AN INVESTIGATION INTO ENERGY CONSUMPTION BEHAVIOUR AND LIFESTYLES IN UK SOCIAL HOUSING: REDUCING OPERATIONAL ENERGY POST RETROFIT

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Abstract

Climate change is the outcome of anthropogenic activities, including burning fossil fuels for generating energy. In the UK, it has been acknowledged that the majority of the housing stock will still be in use in another century. However, due to the widespread inefficient energy performance of buildings, improving the efficiency of existing UK homes has been prioritised in the government ‘s agenda in the last few decades. It has been asserted that several retrofit programmes in the UK have not achieved the expected levels of energy savings due to the ‘Building Performance Gap’ (BPG) where the predicted home energy use does not reflect the actual energy consumed. The reason of this is that energy consumption does not only rely on physical characteristics of buildings, but is directly associated to a series of socio-cultural and behavioural factors concerning occupants. Those factors need to be considered for an improved building energy operation which may consequently benefit to the future retrofit schemes.

In an attempt to address this research problem, this study aims to improve the efficiency of energy operation in the UK social housing sector post retrofit by investigating the impact of occupants’ energy consumption behaviour, occupancy patterns and socio-demographic characteristics on home energy performance. Suggestions are made for policy makers by addressing the results found during the research to improve occupants’ energy consumption behaviour. Behavioural interventions are explored including energy management applications that may help improve occupants’ energy consumption behaviour and help reduce the gap between expected and real performance.

To fulfil the research aims, the research adopts a sequential explanatory mixed-method research design where the method is primarily a questionnaire survey to collect the majority of the research data followed by a focus group interview for further interpretation. Through the practical case study of two social housing estates in London, the questionnaire survey was designed to understand correlations between occupants’ energy consumption behaviour, occupancy patterns, socio-demographic characteristics and energy performance in the UK’s social housing sector. Besides, the focus group interview was designed to further explore the barriers of energy behavioural change and obtain the feedback of occupants’ attitudes towards a series of energy management application features as a viable intervention to address home energy performance.

The results demonstrate that ‘quarterly energy bills’ are correlated with a number of energy consumption behaviours, such as the ‘use of heating controls’, ‘use of windows’ and ‘use of extractor fans’ for ventilation purposes. Besides, variances of energy performance are also identified among different household profiles, such as ‘number of children’, ‘teenagers’, ‘unemployed members’ and ‘total number of occupants’. A number of barriers to improve energy consumption behaviour are also identified during the focus

group interview, such as ‘catering for children needs’, ‘daily workload’, ‘value for money’, ‘personal preferences’. The analysis also shows that those barriers are closely associated with the age groups and family sizes. It indicates that the household profiles and socio-economic factors need to be taken into consideration when designing retrofit programmes. The correlations between ‘quarterly bills’, ‘housing issues’, ‘energy consumption behaviours’ and ‘flat orientations’ also imply that the one-size-fits-all retrofit approach may also need to be altered to more tailored measures by considering the impact of solar radiation on thermal comfort. To make effective behavioural interventions, occupants’ attitudes towards different energy management application features were explored. Most interviewees preferred to receive real-time behavioural suggestions that take account of their socio-demographic information. Suggestions for other application features also include energy comparisons, socialised platform and elements of gamification design options in the energy management application.

The study found that effective and tailored design of energy use information and strategies are essential to improve occupants’ energy behaviours. Consistent and community-based approaches to disseminate energy knowledge targeting diverse household profiles are also recommended. Besides, the energy feedback and interactions with smart technologies, such as energy management applications, may be another effective way to increase occupants’ energy awareness and promote behavioural change. However, the slow progress of rolling out smart meters does not help increase occupants’ energy awareness and provide necessary infrastructure for the deployment of energy management application.

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Nomenclatures and abbreviations

AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
ANOVA	Analysis of Variances
ASWZ	Aspley Super Warm Zone
BBNP	Better Buildings Neighbourhood Program
BES	Building Energy Simulation
BPG	Building Performance Gap
BPE	Building Performance Evaluation
BUS	Building Use Study
CaRB	Carbon Reduction in Buildings
CCS	Carbon Capture and Storage
CERT	Carbon Emissions Reduction Target
CESP	Community Energy Saving Programme
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DBEIS	Department of Business, Energy and Industrial Strategy
DCLG	Department of Communities and Local Government
DECC	Department of Energy and Climate Change
DEFRA	Department of the Environment, Food and Rural Affairs
DHP	Decent Homes Programme
DNAs	Drivers, Needs, Actions and Systems
DOE	Design of Experiment
DTI	Department of Trade and Industry
DUKES	Digest of United Kingdom Energy Statistics
EPCs	Energy Performance Certificates
ESCo	Energy Service Companies
EU	European Union
EU ETS	European Union Emission Trading System
EUCo	Energy Utility Companies
F	Ronald Fisher-statistic
FiTs	Feed in Tariffs
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLA	Greater London Authority
HCI	Human-Computer Interactions

Hrs	Hours
HVACR	Heating Ventilation Air Conditioning and Refrigeration
ICT	Information and Communication Technology
IESVE	Integrated Environmental Solutions Virtual Environment
IEQ	Indoor Environmental Quality
IHDs	In-House Displays
IPCC	Intergovernmental Panel on Climate Change
KTOE	Kilogram of Tonne of Oil Equivalent
KWZ	Kirklees Warm Zone
LCA	Life Cycle Analysis
LDA	London Development Agency
N	Number of variables
NCH	Nottingham City Homes
NE	Northeast
NW	Northwest
Ofgem	the Office of Gas and Electricity Markets
p	Significance of the correlation
PCM	Phase Change Materials
PHE	Public Health England
R	Correlation Coefficient
RCEP	Royal Commission on Environmental Pollution
RHI	Renewable Heat Incentive
SAP	Standard Assessment Procedure
SE	Southeast
Sig.	Significance of correlation and ANOVA tests
SPSS	Statistical Package for the Social Science
STLF	Short Term Load Forecasting
SW	Southwest
TSB	Technology Strategy Board
WAN	Wide Area Network

Publications

Shi. W., Elsharkawy, H. and Abdalla, H. (2017). An Investigation into Energy Consumption Behaviour and Lifestyles in UK Homes: Developing A Smart Application as A Tool for Reducing Home Energy Use. In: the 33rd PLEA International Conference on Passive and Low Energy Buildings (PLEA 2017). Edinburgh, United Kingdom, 2-5 July 2017. Edinburgh: Network for Comfort and Energy Use in Buildings (NCEUB).

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Chapter 1. Introduction

1.1 Research context

1.1.1 Energy consumption in the UK

Climate change has been assumed as one of the primary environmental issues for several decades. It significantly impacts on the environment, human health (IPCC, 2008; McMichael et al., 2006) and the economy (Stern, 2006). Climatic trends indicate an increase in global average temperature as the result of ever-increasing greenhouse gas (GHG) emissions over the last few centuries. The point of view supported by the Intergovernmental Panel on Climate Change (IPCC, 2008) is that the global average temperature is likely to increase in the future due to increased greenhouse gas concentration in the atmosphere, which is caused by human activities such as agriculture, land use changes and energy production. Sixty-one per cent of GHG in the world is derived from energy production (IPCC, 2008).

As one of the primary GHGs, Carbon Dioxide (CO_2) is mainly produced by the burning of fossil fuels such as crude oil, natural gas and coal. To address climate change, national and international initiatives dedicated to reducing CO_2 emissions have been published. The Kyoto Protocol set out that by 2010, a 12.5 per cent reduction of 1990s' CO_2 emission levels needed to be achieved in the UK. With the collaboration of the Royal Commission on Environmental Pollution (RCEP), the UK government set a target for 80 per cent of CO_2 to be reduced by 2050 compared with 1990s' levels.

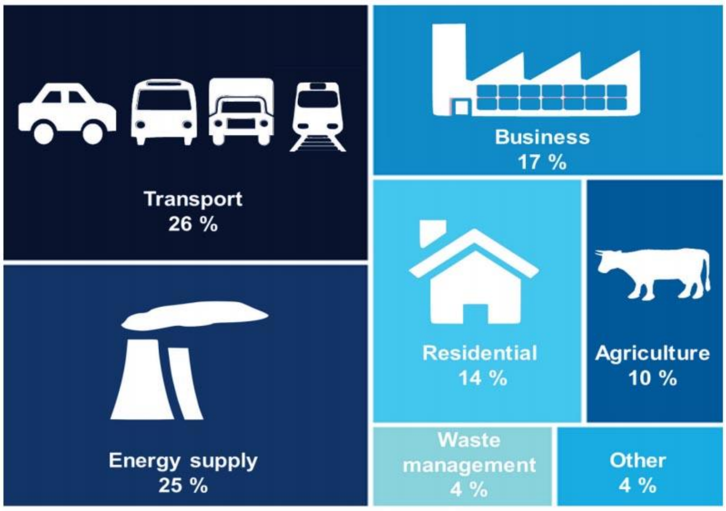


Figure 1. 1. GHG emissions in the UK by sector (DBEIS, 2016).

The percentage that each UK sector contributes to GHG emissions is presented in Figure 1.1 (Department for Business, Energy and Industrial Strategy (DBEIS), 2016). The transportation industry is the largest emitting sector, contributing 26 per cent of GHG emissions in the UK. This is followed by the energy supply sector (25 per cent), business sector (17 per cent), residential sector (14 per cent), agriculture sector (10 per cent), waste management sector (4 per cent) and other sectors (4 per cent). The residential sector, which comprises a remarkable percentage of GHG emissions and which has a big potential for energy conservation, is further examined in the current study.

In 2017, the domestic sector comprised 28 per cent of overall national energy consumption and CO_2 emissions in the UK (Department of Energy and Climate Change (DECC), 2018). Energy consumption in the housing sector reached 40,116 Kilo Ton of oil equivalent (KToe) by the end of 2017, as the second largest energy consumer (DECC, 2018). The current situation of domestic energy consumption is serious as the majority of UK housing stock was built before the impact of CO_2 emissions on climate change was realised. The dated construction approaches and building service systems are not compliant with the current series of sustainability standards more recently established (Ma et al., 2012). Additionally, burning different types of fuels will produce different levels of CO_2 emissions. As energy demand is sharply increasing, it is urgent to make use of energy sources that contribute less CO_2 emissions instead of traditional fossil fuels. Hence, the UK government also set a challenging target regarding cost effective renewable energy consumption: a 15 per cent reduction of energy on heating, transportation and electricity to be achieved by 2020 (UK Renewable Energy Roadmap, 2013).

Energy efficiency in the UK housing sector significantly improved by the 1970s when power stations began to use gas instead of coal (DECC, 2013). The UK currently has 8 million more homes compared to the 1970s' level (19 million homes) (DECC, 2013). Although energy demand has been continuously growing, CO_2 emissions have decreased more than 20 per cent since 1990, due to the increased prices of electricity, solid fuel and oil (DECC, 2013).

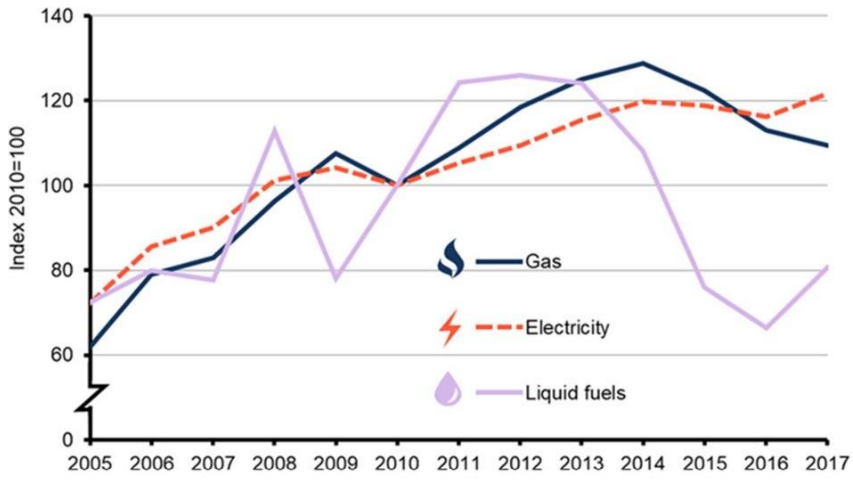


Figure 1. 2. Domestic energy price indices (DECC, 2018).

The increased fuel prices raise the cost of energy and consequently affect energy demand in the domestic sector. Figure 1.2 shows trends in prices of gas, electricity and liquid fuels between 2005 and 2017. Electricity prices have gradually increased since 2005 and reached a peak at the end of 2017. Gas prices are shown to have increased between 2005 and 2014 with a fall in 2010, becoming the most expensive fuel type between 2010 and 2015 (DECC 2015). There was, however, a gradual decrease after that until 2017. Prices of liquid fuels are at the same level in 2017 as they were in 2005 with several instances of steep increases and decreases.

The rise in fuel prices is caused by several elements such as the cost of distribution, the government's environmental and energy efficiency programme and the upgrading of infrastructure (DECC, 2018). However, for low income households, the increased fuel prices mean paying proportionately more on bills. The critical situation of energy demand seems more obvious for low income families as they tend to use less energy to save on bills (DECC, 2018). As the reduction of CO_2 emissions is also subject to more efficient home energy performance through retrofitting dated dwellings, this research focuses on energy reduction of existing housing stock in the UK. and discusses possible solutions to improve their home energy consumption and reduce fuel bills.

1.1.2 Retrofitting the UK homes

To tackle climate change and GHG emissions, this research specifically focuses on improving the energy performance of social housing in the UK domestic sector. As 87 per cent of existing homes will still be in use in 2050, extensive refurbishments were planned in order to meet the CO_2 reduction targets (Fawcett et al., 2014). Social housing stock constitutes one of the most strategic targets for low-carbon retrofit as they comprise 24 per cent of the domestic sector in London (Greater London Authority (GLA), 2015).

