target in domestic sector is to improve the home energy efficiency and close the BPG of the low-carbon retrofit projects. It provides an innovative perspective to improve the current delivery and performance of low-carbon retrofit through a 'bottom-up' approach by focusing on the occupants' behaviour at energy end-users' level. Based on the review of the literature in this field, it is believed that rationalising occupants' energy consumption behaviour will help to close the gap between actual energy performance and performance expectations. Besides, energy end-users' socio-economic and other 'hard-to-quantify' factors are also need to be taken into consideration. the paper preliminarily focuses on the survey design of the questionnaire and the initial data analysis. The in-depth data analysis is still ongoing concerning finding other significant correlations between the key variables. In order to increase the interaction between end-users and the energy management systems, the design specification of an innovative smart phone application will be developed as the ultimate research outcome based on the review of existing energy efficiency tools.

In order to fulfil the research aim and objective, a mixed method research design is adopted where a questionnaire survey was designed in order to capture the essential data for the purpose of the research. As a result, 50 questionnaires were returned out of 153 flats. It has been noted that, knowing the occupants' background at case study is essential as it helps to identify appropriate approach and increase responding rate. Sometimes female investigators may be more welcome due to different cultural and religious issues. If the flats with disabled occupants can be identified prior, alternative approaches may apply in order to increase the efficiency of the process. Additionally, as the project is in collaboration with local authority, it would be better if their staffs can be involved in order to increase the reliability of the research and the responding rate of the survey.

According to the completed questionnaires, the initial key findings include: 84 per cent of the households pay less than £300 for their quarterly electricity and gas bills; the economic status was identified relatively low in social housing flats: only 50 per cent of the households have full-time employed family members and 30 per cent of them do not have any employed members; only 34 per cent of the households have previously changed their energy suppliers or energy plans where 60 per cent of them did it for financial reasons; majority (more than 60 per cent) of the participants tend to save their energy by conventional approaches such as 'close curtain', 'turn off TV and lights when leave the room'. However, a number of approaches have not been highly regarded such as 'adjust wall and boiler thermostats' and 'avoid using energy at peak time'. These approaches with certain level of knowledge will need to be popularised with government and professional's supports; at last, according to the open-ended questions, the specific situations may lead to energy over-consumption especially in the social housings, such as illness, lonely elderlies and children's comforts.

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