Besides, retrofit schemes for social housing stock are highly co-ordinated and are rolled out in large-scale (Fawcett et al., 2014). Moreover, improving the quality of life and socio-economic conditions within the social housing sector generates long-term returns to local councils (Monteiro et al., 2017). Retrofit schemes adopted by the UK government over several decades are considered the most effective way to improve energy performance and reduce CO_2 emissions. As the key vehicle for CO_2 reduction, incentive schemes were launched by the UK government in order to upgrade the domestic sector with more efficient measures and renewable energy. The Carbon Emissions Reduction Target (CERT) was launched in 2008 as the principle mechanism for domestic energy efficiency. It set CO_2 reduction targets for energy suppliers with more than 250,000 clients through implementing retrofit measures, such as cavity wall and loft insulations and replacement of energy-efficient light bulbs (DECC, 2010b).

By focusing on low income and hard to treat homes, the Community Energy Saving Programme (CESP) was launched with funding obliged of energy suppliers. As a result, around 100 communities with 90,000 homes benefitted from the scheme's 'whole house' approach, including wall insulation, replacement of boilers and heating controls (DECC, 2011). As the successor of CERT and CESP, the Energy Company Obligation (ECO) was introduced to support vulnerable and low income households. In addition, the Decent Homes programme was brought forward in 2000, placing responsibilities on local communities. This stated that households which do not meet the Decent Home standards need to be upgraded with a variety of approaches such as boiler upgrades, replacement of heating controls, wall and loft insulations, draught-proofing and energy efficient lighting, etc. (Department of Communities and Local Government (DCLG), 2006). The scheme successfully reduced the percentage of non-decent homes in the social housing sector from 39 to 14.5 per cent by 2010. A new 'Decent Homes Plus' standard has now been introduced for adoption by local authorities. More recently, the Green Deal was introduced as a major energy efficiency mechanism in the UK's housing sector. The scheme permitted loans for energy efficiency measures in households, repaid through energy bills. The upfront costs of installation were covered by private finance. The scheme started in 2012 and was terminated by the Energy Secretary in 2015 due to several major shortcomings. As previously mentioned, some of these retrofit schemes did not meet set targets for energy efficiency and CO_2 emissions reduction (Morton et al., 2018; Rosenow and Sagar, 2016). A review of the schemes is presented along with a discussion of their successes and failures in the current study.

There are a number of issues, including scale and quality of work delivered, were identified during the different stages of retrofit projects. For instance, Webber et al. (2015) argue that inappropriate retrofit scales may affect the efficiency of the project. Smith and

Swan's (2012) also suggest that retrofit projects need to be widely spread geographically to be efficient and effective. Hodson and Marvin (2017) propose upscaling retrofit scope from piecemeal activities to systematic city-region scale would bring huge benefits environmentally and economically. Further, some scholars criticise the delivery of such projects due to that low-quality workmanship may lead to the inefficiency of building energy performance and project failure (Gilbertson et al., 2008; Long et al., 2014; Technology Strategy Board (TSB), 2014).

Adopting appropriate retrofit measures is essential for the success of programmes (Baeli, 2013). Hulme (2012) argues that retrofit measures need to be tailored by considering occupants' profiles. In his case study, upgrade of heating controls applied in general proved not effective among elderly households. A recent report (Greater London Authority (GLA), 2016) additionally argues the criteria for choosing retrofit measures should be duration for fitting the measures and cost-effectiveness. Difficult retrofit measures which require more investment and time but generate less return are ruled out.

There are several issues that need to be dealt with during the installation of retrofit measures. It is argued that efficient installations not only avoid generating waste but also minimise hassle for occupants and therefore keeps them satisfied (Long et al., 2014). During installation is also the best opportunity to provide advice to occupants on how to properly operate new measures and consequently ensure a soft landing of the programme (GLA, 2010 and 2016; TSB, 2012 and 2014). Therefore, sufficient communication between contractors and occupants are important. The successful delivery of a retrofit programme not only requires strategic policies and processes but also the proper operation of retrofitting dwellings. The impact of occupants' behaviour on energy performance is discussed in the next section.

1.1.3 Occupants' energy consumption behaviour

Apart from the issues that need to be addressed during the design and delivery stages of a retrofit programme, the stage after handover is also crucial, as occupants play an important role in home energy efficiency (Galvin, 2014; Aydin et al., 2017). Notably, domestic energy performance is subject to how occupants operate their homes, especially their heating systems. Therefore, the way that occupants manage their homes and their household profiles need to be taken into consideration for building energy performance (Greening et al., 2000; Saunders, 1992). Failure to do so may lead to an energy performance deficit (Sunikka-Blank and Galvin, 2012). In order to avoid that, these factors need to be explored through diverse approaches to try and draw meaningful correlations for reducing energy consumption (Sorrell and Dimitropoulus, 2008; Hadjri and Crozier, 2009). Suggestions are also given in various reports (London Development Agency (LDA) et al., 2010, 2011 and 2014; TSB, 2012 and 2014) on how to regulate occupants' behaviour for more efficient energy consumption, including introduction of smart meters/In-House Displays (IHDs) and more effective communication between construction team, various stakeholders and occupants.

A significant link between occupants' behaviour and energy performance evaluation is supported by Nicol and Roaf (2005), who state "it should be understood as reflecting the changing nature of the relationship between people, the climate and buildings". By carrying out behavioural surveys with occupants, Guerra-Santin and Itard (2010) find that retrofitted households with a programmatic thermostat were found to be consuming more energy than those with a manual thermostat, as the users tended to turn the heating on for longer. Additionally, elderly occupants were found to use heating and ventilation systems for longer durations than younger occupants.

The significance of energy use due to occupants' behaviour has been asserted by Ben and Steemers (2014), who found that positive change of behaviours could lead to between 62 per cent to 86 per cent energy saving. They also found that a higher level of physical improvement to the dwelling may not necessarily imply behavioural improvements. The same point of view is held by Gupta and Gregg (2016), Jad et al. (2016) and Wei et al. (2014). To tackle the impact of occupants' energy consumption behaviour on energy performance, Hong et al. (2016) quantify behavioural factors into parameters for simulation. Occupants' movements and uses of windows, shading devices, lighting and heating systems were monitored by connecting to specific sensors to prioritize the influential behavioural factors. Then, the behavioural module was integrated into building performance simulation programmes to quantify their impact. However, due to lack of benchmark and standards, more efforts still need to be made towards the validations of behavioural models. Sun and Hong (2017) further indicate that 41 per cent of potential savings could be achieved by taking account of occupants' behavioural factors in energy simulations.

The current study documents research undertaken to improve the understanding of how occupants' energy consumption behaviour, lifestyle patterns and socio-demographic characteristics affect home energy performance in the UK. Through exploratory case studies of social housing estates in one of the London boroughs, research is undertaken to gain an insight into the impact of those factors and provide recommendations to improve occupants' energy consumption behaviours following home energy upgrades, hence improve the outcome of retrofit interventions. The rationale of the research is presented in the following sections that encompass the research aims, objectives, research questions, research methodology and significance of the study.

1.2 Research aim and objectives

This research investigates correlations between energy performance in the UK social housing sector and occupants' energy consumption behaviour, occupancy patterns and socio-demographic characteristics. By evaluating exploratory case studies of two social housing tower blocks in one of the London boroughs, the research aims to develop viable interventions to improve the efficiency of operational energy post retrofit in the UK social housing sector.

The research objectives are to: (i) understand housing characteristics, householders' profiles, energy consumption behaviour and occupancy patterns; (ii) explore the correlations between occupants' socio-demographic characteristics, energy consumption behaviour, occupancy patterns and home energy performance; (iii) explore occupants' attitudes towards energy consumption behaviour and the use of smart technologies to manage home energy usage, as a possible strategy to reduce home energy consumption; (iv) identify the particular implications for energy conservation in the UK social housing sector and provide evidence-based recommendations.

To achieve the research objectives, the research questions are indicated below:

- What are the socio-demographic characteristics and housing characteristics that have significant impact on energy performance in social housing estates?

- To what extend can occupants' energy consumption behaviour impact on energy performance in social housing estates?

- How can smart technology help improve occupants' energy consumption behaviour through energy management and behavioural incentives?

- How can the research outcomes contribute to and inform the effective building energy operation that can benefit to the future retrofit programmes in the UK social housing sector?

1.3 Research methodology

In order to fulfill the research aims and objectives; a mixed-methods sequential explanatory research design was adopted where quantitative data was collected at the first stage of the study supplemented by qualitative data in the second stage of the research. The qualitative approach adopted was used to further interpret the quantitative data. The questionnaire survey was undertaken to acquire quantitative data for correlation analysis followed by a focus group interview to acquire qualitative data from occupants in both social housing case studies in London. A number of questions within different themes were asked in the questionnaire survey such as housing conditions, energy consumption behaviour, occupants' attitudes towards smart technologies and socio-demographic information. The correlation analysis for energy performance and different variables was undertaken based on the data acquired from the questionnaire survey. Consequently, occupants were invited to a focus group interview in order to probe into details of the key issues raised in the first stage of the research and obtain their feedback concerning strategies for potential behavioural interventions. To explore the implications between behavioural factors and energy performance, correlation analysis and Analysis of Variance (ANOVA) test with different purposes were conducted by using Statistical Product and Service Solutions (SPSS) software, which is capable of advanced statistical analysis. Insights from the data were explored through correlation analysis for scaled variables and an ANOVA test for the data that does not have a scale. Microsoft Excel was also adopted to record data, code data and run analysis for general findings.

In order to probe more into details of the key issues identified from the questionnaire survey and understand occupants' attitudes towards a number of features of energy management applications, a focus group interview was conducted. The NVivo was adopted to transcribe and analyse the interview data. The barriers of implementing energy conservation technologies such as smart meters and energy management applications are explored by analysing the frequency of the words or themes appearing during the interview. A detailed explanation of research approaches and procedures adopted are discussed in Chapter 4.

The permission for contacting occupants in both case studies was granted by the landlord, in this case, the local authority. The development of the questionnaire survey and focus group interview followed several consultations with the local authority and other relevant stakeholders at every stage of the research. Progression reports and were also presented at regular meetings to keep all the stakeholders informed. Support received from the local authority, contractors, estate management team and other relevant teams helped significantly during the data collection process.

1.4 Significance of the research

This thesis reviews previous retrofit case studies which help to understand the government's 'top-down' retrofit approach, that is generally driven by a series of energy policies and schemes. A number of issues during different stages of retrofit projects are discussed. It is widely recognised that the reasons why domestic retrofit projects may not meet predicted energy performance results may be due to inappropriate project planning, inefficient delivery processes, lack of interactions between households and key stakeholders such as local authorities, contractors, energy companies, etc. (Fylan et al., 2016; Sunikka-Blank and Galvin, 2016; TSB, 2012 and 2014). Notably, there are other remarkable factors that may have significant impact on the delivery and outcomes of these initiatives; such as the way occupants operate their homes and manage their energy consumption (Galvin, 2014). The study investigates the challenges and opportunities to improve social housing retrofit delivery and outcomes by developing bottom-up interventions that may help deliver top-down energy reduction and carbon emissions reduction targets.

In the context of retrofit projects, 2 social housing estates due for retrofit in London have been chosen as sample case studies. The research is expected to contribute to the current body of knowledge by providing: (i) an understanding of households' socio-demographic characteristics which affect the energy performance of both social housing estates; (ii) understanding of how occupants' energy consumption behaviour and occupancy patterns affect the energy performance of their homes; (iii) evidence-based recommendations concerning behavioural interventions that help regulate occupants' energy consumption behaviour in order to reduce home energy operation and consequently support the outcomes of future low carbon retrofit projects; (iv) a proposal of an energy management application for energy end users based on the findings to optimize home operation through behavioural promotion and increase the efficiency of retrofit programmes.

As occupants' behaviour and their socio-demographic characteristics are challenging to measure, these parameters may be ignored when predicting building energy performance (Fylan et al., 2016; Pelenur, 2013; Jones et al., 2016). This thesis suggests that in order to support the government's 'top-down' approach for low carbon retrofit, occupants' energy consumption behaviour needs to be addressed in order to close the BPG and consequently improve building energy performance.

1.5 Thesis structure

The thesis consists of 8 chapters. A summary of each is outlined below.

Chapter 1. Introduction: This chapter defines the scope of the research, provides an overview of the whole thesis and clearly presents the structure of the thesis.

Chapter 2. Retrofitting the UK homes: This chapter presents a review of the UK's low carbon retrofit programmes and the government's top-down initiatives. The literature review is presented in sequence alongside a discussion of energy related legislation, policies and incentive programmes with a series of recent and current retrofit case studies. The successes and failures of low carbon retrofit schemes in the UK are also discussed in order to inform the research design.

Chapter 3. Occupants' energy consumption behaviour and behavioural interventions: This chapter firstly discusses the impact of occupants' energy consumption behaviours through retrofit case studies. It then presents a review of the background and transition of the UK's smart grid system, as the driving factor of the implementation of Advanced Metering Infrastructure (AMI) for receiving more detailed energy feedbacks and promoting occupants' energy consumption behaviour. Additionally, energy management applications and behavioural interventions towards occupants are explored. This is followed by reviews and comparisons of energy management applications in the market. The latter's shortcomings and successes are concluded.

Chapter 4. Research methodology: This chapter outlines the methodology applied in the study to address the research aim and objectives, and answer the research questions. This includes explaining the research design and research methods adopted, as well as the method of data collection. There follows an account of the stages of data processing and methods of data analysis.

Chapter 5. Data analysis: Questionnaire survey: This chapter presents the general findings from the questionnaire survey and correlation analysis of how occupants' socio-demographic characteristics, energy consumption behaviour and energy use patterns affect the energy performance of UK social housing estates.

Chapter 6. Data analysis: Focus group interview: This chapter presents the research findings of the focus group interview that was conducted following the survey data analysis. The reasons for poor energy condition in the case study were explored and believed significantly influenced by different household profiles. Besides, interviewees' preferences in energy management applications are discussed in different aspects.

Chapter 7. Discussion: This chapter presents a summary of key findings from the research and a broad discussion using comparison with relevant studies. A set of evidence-based recommendations are developed in order to improve occupants' energy consumption behaviour that may be supported by policy makers as well as energy end users. A proposal of energy management applications that may potentially improve occupants' behaviour and increase energy efficiency is also presented, following reflection on the research findings.

Chapter 8. Conclusion and recommendations: This chapter concludes the key research findings and identifies how these will contribute to reducing home operational energy post retrofit. Additionally, limitations of the research are highlighted and recommendations to mitigate these in future research are identified.

Chapter 2. Retrofitting the UK homes

2.1 Introduction

This chapter reviews major UK energy conservation legislation, government reports, retrofit programmes and case studies in order to consolidate the current state of knowledge in home energy performance and the influence of retrofit programmes. A literature review is presented along with the UK's approaches to retrofit interventions. The issues were discussed mainly in the UK's social housing sector but also involved with other types of occupancy in the UK's domestic sector to gain comprehensive understanding.

Notably, the transition of the UK's energy network has effectively increased the efficiency of energy use and delivery. The development of a smart grid also has had a huge influence on the government's retrofit policies and measures such as commitment to smart meter establishment (Rhodes et al., 2014). The development of the UK's energy network is first presented to set the context for the UK's retrofit market. Consequently, the landscape of UK government policies and legislation concerning energy conservation are reviewed. Following this, significant findings from reports developed by the UK Government bodies are discussed. In addition, a series of retrofit programmes are illustrated together with the retrofit approaches applied. The successes and failures of those programmes have been investigated through a few relevant case studies. Finally, the current conditions of the retrofit market and barriers to energy efficiency in the UK social housing sector are discussed in order to inform the research design.

2.2 The UK's energy network and smart meters

2.2.1 The UK's traditional energy network and smart grid

The development of traditional energy system in the UK can be dated back to the beginning of the twentieth century when energy was generated by large and centralised power stations (MacIsaac, 2013). The latter have used different types of fuel such as gas, oil and nuclear power, providing different levels of electricity outputs up to fixed maximum capacities. The power plants are connected by high-voltage transmission networks, which are responsible for carrying the generated electricity to where it is needed around the country (MacIsaac, 2013). The energy is transported from distribution sub-stations to end users by lower-voltage networks. Billing and quality of electricity are monitored when the generated energy is leaving power stations. Moreover, frequency and voltage of the electricity are monitored throughout the energy network to ensure they do not exceed adequate tolerances. MacIsaac (2013) argues that as energy consumption at end user level can only be captured termly by mechanical or digital meters from energy companies, the monitoring process for the distribution network is lacking real-time energy recordings and does not describe each particular energy end user.

Apart from domestic energy use, heating and transportation also play significant parts in the UK's energy consumption. Heating in domestic and non-domestic buildings accounted for 39 per cent of the total energy consumption among all sectors in 2015 (Gogreengas, 2018).

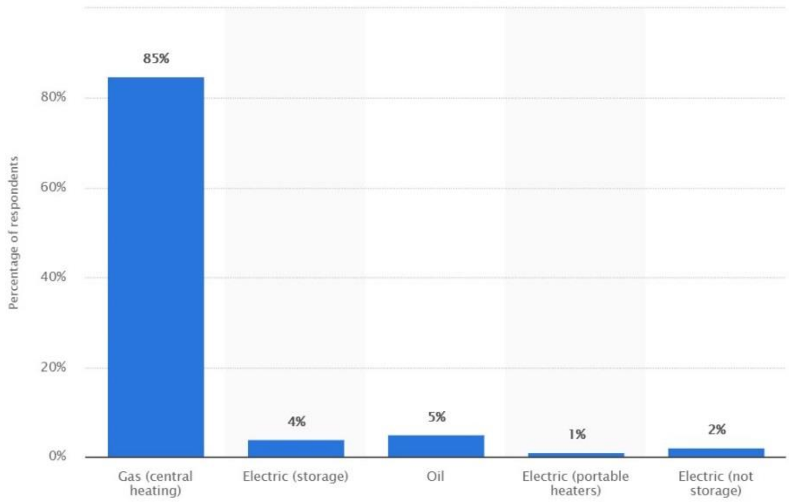


Figure 2. 1. UK heating methods distributions in the UK sector (Statista, 2018).

As shown in Figure 2.1, gas (central heating) is the main heating method, taking up a remarkable 85 per cent of heating fuel usage. It is followed by electric storage, which contributes 4 per cent of heating fuels, and oil, contributing 5 per cent. Other methods are used to generate heating such as electric portable heaters and electric (non-storage), accounting for 1 and 2 per cent of heating fuels respectively (Statista, 2018). The 85 per cent of heating fuels taken up by gas represents a huge composition of traditional housing stock in the UK and a great potential for achieving carbon reduction targets by replacing them with renewable energy sources, such as solar power, wind power and biomass.

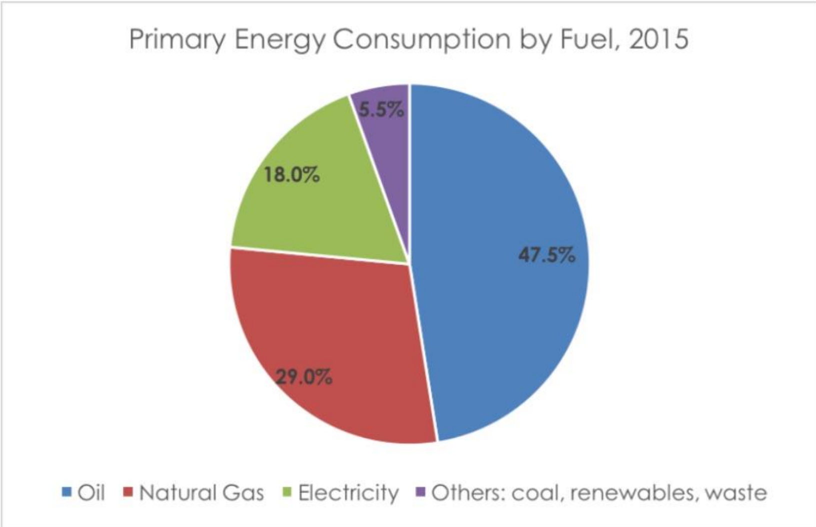


Figure 2. 2. Fuel distributions in all UK energy sectors (DBEIS, 2016).

Figure 2.2 demonstrates that petroleum accounted for an outstanding 47.5 per cent of overall energy consumption in the UK in 2015 (DBEIS, 2016). Petroleum-based fuel is the primary fuel contributing to the UK's transportation sector. The second largest energy source for all energy sectors was natural gas, which accounted for 39.0 per cent of overall energy consumption. This was followed by electricity and other types of fuels, accounting for 18.0 per cent and 5.5 per cent of overall energy consumption, respectively.

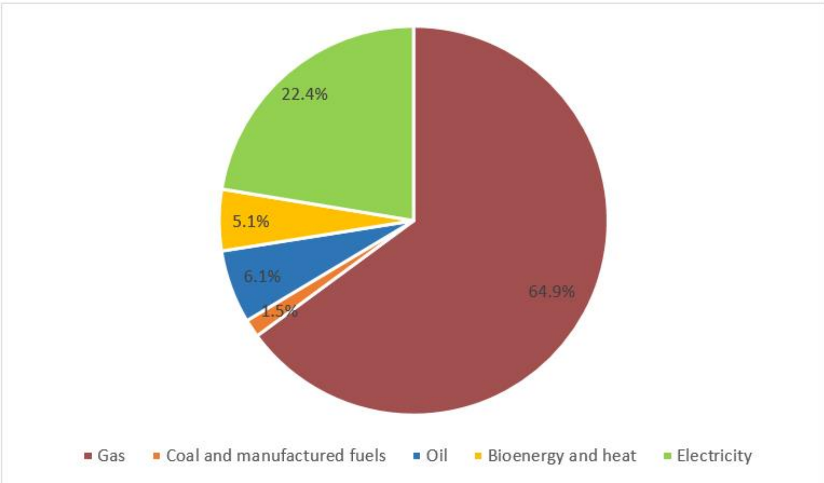


Figure 2. 3. Fuel mix of energy consumption in the UK domestic sector. (DBEIS, 2017).

In the domestic sector, gas consumption plays a predominant role in the UK as it comprises 64.9 per cent of overall energy consumption (Figure 2.3). This is followed by the energy generated by electricity, which comprises 22.4 per cent. The third and fourth largest energy sources in the domestic sector are oil (6.1 per cent) and bioenergy and heat (5.1 per cent). Additionally, 1.5 per cent of domestic energy consumption is generated by coal and manufactured fuels.

The figures above demonstrate a large dependence on fossil fuels in the UK's energy sectors. Furthermore, the majority of fuels are imported from foreign countries (DECC, 2009). Fossil fuels are depleting with extremely long regeneration cycles. As a result, the UK government has determined to transform its energy system and make it cleaner and smarter in the future. The target was set out that by 2020, 40 per cent of overall energy sources in the UK will be low carbon (DECC, 2009). Within this target, 30 per cent of sources will be renewables such as solar power, water power, wind power and bio-power. It is notable that traditional fossil fuels will not be replaced completely and will still form part of the UK's energy plan for 2020. A recent study (Li et al., 2016) indicated that relying on renewable sources may be challenging due to unpredictable climatic conditions, hence, the energy generated may not meet the set requirements. As a result, the UK government proposes to create sufficient storage systems, such as thermal stores, heat and electricity batteries, to save redundant energies and make use of them when necessary (DECC, 2009).

The UK government not only focuses on upgrading energy sources but also makes an effort to improve the efficiency of the energy network. To reduce carbon emissions and increase energy efficiency in the heating sector, primary energy sources such as gas-fired and coal-fired electricity will need to be incorporated with Carbon Capture and Storage (CCS) technology to produce cleaner electricity (DECC, 2009). On end user level, individual dated gas boilers are to be replaced by high efficient ones. Therefore, less gas will be consumed while the same amount of electricity is produced. In a long-term plan, upgrading the current energy system requires substantial change in traditional heating systems and renewables such as solar water heating or combustion systems. A number of new types of heating systems have also been implemented in the UK such as Combined Heat and Power (CHP), heat-to-electricity conversion and district heating systems (DECC, 2009).

Another difference between the traditional energy networks and the smart grid is the introduction of smart meters to the smart grid, which is planned to be installed in all UK households by 2020 (DECC, 2009). The reason for this is that the installation of smart metering devices give end users a better understanding of how energy is consumed and increase their energy saving incentives (Darby, 2010). Energy companies are also encouraged to provide the most appropriate energy plans to households with regard to the particular energy use patterns recorded by smart meters (Darby, 2010). Energy companies will also benefit from the information acquired from smart meters and the advanced metering infrastructure as the technology saves manpower required for gathering these data for analysis. According to DBEIS (2017), the implementation of smart meters is still in progress with 4.04 million installations of electricity and gas meters completed by the end of 2016. As the government's target has not materialised, alternative approaches need to be adopted for the process of energy monitoring.

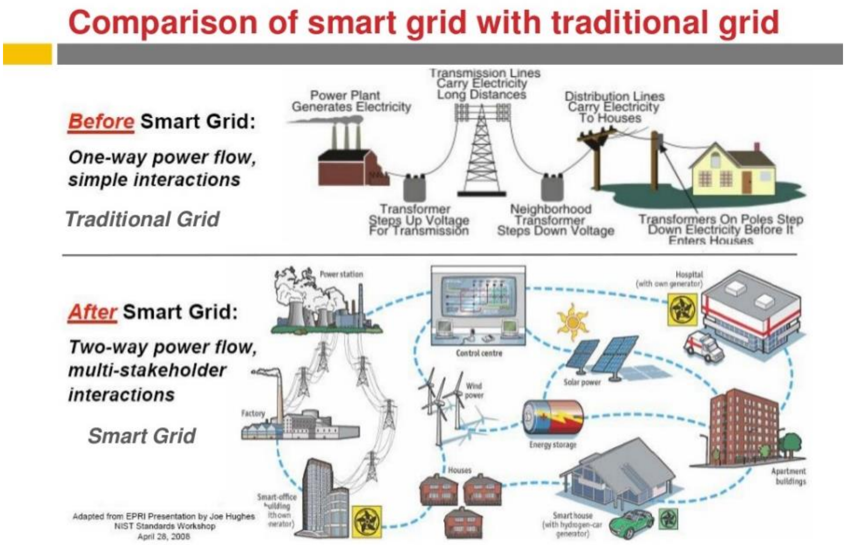


Figure 2. 4. Comparing the UK's traditional and smart grid energy networks (Hughes, 2008).

Among countries, the UK has had remarkable achievements and become one of the leading examples of the transition of energy system. As illustrated in Figure 2.4, the traditional system is a unidirectional linear network with limited feedback obtained from energy output and consumption (Hughes, 2008). Therefore, the energy demand set up at the beginning cannot be flexibly changed in response to particular circumstances. This leads to the result that energy is not used properly and the system may not be adequately efficient. The new smart grid system, which is currently under transition, is a bi-directional distributed energy network. Apart from the remaining centralised and fossil fuel powered power stations, other power sources are employed in the smart grid system such as renewable and micro power generations (Hughes, 2008). Battery storage is also largely equipped for reasonable uses of renewable energies. Feedback systems at the distribution level will be able to respond to the control of a transmission system. Thus, an appropriate adjustment can be made in order to avoid energy waste.

The roles of government, industry and academia in the smart energy network have been defined by Jones et al. (2014). The government needs to set clear objectives for the industry through policymaking and use a balanced approach to encourage the engagement of industry as the latter may be weighted by increased costs and profit loss. The industry needs to gear up for the low carbon economy and protect its interests during the change. Academia and research are also required to drive innovation of low carbon products and provide societal education.

2.2.2 The end use device: smart meters

2.2.2.1 Definition of smart meters

Diagnosing energy performance at energy end levels has become more and more important in the smart grid system (Darby, 2010). This drives fast implementation of the Advanced Metering Infrastructure (AMI), which includes a series of hardware, software, controllers, communication and displays such as smart meters. The definition of smart meters has been indicated by Climate Group (2008) as “advanced meters that identify consumption in more detail than conventional meters and communicate via a network back to the utility for monitoring and billing purposes”. The most significant difference between smart meters and conventional energy meters is that the former can communicate electronically (Darby, 2010). Darby (2010) also attempts to interpret smart meters in a more explicit way, stating a fully smart metering system needs to have 2 functions: “measure and store data at specified intervals” and “act as a node for 2-way communications between supplier and consumer”. Due to the increased capability of remote controls, the relationship between energy users and utilities has radically improved. Although upgrading the traditional energy meters will increase energy efficiency, it requires a certain amount of financial investment. Newton (2012) argues that the £12 billion investment of the current proposal places huge pressure on the consumer as many of them are appointed by their energy suppliers to install the smart meters without a chance to opt out. The progress of it is not optimistic as the majority of the energy providers are failed to meet the annual targets (Vaughan, 2017). Alternatively, householders can equip their existing energy meters with communication capabilities as another option with less financial costs, such as smartphone applications to display energy information.

In general, there are 2 types of smart metering devices, the Automated Meter Reading (AMR) and AMI. The former only has 1-way communication from energy users to utilities; the later has bi-directional communications between energy user, utilities and the communication hub (Darby, 2010). The AMR has been applied as one of the options to replace conventional energy meters. Although it establishes more straightforward controls for energy users with more accurate billing and meter credits, it is not capable of providing feedback or suggestions to users about current energy performance. On the other hand, the AMI not only provides what the AMR does but also gives demand response to the communication hubs. As a result, the AMI optimises the operation of energy networks and supplements the supply of renewable energy (Batlle and Rodilla, 2008). Prospects for energy performance will also be provided to occupants. Additionally, in order to solve the fluctuations in energy transmission which are caused mainly by intermittent renewable generations, the AMI can remotely control the electricity loads of each appliance every second to increase stability.

As one of the important components forming the new smart grid system in the UK, experimental case studies of implementation of smart meters in the UK will be discussed in the following section. Further, new energy saving strategies relating to smart meters and the possibilities of connecting smart metering devices with energy management tools are discussed.

2.2.2.2 Smart meters in the UK

Compared with other European countries, the UK has more smooth demands during energy distribution and less fraud where consumers tamper to steal energy from their suppliers. The responsibility of the roll-out of smart meters is assigned to energy companies by the UK government. DECC (2009b) and DECC (2009a) identified a few functions which a smart metering system is expected to provide: accurate energy readings remotely in a defined period, bi-directional communication between end users and energy suppliers, real-time energy information connecting with in-home display, remote control of electricity appliances, remote disabling or enabling of energy supply and measurement of energy exports. The developments of energy management network will effectively reduce energy consumption and environmental impact, and increase the security of energy supplies (Jones et al.,2014). A mature energy management system also relies on good communication between energy end users and the energy distribution level.

Although a smart metering system is expected to be fully implemented in the UK by 2020, there are still a lot of work required at the energy management level. Apart from a series of testing and validating mechanisms prior to the implementation of the new system, there are plenty of regulatory and legal mechanisms to be accomplished before implementation. For instance, the purpose of the implementation of smart meters has been clearly identified by DECC (2009a) as a fundamental approach to pave the way for the UK's energy transformation. Besides, large energy providers are requested by the government to submit implementation plans, annual milestones and enforcement actions in order to ensure the successful delivery. They are also obligated to fund and monitor their operations. The fulfillment of obligations will be supervised by Ofgem (the Office of Gas and Electricity Markets) (DECC and Ofgem, 2014). The smart metering is expected to play an important role in energy security and carbon reduction. Additionally, it is an important step towards the development of a smart grid and the introduction of increased use of renewable energy.

Many scholars argue that the promising penetration rate of smart meter implementation and percentage of energy saving are subject to close interactions with occupants (Darby, 2010; Stromback et al., 2011). In the UK, it is believed (Logica, 2007; energywatch, 2007) that in many cases, energy end users may not be able to fully interpret their energy bills. It has been asserted that one third of energy users understand their energy consumption from estimations rather than meter readings. According to electricity and gas consumption trends (DECC, 2009) in Digest of United Kingdom Energy Statistics (DUKES), energy end users have not fully engaged in energy management through their current meters as they are not confident about selecting appropriate energy appliances, maintaining their buildings and following appropriate energy use patterns. The reasons that prevent engagement include personal interests, lack of energy knowledge, education level and personal comfort (DECC, 2009). Therefore, a new approach needs to be adopted in order to engage more people by addressing the different barriers.

A number of researchers and scholars have tried to assess the successes and failures of the implementation of smart meters through a series of experimental case studies. The discussions and results of these are discussed in the following section.

2.2.2.3 Direct and indirect energy use feedback

Supported by the UK government, smart meters have been implemented in homes throughout the country. The advantages and disadvantages of this have drawn much attention from scholars and specialists. There are a number of energy use feedback mechanisms developed to help occupants save energy. Real-time feedback is generally based on the installation of smart meters. Additionally, some feedback mechanisms are based on the processed energy information, such as the feedbacks through websites or through billing statements. These are referred to as indirect feedback. A study (Ehrhardt-Martinez et al., 2010) showed that providing occupants with real-time feedback using smart meters achieved higher electricity savings than providing indirect feedback such as an estimated web-based energy audit. To further explain this, Darby (2006) argues that real-time advice and feedback is more suitable for addressing the impact of smaller end uses. On the contrary, indirect feedback plays a better role in addressing changes in heating consumption in homes and investment in retrofitting as it can provide a compelling picture to the users on what is happening on heating load. This point of view is also supported by Soren (2016).

Ehrhardt-Martinez (2012) believes different types of energy use feedback work well in relation to particular energy saving behaviours. For instance, indirect feedback through enhanced bills is suited to turning off lights, replacing bulbs, setting up a thermostat, unplugging electricity appliances, etc. Indirect online feedback is most likely to affect occupants' behaviour in the aspects of replacing bulbs, using blinds, reducing washing loads, turning off computers, etc. Occupants who receive real-time feedback are more likely to make use of power strips, reduce the wattage of bulbs, turn off external computer speakers, clean dryer lint filters, etc. This is backed up by Vellei et al. (2016), who state occupants' behaviour can be classified within 3 categories: purchase, operation and maintenance. Real-time feedback is particularly suitable for prompting smaller operation-related behaviour such as lowering radiators and room temperature. Thus, real-time feedback will work more effectively in cold countries. Ehrhardt-Martinez (2012) further shows that occupants are more likely to change behaviours to save energy rather than make investments.

On the other hand, Foulds et al. (2017) argue there are no clear definitions of energy feedback and energy monitoring. Through a case study of a group of homes for which an online feedback tool named 'iMeasure' was deployed, it was shown that energy monitoring is particularly good for measuring energy use and identifying trends. However, energy monitoring does not guarantee users will actively seek energy-saving actions. The reason for this is that energy monitoring fails to connect to other energy users. Occupants tend to be influenced by their neighbours with greater energy savings. It is suggested (Foulds et al., 2017) that government needs to work on identifying the terms of energy monitoring and energy feedback in its policies. As a result, a combined approach needs to be adopted based on energy monitoring and feedback to induce occupants' incentives for behavioural change.

Following the background of the transition of the UK energy network and the adoption of smart metering, the current situation of domestic retrofit in the UK is discussed below with reference to the top down approach.

2.3 UK government initiatives for carbon emission reduction and energy savings

It has been widely recognised that the major cause of climate change is anthropogenic activities (Stocker et al., 2014; Hook and Tang, 2013; Parmesan et al., 2013). which includes increasing populations, environmental damage, fossil fuel depletion, among many other factors. GHGs, especially CO_2, are released into the atmosphere with burning fossil fuels. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations, 1992) was agreed by 197 parties including the UK in order to respond to climate change through international cooperation. This was the milestone of the UK's efforts to tackle climate change with the government starting to establish a series of policies and legislations. As an extension of the UNFCCC, the Kyoto Protocol (United Nations, 1998) was signed by 192 countries and parties in Kyoto, Japan in 1998. The protocol follows the objective of the UNFCCC, aiming to mitigate climate change by reducing GHG emissions and concentrations in the atmosphere. At the European level, the European Union (EU) developed multiple initiatives in order to respond to climate change and reduce GHG emissions since the UNFCCC was established. A few years after the launch of the UNFCCC, the EU launched the European Climate Change Programme (ECCP) (European Commission, 2000), which consists of a number of concerted policy measures for CO_2 reduction. Each member of the EU is requested to take action on its domestic policy measures in compliance with or as a complement to the ECCP. The UK government has also had its position and set out its targets in response to climate change which is discussed in the following sections.

2.3.1 Greenhouse gas reduction policies

In 2008, the UK government published the UK Climate Change Act, which was seen as the substantial driving factor of the UK's low carbon retrofit. The Act set up national binding 'carbon budgets'. It set out CO_2 emission reduction targets for the UK of 34 per cent by 2020 and 80 per cent by 2050 based on the 1990s' CO_2 emission levels (Climate Change Act, 2008). The carbon reduction targets were also set out through the publishing of the Carbon Budgets Order (2011) covering three 5-year periods, '2008 – 2012', '2013 – 2017' and '2018 – 2022', to ensure 80 per cent CO_2 reduction in a step by step approach. Besides CO_2 emission reduction, the Act also aimed to provide more secure energy supplies, maximise economic opportunities and support the most vulnerable (Climate Change Act, 2008).

In 2009, the DECC issued the 'UK Low Carbon Transition Plan', which aims to tackle climate change by protecting people from immediate risk such as flooding, taking climate risk factors into account in future decision-making processes, leading to an international climate agreement to mitigate the impact of global warming, cutting CO_2 emissions and supporting the development of different roles of the UK housing industry. The plan indicates that although the UK has cut 21 per cent of CO_2 emissions since the 1990s, further efforts are still required. The government aims to import 60 per cent of gas by 2020 compared with the 25 per cent import rate at present (DECC, 2009). As the technology of energy efficiency is developing fast, the gas import rate could be reduced by 45 per cent by 2020 (DECC, 2009).

To help tackle energy efficiency, the UK government encourages the delivery of reliable and secure-supplied energy (DECC, 2009). This plan will also increase opportunities in the UK's financial sector because tackling climate change will only cost 1 to 2 per cent of global Gross Domestic Product (GDP) as compared to 5 to 20 per cent of global GDP currently being spent to mitigate the effects of climate change. At the first stage, all developed countries are required to reduce CO_2 emissions between 25 and 40 per cent by 2020. The UK also proposes that all developing countries need to reach a CO_2 emission peak by 2020 and reduce 50 per cent of their peak demands by 2050 compared with 1990s levels. Detailed solutions for each sector were given in the white paper regarding power, homes and communities, workplaces, transportation and farming lands. In the domestic sector, the government aims to drop 29 per cent of CO_2 emissions from heating compared with the 2008 level, contributing 13 per cent of emission saving between 2018 and 2022 (DECC, 2009).

The Carbon Accounting (2013–2017 Budgetary Period) Regulations (2015) was also published in order to monitor the carbon accounting system and determine compliance with the set target of the second carbon budget period. The regulations clearly set out the carbon units which could be credited to or debited from the net UK carbon account including carbon emissions from domestic aviation and the EU Emission Trading System (EU ETS). Further, the carbon units need to be cancelled at the end of this budget period by the Secretary of State. The methodology of calculating carbon units is also identified in the regulations.

It is notable there are encouraging progressions that have been made by the UK government. By comparison with previous initiatives, which can be dated back to the early 1990s, differences are reflected in the extensions of policy planning and the government's determined targets. The UK government's efforts in reducing energy consumption particularly in the domestic sector are presented in the following section. These efforts previously only focused on the most vulnerable homes but have extended to the entire UK domestic sector and housing-related sectors, such as construction and manufacturing sectors. The objectives, targets and approaches set out in a few significant policies are laid out in more detail below.

2.3.2 UK domestic energy reduction initiatives

The landscape of UK built environment legislation indicates a huge improvement in relation to the concerns of energy conservation and sustainability. Similar to evolutions in UK legislation, the policy-making of UK domestic energy performance tends to be more detailed with wider scopes. The UK's energy policies and white papers reveal their ambitions for energy transformation.

The UK government's strong environmental ambitions for the domestic sector can be traced back to 1966 when the first national mandatory requirements were published (Calderdale Council, 2010). It aims to provide better quality buildings in the aspects of construction materials, site preparation, structure stability, fire precautions, etc. The thermal insulations of the building are also requested to meet certain standards to provide a good living environment and reach energy efficiency. The first milestone of the UK government's energy policy was the establishment of the 'Building Act' (1984), which regulates detailed terms and conditions for different aspects of the built environment. In June 2000, the Royal Commission for Environmental Pollution (RCEP) published the report 'Energy – The Changing Climate', which sets out the CO_2 emission reduction target (RCEP, 2000). Fuel poverty was then firstly defined by DECC (2001) in that a household is considered fuel poor if it spends at least 10 per cent of household income to heat the house to an acceptable temperature (21°C). In 2003, 'Our Energy Future' (Command of Her Majesty, 2003) was also established. It indicates that the UK was facing energy challenges environmentally, reduced numbers of original energy suppliers and inefficient energy infrastructure. Other reports (Housing Act 2004; Command of Her Majesty, 2006; Department of Trade and Industry (DTI), 2007) have also contributed to domestic energy reduction through establishing energy schemes or implementing energy saving approaches. The review of earlier reports aims to provide a more consolidated energy policy background and consistent energy policy landscape in conjunction with the reports discussed in the following sections.

In 2007, the UK first put its CO_2 reduction targets on a legislative level. The draft framework that was developed by the Department of Environment, Food and Rural Affairs (DEFRA) sets out a CO_2 reduction target of 26 to 32 per cent by 2020 and 60 per cent by 2050 compared with 1990s' levels (DEFRA, 2007). To advocate public awareness of good building design and its advantages for energy savings, the UK DCLG developed the 'Code for Sustainable Homes' (DCLG, 2008) in order to regulate building design approaches concerning optimised energy and CO_2 emission, water, building materials, surface water run-off, waste, health and wellbeing, management and ecology. The Code stated that CO_2 emissions need to be calculated by Dwelling Emission Rate (DER) and that Standard Assessment Procedure (SAP) needs to be employed for energy simulations in the design stage of retrofit programmes. To increase the implementation of zero carbon homes, the UK government launched the Heat and Energy Saving Strategy (Department for Energy and Climate Change, 2009). The purpose of the strategy is 30 per cent of existing housing stocks achieving zero carbon through a series of approaches by 2030 and all existing housing stocks to achieve zero carbon by 2050. To secure the delivery of decarbonisation and energy conservation targets, the Energy Act (Acts of Parliament,

2013) was established to provide comprehensive guidance for all energy sectors.

The UK electricity supply targets were set out by DECC (2011) in the 'Planning Our Electric Future: A White Paper for secure, affordable and low carbon electricity'. The targets stated that the UK will benefit from a responsive and smart electricity system powered by more safety and multi-resourced electricity by 2030. Also encouraged is implementation of a full energy management system with good interactions between energy users and energy providers (DECC, 2011). Notably, it has also asserted that all coal-fired electricity plants will be closed in the future by 2023 to reduce pollution, and their replacements need to be more powerful, effective and sustainable. Electricity-generating plants are also expected to face a big decarbonisation in the future in order to meet 2020's 15 per cent renewable energy target and 2050's 80 per cent CO_2 reduction target. By introducing the 'Electricity Market Reform: policy review' (DECC, 2012), the DECC aims to respond to the abovementioned challenges by offering reliable contracts to electricity generators, providing investor-trusted delivery arrangements and achieving diverse generation portfolios.

It is recognised the fluid but inclusive approach of the UK government is one of the crucial ways to ensure successful delivery of retrofit interventions in the domestic sector. By 2011, the government released the most important legislative document regarding the UK domestic built environment - the 'Approved Document Part L: Conservation of Fuel and Power' (Planning Portal, 2011) where minimum energy performance requirements were identified in the document. In the same year, Great Britain's housing energy fact file (DECC, 2011) was developed to provide comprehensive explanations of domestic energy use between 1970 and 2008. Specific data of households was analysed and interpreted with reference to dwellers, households, geographical location of dwellings, dwelling typology, dwelling age, ownership, energy cost and household incomes. The UK government has also made great efforts towards households implementing better insulation, double glazing and more efficient heating systems. The Digest of United Kingdom Energy Statistics (2015) also shows key developments in the UK energy systems through providing detailed statistics of UK energy consumption, demands, energy prices and environmental impact. These statistics have been designated as National Statistics. It is also stated (DECC, 2015) that the components of energy resources have been reforming since 1980. Total energy consumption between 1980 and 2014 is generally steady. A continuous and slow decrease has been shown in the period between 2005 and 2014.

2.3.3 Government retrofit schemes: successes and failures

Along with the establishment of the Climate Change Act 2008, which sets out the UK's ambitious target of 80 per cent CO_2 emissions reduction by 2050, the UK government has accelerated its pace of domestic energy conservation interventions. For example, the government tightened its energy efficiency standard (DCLG, 2013a) in order to meet the 80 per cent of CO_2 reduction. Additionally, a number of incentive schemes were launched to support the uptake and delivery of low carbon retrofit programmes such as the Green Deal, Decent Homes, Warm Front, Carbon Emissions Reduction Target (CERT), Community Energy Saving Programme (CESP) and Landlord Energy Saving Allowance (LESA). Although the majority of these initiatives have already been completed, current major policies are still playing important roles in increasing occupants' incentives and project uptake rate. These initiatives include the Renewable Heat Incentive (RHI) and the new version of Feed-in Tariffs (FiTs) launched in 2016. Several significant domestic retrofit schemes are demonstrated and discussed in the following sections.

2.3.3.1 Green Deal

The UK government accelerates programme implementation by increasing households' incentives through policy-making. The Green Deal, launched in 2012 and terminated in Autumn 2015, was designed to achieve energy efficiency of UK homes (DECC., 2012b). The government permitted loans to householders for a series of energy efficiency improvements. Costs were recovered by the government through the savings of household's energy bills. The government aimed to make over 7 million UK homes benefit from this scheme by 2020. Practically, an assessment would be carried out by a Green Deal Assessor to evaluate if a particular house would benefit from the improvements. Recommendations from the assessor would reveal options for the most appropriate retrofit approaches in each particular case (DECC., 2012b). Although the Green Deal has been terminated by the Energy Secretary due to failed objective fulfilments, it is still acknowledged as one of the important energy schemes in the UK.

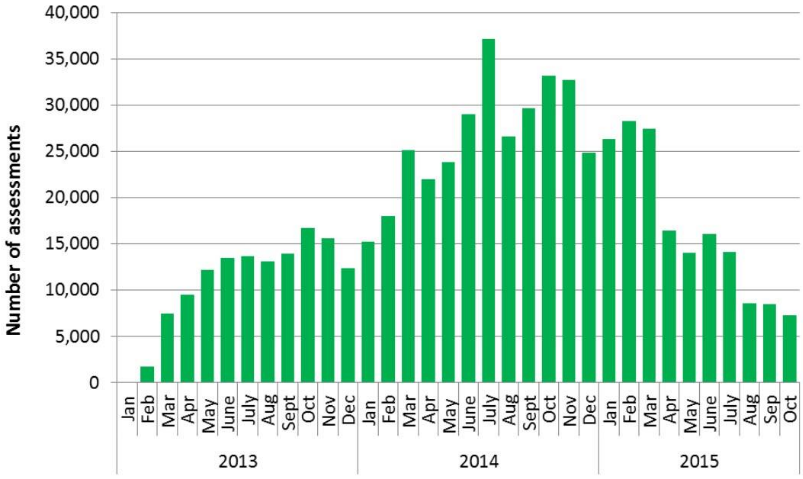


Figure 2. 5. Number of Green Deal assessments registered (DECC, 2015).

Figure 2.5 shows how many Green Deal assessments were registered through the entire period of the scheme. It can be seen that assessment registrations gradually increased and reached their peak by July 2014, and generally kept above 25,000 until March 2015. A big drop followed from 27,500 to 16,000 registrations. Thereafter, the number of assessment registrations gradually decreased to less than 10,000 until the scheme terminated. The decreasing tendency indicates that the Green Deal fail to stimulate occupants' engagement through its mechanism. The reasons of its failure are discussed below in a variety of aspects.

It is recognised that the Green Deal has not fully met the set targets (Morton et al., 2018; Howarth and Roberts, 2018; Rosenow and Sagar, 2016). Morton et al. (2018) argue that the uniform retrofit measures of implementation, regardless of particular situations, led to the failures of the programme. However, (Morton et al., 2018) a number of factors would increase the uptake rate of such programmes, including large families, university-educated family members, detached homes and young families. On the other hand, personal income, self-employed family members and energy efficiency levels of properties negatively impact on programme uptake rates. Howarth and Roberts (2018) argue that a great number of occupants did not want to pay the upfront assessment fees of Green Deal. The high uptake rate of energy assessments only happened in high energy-aware households. Hence, efforts could be made towards low or non-energy-aware families who need more efficient energy conservation approaches. In addition, lack of visualisations of retrofit measures could impact on the adoption of certain approaches. For instance, loft insulation as one of the most effective approaches is not attractive to households as its importance could be easily ignored by householders. Rosenow and Sagar (2016) point out several key areas that led to the failure of Green Deal such as lack of tailored retrofit measures, low market demand and lack of upfront funding support. It is argued that policy makers need to focus on what householders need and expand the market by introducing more attractive incentives to householders. Further, occupants' health and comfort are areas policy makers need to focus on in the future rather than prioritising costs (Rosenow and Sagar, 2016; Marchand et al., 2015).

Guertler (2012) argues that energy and social programmes fail to stop the increase of fuel poor households. It has been suggested that adopting flexible designs for Green Deal finance would have made the scheme more successful. Mark et al. (2012) explore the relationship between retrofit programmes and the government's policy-making. They believe that the UK domestic retrofit is not in a satisfactory condition as almost half of domestic retrofit programmes do not meet energy conservation targets in terms of energy savings (Mark et al., 2012). More reasons for this were analysed through exploring the relationship between policy-making (mainly for Green Deal) and the incentives for investors. Introducing incentives to investors and households for successful uptake and delivery of retrofit schemes is crucial.

Gillich et al. (2016) conclude the lessons that need to be learned from Green Deal by comparing it with one of the successful retrofit programmes in the United States, the US Better Buildings Neighbourhood Program (BBNP), in the aspects of conversion rate of assessor appointments to retrofit agreed and financial incentives. It is believed (Gillich et al., 2016) that failure to develop more active approaches to marketing and outreach meant not meeting objectives. More efforts needed to be made on communication strategies of the Green Deal. Both technical and non-technical aspects of the retrofit programme should have been thoroughly developed to secure its success. A study (Pettifor et al., 2015) states that Green Deal is particularly helpful for groups of people who already intend or are considering renovating their homes because the scheme successfully strengthens their intentions for this through a series of approaches. Pettifor et al. (2015) also suggest it is important to clarify retrofit approaches to participants at an early stage of the renovation. Further, the occurrence of any uncertainty, for example, the financial benefit generated following the retrofit, may weaken participants' intentions.

2.3.3.2 Energy Company Obligation (ECO)

As a domestic energy efficiency scheme, the Energy Company Obligation (ECO) refers to the requirement for energy companies to deliver energy efficiency measures across the UK domestic sector (Energy UK, 2018). The measure worked alongside Green Deal to retrofit dwellings. Green Deal mainly focused on the most cost-effective energy saving measures while the ECO focused on other approaches that do not follow the golden rules where the expected savings of retrofit measures must be greater than their costs attached to the energy bills (Rosenow and Eyre, 2013). The ECO started in January 2013 and was designed to replace its predecessors, the Carbon Emission Reduction Target (CERT) and Community Energy Saving Programme (CESP), which both ended in December 2012. The first period of the ECO ended in March 2015, whereas the second period started in April 2015 and ended in March 2017. The third period, which started in April 2017 is due to end in September 2018. There are 3 obligations for energy companies within the latest ECO: the carbon saving obligation (CSO), a continuation of a previous obligation, the carbon saving communities obligation, with a target saving of 15 per cent in the most deprived and rural areas of the country, and the affordable warmth obligation, targeting reduction of energy costs of low income families (DECC, 2012b). The major approaches of the ECO include SWI (solid wall insulations), CWI (hard-to-treat cavity wall insulations) and loft insulations.

Rosenow and Eyre (2013) examine the failures of the ECO in a variety of aspects. For instance, the projected £30-60 billion for SWI installations to be supported by the ECO seemed impossible for bill payers and easy to reversal due to lack of effective policy for SWI. It would be better to follow the policy of CERT, which employed low-cost measures and looked for external funding for high-cost ones. The supply chain of energy efficiency measures, such as CWI and SWI, as one of the most important parts of project efficiency was also limited by the ECO's capacities. Although supply of energy efficiency measures increased to a certain extent every year, it failed to catch up with the increase in demand. Rosenow and Eyre (2013) also argue the 130 per cent increase in employment rate, due to running the scheme, stated by DECC (2012d) was too optimistic. The estimation was based on 10,000 installers in 2015, which was not realistic. By evaluating the second phase of the ECO, Rosenow et al. (2013) further indicate that the programme failed to deliver sufficient energy saving measures for fuel poor homes because these are poorly targeted in the policy. In order to improve efficiency of energy supplier obligations, areas with a high proportion of low-income and low-efficiency homes would need to be targeted with tailored approaches.

Miu et al. (2018) test the feasibility of 3 policy frameworks as replacements for the current ECO by tackling a number of identified barriers, such as 'lack of certainty in existing schemes', 'lack of long-term planning', 'ownership issues' and 'the compliances with business models of stakeholders in charge'. The current ECO focuses more on overcoming technical and economic barriers than non-economic ones such as the impact of political commitment on retrofit measures. Miu et al. (2018) also find that the combined policies of the Variable Council Tax, Variable Stamp Duty Land Tax and Green Mortgage would effectively overcome most barriers, including motivating tenants and landlords, market expansion, customer-related issues, minimising cost and maximising demand.

2.3.3.3 Feed-in Tariff (FiT)

To encourage implementation of renewable and low carbon technologies, the UK government announced the launching of Feed-in Tariffs (FiT) in April 2010. This encourages individual households to employ small-scale renewable technologies such as installation of wind turbines, solar panels, etc. According to consultations on the FiT scheme (DECC, 2015), homes with installations of renewable and low carbon technologies can be paid at a fixed rate for each unit of electricity generated by licenced energy suppliers. Homes can also be paid for any electricity exported. As renewable electricity will offset energy consumption, households will also benefit from bill savings.

The feasibilities and influences of FiT in the UK domestic building sector have been widely discussed by a number of researchers and scholars. Pearce and Slade (2018) examine the feasibilities of the FiT scheme in the UK between 2010 and 2016. In the aspect of policy, uncontrolled cost escalation of energy led to the failure of the scheme during 2010 and 2011. It is also pointed out (Pearce and Slade, 2018) that the cost of photovoltaic panels is the driving factor of FiT. In addition, the current low tariff led to the weak influence of the scheme. Muhammad-Sukki et al. (2013) also argue that the UK has the lowest energy and financial returns compared with other European countries, which may lead to a downward trend of solar photovoltaic implementation rate in the future. Grover and Daniels (2017) examine the FiT policy by linking data of payment distribution with spatially organised census data in England and Wales. As a result, inequity in social aspects of the programme is highlighted. It is found that a number of factors need to be considered in relation to the FiT policy, including tenancy status, property type, social class of occupants, settlement density and information spillovers.

On the other hand, Cherrington et al. (2013) believe that the FiT scheme has a positive future if it focuses on providing sustainability in the manner of off-setting electricity from the national grid rather than being simply a subsidised scheme. Their investigations were carried out through a PV photovoltaic installation case study in Cornwall. It was found that a healthy return can be obtained from PV installations under the most updated FiT scheme. Although a positive result was indicated by Cherrington et al. (2013), the geographical issue needs to be considered as Cornwall, with more sufficient solar radiation, would make the FiT scheme more efficient than cities in the north of the country such as Glasgow. Saunders et al. (2012) also believe that the FiT scheme may essentially support fuel poor homes if a third party may be involved with financial support. Walker (2012) supports the same point of view by testing the UK government's 2 per cent renewable energy target through a dynamic simulation modelling package – Green-X. Referring to the advantages of FiT, it is predicted by the UK government that 2 per cent of electricity consumption in the UK will be generated by renewable sources from projects which have less than 5 MW capacities by 2020. It appears that the FiT scheme will only be capable of delivering 1.6 per cent of electricity by 2020 the maximum in a high wholesale electricity price scenario.

In summary, the FiT scheme does not work as expected due to decreased uptakes of small-scale renewable technologies. The reasons include cost escalation, low financial returns and inequity in social aspects. Therefore, the policy needs to be reworked according to different social aspects, housing characteristics and locations with sufficient financial support.

2.3.3.4 Domestic Renewable Heat Incentive (RHI)

Launched by the DECC, the Renewable Heat Incentive (RHI) is a financial scheme that accelerates the implementation of heating systems with renewable sources. The scheme is separated into 2 parts: The Non-Domestic RHI scheme and Domestic RHI scheme. It essentially works as a FiT for renewable heat. RHI was launched in 2011 and later launched again in April 2014. In the domestic sector, if a property has a renewable heating system which assists in reaching a higher level of Energy Performance Certificates (EPCs), it will be eligible for this scheme. Approved domestic properties would benefit from quarterly payments for 7 years.

Abu-Bakar et al. (2013, 2014) state that implementation of the government's RHI scheme would increase the penetration of solar thermal system installations in the UK. However, they examine whether the RHI is financially feasible through analysis of the net present value and international rate of return. The RHI scheme has not been found to work well in this respect as it has been attractive for a relatively long period or high RHI rate options. Snape et al. (2015) support this point of view that particular factors constrain the uptake rate of the RHI scheme. An agent-based model has been created in order to analyse all identified non-financial barriers of the policy. By analysing both social and hassle barriers, it has been found that improved home inspections and heat emitter performance could mean overcoming the current barriers and increasing uptake rates. By contrast, Saunders et al. (2012) expressed a more positive view towards the government's RHI scheme. They discussed how launching RHI would potentially support fuel poor homes. It is obvious that the latter are unlikely to pay for the installation. However, these homes will benefit from the scheme if there are interventions by a third party, normally energy suppliers or private companies working for local communities.

Moreover, the policy framework of RHI was examined by Donaldson and Lord (2014) through a case study of school refurbishment for geothermal heating in Glasgow. It is argued that the policy context has been clear but improvement ought to have been made in the construction phase to fully aid implementation. A broader awareness of the importance of RHI needs to be raised during the entire project with more accessible guidance for installers. It is also argued (Donaldson and Lord, 2014) that accreditation needs to be improved during the planning stage to make sure sufficient credited installations are available online for supply. Additionally, the integrated control measures of RHI need to be ensured for its success. Pioneering examples to test feasibility, cost and revenue and identify risks would also speed up implementation. A recent report (Parliament.UK, 2018) stated that RHI failed to meet its objective with over-optimistic take-up prediction in the planning stage. As a result, there were only 60,000 renewable applicants equipped compared with 6.2 million gas boilers that should have been replaced. To increase the take-up rate, policy makers need to address consumer heat choices with a flexible heat strategy. Further, upfront costs of the upgrades remained the major barrier for RHI as occupants tended to choose gas or oil boilers for a cheaper investment. Additionally, it is believed (Parliament.UK, 2018) that some of the renewable heat approaches contribute to air pollution and consequently impact on human health, such as the air pollutants emitted from geothermal and biomass systems.

The Energy Saving Trust (2011) concluded there were 3 main hurdles in implementing retrofit projects: information and awareness, hassle level and investment. These issues have been broadly discussed along with the development of the UK government's main retrofit schemes. It is obvious that there are still huge efforts to be made by policy makers in order to improve the domestic retrofit market and increase the uptake rate of retrofit projects. Successes and lessons are discussed through particular retrofit case studies in the following section.

2.4 Home retrofit case studies in the UK: successes and failures

2.4.1 Decent Homes Programme (DHP)

The Decent Homes Programme (DHP) was launched by the UK government in order to upgrade all the buildings in public sector to the standard of decency by 2010. The standards request compliance with hazards under the Housing Health and Safety Rating System (DCLG, 2006) and with reasonable conditions of repair, modern facility and thermal comfort. The programme was conducted by local authorities, mainly focusing on social housing estates with limited extension to private sectors (DCLG, 2006). By working alongside the Warm Front Scheme, the DHP aimed to tackle fuel poverty and improve domestic energy efficiency. It was stated that 39 per cent of social housing properties were in a non-decent state and in need of upgrades urgently before the DHP started (National Audit Office, 2010). As a result, more than 1 million social properties were retrofitted by the time the programme ended, which reduced the percentage of non-decent social housing to 14.5 per cent ((National Audit Office, 2010). The costs of the upgrades normally ranged from £3,600 to £10,500 according to the physical condition of each dwelling with a variety of approaches applied. It is notable that a more efficient standard of 'Decent Homes Plus' is being adopted by a number of local authorities. The more recent standard included the additional provisions of double glazing, replacement of energy efficient boilers, draught-proofing and energy efficiency doors and lighting systems (Dowson et al., 2012).

Through interviews and surveys of some social tenants in the DHP projects, a number of scheme shortcomings were identified by Hulme (2012). It is argued that cavity wall insulation need to be approached on an individual case basis as some of them were already partially filled or too narrow to add internal insulations. In addition, Hulme (2012) stated that retrofit approaches may depend on household profiles rather than be uniformly adopted. Moreover, it was found that the upgrade of heating controls might not be desirable to elderly tenants where twenty-five per cent of the participating households supported this view.

Another study (Gilbertson et al. 2008) evaluated the results of the DHP conducted in social housing estates in Ealing, London. Further challenges were identified as a series of service programmes maintaining the achievement of the DHP (Gilbertson et al., 2008). These include establishing an effective responsive repair service and providing effective compliance programmes to meet asbestos, fire safety and other health requirements. The study additionally suggested that the remodelling of kitchens and bathrooms would effectively reduce cold and condensation issues and promote independent living.

Furthermore, Jones et al. (2016) conducted a comprehensive evaluation of the DHP that was led by Nottingham City Homes (NCH) in 2008. With its local brand of Secure, Warm, Modern (SWM), the programme had upgraded 28,300 social properties worth £187 million of investments. The programme aimed to generate wider social benefits in concerning crime, security, health and wellbeing. It was found (Jones et al., 2016) that although occupants felt safer, warmer and more comfortable in their homes, all the external doors in their properties could be replaced to improve overall security and thermal comfort rather than only replacing the old and broken ones. Further, although the retrofit led to an outstanding increase of energy efficiency rating from 60 per cent to 68 per cent in SAP, actual energy savings varied according to occupants' choices and behaviour. Jones et al. (2016) stated that the retrofit would only increase the potential of housing energy efficiency. Actual savings would only be achieved by combining user-friendly technologies with occupant behavioural improvements and awareness.

Another study (Elsharkawy and Rutherford, 2018) examines the feasibilities of the Aspley Super Warm Zone (ASWZ) scheme in Nottingham by investigating the impact of occupants' energy consumption behaviours and awareness on the delivery of the government's retrofit programmes among social housing estates. Through a 2-phased survey of pre-intervention and post-intervention homes, it has been found that although significant energy savings and housing improvements can be acknowledged, the expectated£300 annual savings on energy bills were not achieved. The reason for this has been found to be partially due to occupants' energy consumption behaviours which, in many cases, have not improved in order to properly operate the retrofitted dwellings and achieve the maximum savings. Energy consumption can also easily be compromised for personal comfort (Elsharkawy and Rutherford, 2018). Further, more communication methods are needed in order to inform and educate occupants in a variety of ways and consequently increase their energy awareness and knowledge.

2.4.2 Kirklees Warm Zone (KWZ)

The Kirklees Warm Zone (KWZ) is a large scale domestic retrofit programme which was led by Kirklees Council to provide free loft and cavity wall insulations for all suitable households, including social and private housing, between 2007 and 2010 (Liddell et al., 2011). The programme won the Ashden Award for best practice of a local authority's energy scheme in the UK to tackle climate change and fuel poverty. Kirklees is located in West Yorkshire, England, with a population of 401,000. There were 35,000 to 45,000 homes under fuel poverty in 2006 before the programme started. The KWZ aimed to change energy conditions by tackling fuel poverty, delivering low carbon district heating, improving uptake rate of state benefit support by residents and creating jobs for local people (Liddell et al., 2011). As a result, the delivery of the KWZ brought benefits in a number of aspects: 30,207 homes were insulated, which comprised 15.4 per cent of overall homes in Kirklees; £9.1 million in project investment against £10 million annual energy savings (Backhaus, 2009); besides a further-reaching benefit of increased awareness in the population.

There are several elements that could be learned from the planning stage of the KWZ. Through an exploration of the UK's largest retrofitting scheme, Webber et al. (2015) suggested that the wider the project spread, the more efficient a project would be. A large-scale post-evaluation was carried out in order to investigate the real impact that the KWZ brought. It was found that the pace of programme adoption needs to be accelerated, also suggested by Smith and Swan (2012.) Due to the concern for cost-effective installation, a large scale retrofit programme was seen to be more appropriate. Bergman and Foxon (2017) also argue that the ideal package of UK domestic retrofit should consider the KWZ mechanism plus the aggregation of ward-based projects with local knowledge of particular situations. Enlarging the scale of the programme will effectively lower investment. But tailored approaches need to be adopted to address local challenges. Further, Bergman and Foxon (2017) put forward that the approaches adopted in KWZ might be difficult to duplicate due to the current economic and policy environment. Although great success was achieved by the Kirklees Council, improvements that could be made in future projects are possible.

Fawcett et al. (2014) also argue that the pace of implementing low carbon retrofitting needs to be accelerated, and that the number and scale of projects in public and private housing sectors are still too small. Through presenting 'time, scale and business' models, the research aims to inform the most appropriate retrofit approaches for policy makers and project leaders. By modelling a number of case studies with different typologies, it was found that the ideal retrofit target would be a highly co-ordinated large-scale area-based programme such as large scale social housing estates (Fawcett et al., 2014). Private housing sectors are found to be difficult to work with as there is a lack of co-ordination between individual householders. Individual retrofit projects may also, due to their smaller scale, lead to more financial and technical complexities.

To ensure a high uptake rate of the scheme, it is also important to increase incentives for householders to participate. Through a different approach, Long et al. (2014) conducted a survey targeting 500 householders in the Kirklees Warm Zone scheme. The research aimed to explore the factors that could potentially impact on householders' attitudes and incentives, and consequently support the delivery of retrofit programmes with higher uptake rates. The result of the survey showed that people were willing to be engaged if the scheme is from a highly trusted provider. Also, advantages of a low carbon retrofit should be emphasised such as energy saving, health improvement and financial benefits. The factors that might decrease householders' participation include the poor design of the programmes, time demands and concerns about the hassle from installation. The same point of view is supported by Pettifor et al. (2015) that participants' intentions may be weakened by uncertainties such as unclear financial benefit. Additionally, the method to get participants involved in the process needs to be improved from a 'one-off event' to 'a series of stages': inform and communicate with participants with proposed retrofit approaches at an earlier stage, and help them to make the most appropriate renovation decisions. Fylan et al. (2016) carry out an unstructured interview with 48 participants in 6 different professional positions in relevant fields to investigate what the main barriers are to low carbon retrofit schemes. As a result, 4 issues were identified; funding mechanism, installation, people, and predicting performance. It was identified that funding mechanism acts as one of the major barriers due to insufficient time on funding preparation. because the time taken over scheme planning, publicising and evaluating is insufficient.

2.4.3 RE: NEW

Driven by the GLA and in collaboration with the LDA, London Councils, the Energy Saving Trust and London Futures, RE: NEW was launched in 2009 to meet London's CO_2 emissions reduction target of 60 per cent by 2025. It is reported (GLA, 2010) that "RE: NEW brings together London's existing domestic energy retrofit programmes into a coherent model to cost-effectively up-scale efforts on domestic CO_2 reduction and has established a consistent 'London-wide' and 'area-based' delivery model in order to achieves this". It was planned to retrofit 200,000 private and social homes by 2012 and 1,200,000 by 2025. By early 2016, more than 110,000 private and social homes had been improved and 30,000 tonnes of CO_2 saved annually on average (GLA, 2016). The programme provides extensive supports to social housing providers and local authorities in the aspects of environmental consultancy, promoting behavioural change, communicating to hard-to-reach audiences and large scale investment management.

It has been reported (GLA, 2010; GLA, 2016) that the area-based, ward-sized approach helped achieve an efficient implementation rate in the scheme. The highest penetration rates appeared in Southwark, Croydon and Lewisham. It has been asserted that offering easy and immediate retrofit measures to households will help achieve immediate CO_2 and bill savings as it further increases the likelihood of households carrying out future retrofit measures.

However, one of the problems identified (GLA, 2010) is that property assessors may miss-identify referrals due to a lack of accuracy in reporting. In order to incentivise occupants and increase the conversion rate from home visit to installation, referrals were made where home assessors could install small energy or water measures which are suitable to the target property, such as more efficient energy meters and low flow faucet and showerheads (GLA, 2010). The conversion rate from home visit to first installation is consistently low as the delivery agent only works during the daytime and limits their scope to social housing properties only. The connection with landlords has also been seen as insufficient (GLA, 2010). The report further stated that offering free, easy measures increases the likelihood of carrying out further retrofit approaches but may negatively impact on the programme. The reason for this is that the free measures are always the most cost-effective among all of them. Therefore, harder measures which require much more investment of time, funds and energy but with less return may not be preferred by occupants. Some may even have failed in particular property situations, such as the installation of insulations and replacement of boilers. It was suggested that energy display units and water-saving devices should always be considered as some of the most cost-effective retrofit measures. It was stated (GLA et al., 2010) that to improve the referral process, better training of Home Energy Assessors (HEAs) before a home visit and better identification of the potential for referral will effectively result in more robust referrals.

As part of the RE: NEW programme, Amicus Horizon was appointed as the contractor to conduct area-based retrofit interventions for 204 social housing properties in Stockwell, South London where most of the occupants were hard to reach with certain degree of language barriers. A translation service and several approaches were adopted to reach the occupants, such as letter, emails and phone calls. The lessons learned from that project were concluded by Holgado and Davies (2016) that more investments need to be made towards communication. Besides, desktop validations of energy data were not sufficient during the design stage of the project. Therefore, the identified SAP ratings of the target properties were not accurate enough to inform the most appropriate retrofit approaches. In addition, literature posted to the occupants in order to prompt the projects was abundant but too complicated. It confused occupants and affected the communication between them and the contractor during the project. It is recommended that promotion of the retrofit programme needs to be more informative and strategic to strengthen collaborations between stakeholders and deliver on saving costs.

2.4.4 Other case studies of retrofit programmes

The UK government has great ambitions for energy conservation in the UK's social and private housing sectors. Although a great number of programmes have been completed, the results of them did not fully meet set targets. Sunikka-Blank and Galvin (2016) discuss how the target group of occupants needs to be explicit to ensure successful delivery of the programme because retrofit measures vary depending on household profile and housing typology. Regarding existing UK homes with historical value, a qualitative interview was carried out to investigate how aesthetics and traditional features influence thermal retrofit decisions (Sunikka-Blank and Galvin, 2016). It was found that homeowners are struggling to balance those issues. Normally homeowners prefer not carrying out thermal efficiency improvements due to concern over traditional features such as traditional facades and slate or lead roofing. This is also believed as one of the reasons why the government does not prefer to get homeowners involved in such schemes.

In the case study of 20 owner-occupied households in East Midlands, UK. Five different personas of retrofitting packages with whole-house approach were tested among participants including boiler replacement, suspended timber flooring insulation, double glazing, draught proofing, ventilation system, wall and roof insulations. It is found by Simpson et al. (2016) that the sequence of apply those approaches are different among scenarios. It is found that implementing whole-house retrofit with different sequences would result in the differences of energy savings between 42 and 24 per cent. Hence, the intervention sequences need to be carefully designed. A significant variance between predicted and actual energy savings was also identified. The reason for this is that as the operational performance of an individual energy saving technology depends on what other technologies have already been employed, different intervention sequences will lead to different cumulative energy savings (Simpson et al., 2016).

Through combined approaches of energy and thermal modelling and field measurement, Jones et al. (2017) examine the impact of the 'whole house' retrofit approach on 5 individual houses of different typologies in social housing sector. Aspects examined include annual energy consumption, CO_2 emission and cost savings. The system-based approach tested during the investigation included reduction of energy demand, renewable energy supply and battery storage. The results showed that the 'whole house' approach may reduce 50-75 per cent of CO_2 emissions with cost savings between £420 and £621. Apart from the financial benefits, the retrofit approach also helped reduce fuel poverty, releasing stress on the electricity grid and reducing CO_2 emissions. Adopting the same approach, Li et al. (2015) also examine effectiveness of the different retrofit strategies for 3 different types of houses in Wales. The results asserted that the fabric approach is one of the effective ways to optimise energy performance for poorly insulated homes. More than 90 per cent of electricity demands were also made through the installation of PV panels. In addition, a system-based approach with a renewable energy supply is more effective if the house is properly designed (Li et al., 2015).

By monitoring 36 homes in Milton Keynes as part of the Carbon Reduction in Buildings (CaRB) project, Lomas (2010) indicates that reducing energy consumption through energy efficiency measures is not optimistic as the feasibilities of current energy policies cannot be assessed by any form of tool or information. Further, cost-effectiveness still needs to be improved in particular buildings such as larger detached properties. Through retrofit simulations in a typical terraced house in the UK, the thermal environment is assessed by Lee and Steemers (2017). They find that improvements of insulation may lead to substantial overheating if the dwelling is not properly ventilated and protected from direct solar radiation. As a result, retrofit approaches need to be systematically considered as a whole package to prevent potential problems. However, Lawrence and

Keime (2016) argue that "comfort and energy efficiency should not be seen as mutually exclusive" as a win-win situation still can be achieved: dwellers' perceptions of comfort can be improved if the degree of environmental control is improved in the dwelling. It shows that people may feel more comfortable even if energy consumption is not amplified. By carrying out surveys of thermal comfort, energy performance and environmental strategies at two higher education buildings in Sheffield with 101 participants, it was found that occupants' tolerance will improve along with increasing the degree of environmental controls. It is also suggested that active and passive design need to be utilised in the design stage to achieve a better post-occupancy building energy performance (Lawrence and Keime, 2016).

In addition, quality of the delivery of retrofit measures has significant impact on energy efficiency in social dwellings. Gupta and Gregg (2016) state that ineffectiveness of installation work of Retrofit for Future (RfF) could lead to gaps between expected energy performance and actual energy result. The RfF was initiated to target to the UK's social housing sector by implementing whole-house approach. Based on their building performance evaluation (BPE) of two different types of UK homes in social housing sector, it was found that the U-values of retrofitted homes were actually higher than the ones used in the energy modelling. As a result, the targets of CO_2 reduction and energy saving were not met in reality. The reason why gaps occurred is that contractors improperly installed insulations and windows due to poor planning and working around the residents. The installation work was less efficient if occupants are in-situ. Moreover, through an interview of 48 interviewees working with local authority, housing association and retrofit delivery, Fylan et al. (2016) found that onsite installation may be adapted from the original retrofit design due to lack of design details. Further, sufficient information regarding benefits and energy consumption behaviour needs to be provided to occupants alongside the retrofit intervention. This can effectively prevent the failure of the project from improper operation at the post-retrofit stage (Fylan et al., 2016).

This section provided a broad discussion of major UK retrofit schemes and a number of projects carried out at local level. The lessons learned from these projects were presented. In summary, one of the common problems is that retrofit measures need to be designed according to household profiles and physical conditions of homes. The scale of a project also impacts on its outcome. Additionally, funding, is one of the primary issues, which can directly impact on occupants' incentives and uptake rate of projects. Further, upgraded homes need to be taken care of after handover to maintain their efficiency through a variety of services that should be provided. Most commonly argued is that occupants need to properly operate their homes to achieve the expected energy performance result.

2.5 European home retrofit case studies: lessons learned

In order to tackle climate change and meet CO_2 reduction targets, a series of schemes and policies have been realised to help retrofit existing housing stocks worldwide. A number of UK retrofit programmes with their successes and failures were discussed in the previous sections. Aside from that, a number of retrofit programmes conducted across Europe are hereby presented and used as reference. Their results and adopted approaches have been examined by researchers and scholars in order to inform future retrofit programmes with more efficient solutions.

Taking the example of how Germany undertakes low carbon retrofit programmes, policy-making is assumed to be fundamental to the success of these projects. Several reports (Power and Zulauf, 2011; Schirmer, 2011) state the reason why low carbon retrofit can be implemented thoroughly in Germany is that it is benefitted by the advanced '3-pillars' system, which includes clear legislation and tight regulations, robust financial incentive schemes and good knowledge and information delivery. As a result, Germany is retrofitting 200,000 buildings (or 400,000 households) each year with 900,000 new jobs created in the market since 2006 (Schirmer, 2011).

The Low Energy Housing Report (LEHR) was produced in Belgium in order to identify exemplary housing renovation projects, spread knowledge to home owners and give design insights to project planners (Mlecnik et al., 2010). Different approaches are encouraged for different retrofit scenarios. For example, private building owners are reached, advised and given demonstrations of low carbon retrofit simulations when demand for housing renovation appears. On the other hand, for private rented sectors, it is more important to set up examples of quality improvements in order to highlight particular difficulties and solutions. As for social housing, cooperation between occupants and their representatives such as housing associations or local authorities is essential. Any good practices in these scenarios should be reinforced in the energy policy-making process. The development of the LEHR is a collaboration with the European Project, E-Retrofit-Kit. In order to inform the feasibility of low carbon retrofit for different building typologies, the E-Retrofit-Kit has been developed by the Energieinstitut Vorarlberg in collaboration with Austria, Denmark, Lithuania, Spain and the Netherlands (Passive House Retrofit, 2008). With the comprehensive information of building typologies provided by those countries, the tool allows decisions on whether retrofit schemes can succeed or not by assessing particular types of building stock in the aspects of principles, finance, best practices and non-energy-related issues. The development of the toolkit aims to inform the feasibility of targeted buildings and help make the right decisions for stakeholders, local authorities and the government at management level. It helps to refine the 'top - down' approach and make retrofit programmes more energy-efficient.

One of the most noticeable and successfully government-supported retrofit schemes is the 'Energiesprong' in the Netherlands. The scheme uses social housing sector as launching market in several countries. It aims to deliver a 'whole-house' retrofit approach within a week (1 to 2 days minimum and 7 days maximum) to make a property reach zero carbon level (the Energiesprong UK Limited, 2015). Comparing this with the UK's conventional retrofit programmes, the 'Energiespong' keeps occupants 'hassle free'. It is shown (Dowson et al., 2012) that 'hassle' is one of the biggest barriers preventing householders from taking part in such projects. The reason why such a short installation time is applied in the Netherlands is most of the works are expected to be precast off-site. Hence, the time-consuming in-situ is much reduced. Another advantage of the Dutch project is that it emphasises the importance of the product's appearance in order to meet occupants' aesthetic demands and increase their interest. To ensure the success of the project, the supporting policy framework is important. The business plan of the project is designed to transfer a household's energy bills to an energy plan. Households are promised a fixed energy bill the same as they have previously paid including instalments of project costs (the Energiesprong UK Limited, 2016). This plan increases incentives for householders and prevents the risk of their bill increasing. Additionally, monitoring devices are installed to diagnose and report on unusual energy and temperature performance for future technical interventions. The technology employed in off-site pre-casting and consideration of products' appearance are useful points to consider for the capability of the UK industry.

A report (De Kluizenaar et al., 2016) on the Dutch retrofit project - RETROKIT - indicates the importance of design adverse effects prevention strategies in retrofit programmes. A series of experiments were carried out to measure occupants' perceptions, energy performance and indoor environment quality (IEQ) after the RETROKIT had been completed. Problems found include that although a winter temperature is perceived comfortable, a summer temperature is 'somewhat' too hot and uncomfortable. Additionally, outdoor noise is perceived to affect occupants' living environment. Moreover, through monitoring of the indoor environment, it is indicated that some chemical gases such as formaldehyde and α-pinene exceed limited levels and will impact on human health. The basis for optimisation of future retrofit programmes is identified (De Kluizenaar et al., 2016) as retrofit programmes not ending at the stage when installation works are completed. Huge and consistent efforts are also recommended including gathering occupants' feedback, return visits, project maintenance and adverse effects prevention strategies. Based on this review of UK and European retrofit projects, the issues preventing efficiency of the projects are concluded in the next section.

2.6 Issues of home retrofit programmes

2.6.1 Scope and measures

Several case studies reflect that the scope of retrofit programmes needs to be carefully considered in order to maximise their outcomes and achieve optimum energy saving. The success of the KWZ in the UK proved that large-scale projects are more cost-effective for retrofit measures and installations (Smith and Swan, 2012; Fawcett et al., 2014). Some reports (GLA, 2010; GLA, 2016) also state that the UK's RE: NEW projects adopted a 'London-wide' project scale to increase impact. However, the 'area-based' approach was also adopted to increase implementation rate of the projects as retrofit measures need to be tailored according to a number of social and technical factors (GLA, 2010; GLA, 2016). Dowson et al. (2012) also believe that incentive schemes do not cover the full extent of private and social homes. Apart from policies issues, societal barriers have also been discussed. It was pointed out that householders are not willing to carry out low carbon retrofit because of the interruption of installations, huge amount of investment and the uncertainties of retrofit perspectives.

To identify proper retrofit approaches is critical to the success of retrofit programmes (Rosenow and Sagar, 2016; Rosenow et al., 2013; Ma et al., 2012). Jones et al. (2017) argue that the package of retrofit measures applied needs to address the specific needs of each individual house and will differ from house to house. In order to do this, housing conditions and a number of social and economic factors need to be taken into consideration. The same point of view is supported by Fylan et al. (2016), who put forward that the whole preparation process of the retrofit scheme is normally not consistently undertaken. That leads to insufficient time spent on determining the most appropriate approach for different dwellings. In addition, the importance of taking a proper retrofit approach is to effectively use funding, thus reducing initial upfront cost and increasing targeted dwelling numbers. Retrofit schemes commonly focus on insulation of walls, lofts and roofs with less focus on smaller elements as they do not play an important role in overall energy savings. Gillott et al. (2016) urge the importance of improving dwellings' airtightness by using draught-proof measures. It was found that air permeability in the case under study was reduced by 30 per cent by combining draught-proof measures with conventional air tightness ones. Additionally, the predicted retrofit result was improved from 32,373 to 23,197 kWh (Gillott et al., 2016).

In evaluating the current condition of the low carbon retrofit market in Germany, Neuhoff et al. (2011) state that in order to meet the 80 per cent CO_2 emission reduction target by

2050, deep thermal retrofit approaches that are normally packages of combined retrofit measures to achieve a higher energy saving percentage need to be widespread. The research study also emphasised the importance of the exteriors of buildings following retrofit interventions.

2.6.2 Energy modelling in design stage

The 'Building Performance Gap' (BPG) is defined as the disparity found between predicted energy use during the building design stage and actual energy use in operation (Menezes et al., 2012). One of the reasons for performance gaps is unrealistic input parameters of occupancy behaviour and building management in the energy performance model (Martincigh et al., 2016; Jad et al., 2016). Therefore, communication between model designers and occupants is crucial as occupants' energy use patterns need to be taken into consideration (Lopes et al., 2012; Guerra-Santin et al., 2016). Case studies conducted in Germany (Sunikka-Blank and Galvin, 2012; Rosenow and Galvin, 2013) indicate that the energy rating system may overestimate energy savings, underestimate payback periods and discourage cost-effective measures. Those problems are often caused by a 'rebound effect' or 'comfort taking', which offsets the benefits of retrofit measures due to behavioural issues. A case study of public buildings has been employed focusing on lighting and small power and kitchen appliances to demonstrate that combined data monitoring and predicating modelling will improve the energy simulation result to within 3 per cent of actual energy performance (Martincigh et al., 2016).

In addition, De Wilde (2014) classifies the BPG into 3 categories, the gap between prediction and measurement, gap between machine recognising and measurement and gap between prediction and display certificates. It is believed that to bridge the BPG, an integrated approach needs to be achieved with respect to model validation, improved data collection and improved forecasting. Gupta and Gregg (2016) also support this point of view. Looking at building performance of two different types of homes at pre-retrofit and post-retrofit stage, it was found one of the issues leading to unexpected actual energy performance is inaccuracy of the input parameter such as the buildings structures. Calibrating real data of energy and environmental performance into the design of energy modelling is recommended. Gupta and Gregg (2016) also argue a series of social factors need to be taken into consideration at the model designing stage such as the number of occupants and occupancy profiles.

A report by Li (2014) suggests the two major conventional types of energy simulation models have their own problematic aspects: physical models are good to employ at planning stage but lack precise parameters; and empirical models completely relying on data lack practical applicability. The principle shortfall of both types of model is over-parameterisation and lack of system mechanisms. The proposed energy simulation model allows easier operation and provides more accurate predictions for an indoor environment with dynamically modelling the interactions and uncertainties in energy performance.

2.6.3 Uptake of retrofit programme

Householders' incentives are considered one of the key issues determining the success of low carbon retrofit. Carrico et al. (2011) argue that combined strategies need to be employed to increase target groups' incentives with respect to motivations and information clarity. By carrying out a comprehensive two-phased housing survey, Mlecnik et al. (2010) found occupants' incentives for renovating their housing are better use of space, housing quality improvement, comfort improvement and enhanced quality of life. It is suggested that policy-making should also address a number of non-financial motivation factors such as improved quality of life, energy conservation and housing appearance. Ravetz (2008) and Power (2008) found that dwelling owners were not keen on conducting retrofit due to conflicting interests between them and the government. It is stated (Mallaband et al., 2013) that energy savings are always considered as an additional benefit instead of people's main incentive. Usually, refurbishing a house with new facilities is considered prior to energy savings by occupants and needs to be addressed in policy making.

Beillan et al. (2011) investigate the implications of socio-economic factors and occupants' incentives through case studies in five European countries: Germany, Switzerland, Italy, Spain and France. Research data was collected through interviews of retrofit programme decision-makers (the occupants) and stakeholders. Occupancy experiences and context of retrofit projects such as motivations, works undertaken and participants' attitudes, were queried. The study found that energy saving was not the exclusive reason to get people involved in a retrofit project. Further, more specialists need to be properly trained for the delivery of retrofit projects and public support schemes to avoid low quality installations.

In order to increase occupants' incentives to implement more housing insulation, 'FIXIT' was developed by Tong et al. (2018) to highlight the advantage of a retrofit approach for reduction of carbon emission and coal consumption. The toolkit comprises the Integrated Environmental Solution - Virtual Environment (IESVE) that was used to evaluate the impact of physical building characteristics on energy consumption and the Design of Experiment (DOE) model, used to identify mathematical relationships between different factors. Without in-depth engineering knowledge being required, occupants should use 'FIXIT' to understand building performance and make decisions on installing insulations in their homes. To help occupants identify the most appropriate retrofit approach, Jafari and Valentin (2017) have developed an innovative decision-making application suite for low carbon retrofit primarily focusing on cost-optimisation and occupants' financial benefit. With a number of criteria adopted, such as energy simulation, retrofit approaches identification, Life Cycle Analysis (LCA), budget and retrofit strategy optimisation, the application is used as a benchmark in Mexico to propose and assess the best retrofit approaches.

Erik and Nirooja (2013) explore innovative approaches that can increase householders' energy saving incentives. A model combining 3 influencing components of the householder's retrofit incentives was introduced and analysed. Data was collected through surveys capturing participants' decisions. Based on the findings, Erik and Nirooja (2013) argue that there is a combination of factors appearing when making decisions on whether to take part in a retrofit projects or not: householders' incentives and policy-based influences. The same study also suggested that householders' retrofit decisions are subject to affordable materials and installation costs if the programmes are not funded. The project, not only focused on providing decision-making suggestions for retrofit programmes, but also contributed to pro-environmental behaviours. The factors that impact on occupants' uptake incentives of retrofit programmes are broadly discussed in this section. Apart from the financial and environmental benefits, the importance of social and behavioural benefits that retrofit could potentially bring to the occupants need to be also addressed.

2.7 Conclusion

Based on the reviews of the above-mentioned literature, a number of common issues that potentially impact on energy efficiency in both social housing and private rent sectors are identified. The way to tackle the challenges in the retrofit market is also discussed by the researchers and experts. However, there are still some gaps that have not been focused on in either theoretical studies or the practices of retrofit projects. The issues demonstrated cover comprehensive aspects in the relevant fields.

In the design stage of retrofit, more arcuate modelling is essential to forecast the results of retrofit interventions (Menezes et al., 2012; Galvin, 2014; Wilde, 2014). In order to do that, occupants' behavioural issues need to be taken into the consideration together with improved model validations and data collection (Menezes et al., 2012; De Wilde, 2014). In the project delivery stage, inappropriate conduct has also been proven as one of the major issues that leads to failure of a number of projects (GLA, 2010 and 2016; TSB, 2012 and 2014; Long et al., 2014). Additionally, the best opportunity to educate and inform occupants to secure soft-landing of a project is during the delivery stage. Hence, sufficient communications between specialists and occupants are crucial (Gilbertson et al., 2008). Moreover, occupants' incentives are valued as one of the key issues for the success of low carbon retrofit programmes. A number of researchers focus on how to increase society's incentives when retrofit policies are created. It is reported that occupants' incentives could be significantly increased through adopting decision-making devices at the user's level (Firth et al., 2013; Dowson et al., 2012). Furthermore, lessons and exemplary projects in European countries can also inspire the development of the UK's retrofit projects in the future. Better appearances of retrofit products would potentially increase occupants' incentives (the Energiesprong UK Limited, 2015). The off-site precast component would minimise the period of the project and the hassle it brings to occupants. Further, non-financial and non-energetic motivation parameters are also essential for policy makers. It has also been stated by Thomsen et al. (2016) that a retrofit project will be more efficient if participants are involved in the decision-making process.

It is noted that occupants' energy consumption behaviours and their lifestyles further significantly impact on home energy performance. In relation to the UK's low carbon retrofit, the impact of occupants' behaviours and possible behavioural interventions to improve these are presented in the next chapter.

Chapter 3. Occupants' energy consumption behaviour and behavioural interventions

3.1 Introduction

After examining the delivery and outcomes of several major UK retrofit programmes in Chapter 2, this chapter undertakes further exploration of their successes and failures by focusing on the impact of occupants' behavioural issues. The focus is primarily within the UK's social housing sector but also extended to owner-occupied and private rent housing sectors for more comprehensive and meaningful discussion. It is believed that although the UK's retrofit programmes are relatively successfully delivered, energy performance may still not meet expectations. The reason for this is the way occupants operate their homes will also lead to the BPG (Galvin, 2014; Zahiri and Elsharkawy, 2018; Zahiri et al., 2018). The methods of regulating energy consumption behaviours and consequently improving energy performance is another focus of the current study. The approaches adopted in order to improve occupants' energy consumption behaviours are widely discussed in the following sections. Additionally, in the background of the transition of the UK's energy network, a great number of components are adopted to help improve occupants' energy saving awareness such as IHDs and smart meters. Their impact on occupants' behaviours is also discussed. Through examination of energy management applications, there is an aim to explore the potential opportunities to contribute to home energy conservation in a new and innovative direction. The review of applications helps to identify gaps and inform the research questions on how to provide more effective behavioural interventions through energy management applications.

It is noted that behavioural interventions for occupants need to be designed by considering both, policy makers (top-down) and end users (bottom-up). The ways that occupants operate their homes could be influenced by tailored policies supported by strategic interactions with energy management applications or smart meters. Reports (Abrahamse and Steg, 2009; Gupta, 2010) suggest that policy making needs to consider occupants' varying socio-demographic background, such as age and family size, to promote behavioural change. Due to insufficient energy knowledge, user manuals for home operation need to be simple and clear (Elsharkawy and Rutherford, 2018). Besides, 'face-to-face' and other format of interactive approaches could be implemented by policy makers to suit different group of people (Zhao et al., 2017). This chapter aims to examine the importance of occupants' energy consumption behaviour on home energy performance and existing approaches to promote home operation.

3.2 Occupants' energy consumption behaviour and home energy performance

3.2.1 Impact of energy consumption behaviour

As previously stated, the significant impact of occupants' energy consumption behaviour has been increasingly realised as energy performance may still not meet the set targets albeit retrofit measures are successfully installed. In general, there are two types of energy performance deficits identified: the 'rebound effect' and the 'prebound effect'. The former is identified as when real energy performance is higher than expectations and the latter when real energy performance is lower than expectations (Galvin, 2014). As many retrofit projects could not achieve expected levels of energy savings, the research focuses on the issues that lead to 'rebound effect', which mainly happens following project handover. This is mostly related to occupants' lifestyle and occupancy patterns and the way in which they operate their retrofitted properties.

The importance of addressing 'rebound effect' is emphasised by Galvin (2014) as being "more useful for performance evaluation of thermal retrofits of existing homes: defining the 'energy savings deficit' and the BPG". The 'rebound effect' has been widely discussed by experts and scholars. Greening et al. (2000) argue that the definition of rebound is not clear as it has various interpretations. It is stated that the primary issue that leads to rebound in the residential sector is the space heating and space cooling behaviour of energy end users (Greening et al., 2000). A range of 0-50 per cent rebound was identified for a 100 per cent increase in energy efficiency. The impact of 'rebound effect' was also advised by Sorrell and Dimitropoulos (2008), who state that serious and extensive rebound may destroy policy measures for energy efficiency in domestic and public sectors. To tackle the 'rebound effect', Li et al. (2017) examine a number of mitigating factors through the implementation of a computable general equilibrium model for policy. The computable general equilibrium model is generally used to predict how economy reacts to the changes of policy by employing actual economic data. They suggest that energy subsidies reformation which includes replacing the current fossil fuel subsidies and providing clean energy subsidies could fundamentally offset it.

The mitigation of energy savings due to occupants' behavioural issues were also identified by the researchers based on the investigation of social housing estates. Through the investigation of social housing tower block in Newham, London, Zahiri and Elsharkawy (2018) and Zahiri et al. (2018) indicate that home energy consumption patterns and indoor thermal comfort are significantly influenced by occupants' energy behaviours and their socio-demographic characteristics through a variety of approaches such as simulation modelling, site monitoring and structured interviews. The study has found that an improper method of operating homes may lead to energy over-consumption. Through the evaluation of 10 recently retrofitted multi-family residential buildings that cover 1,100 flats in Geneva, Jad et al. (2016) asserted that only 42 per cent of the predicted energy savings could be achieved in reality. The failure of the retrofit is due to building operation and occupants' behaviours. Other scholars supporting this include Gupta and Gregg (2016), Jad et al. (2016) and Mills and Schleich (2012).

By monitoring electricity consumption of 72 UK dwellings from 4 social housing estates and 1 owner-occupied estate for a two-year period, research by Firth et al. (2008) identifies that the built form does not play an important role in dwellings' energy performance. Instead, various social and behavioural issues determine how much energy will be consumed such as number of occupants, types of electronic appliances used and occupants' behavioural patterns. From another study (Guerra-Santin and Itard, 2010), households with a programmatic thermostat were found to be consuming more energy than households with a manual thermostat because users tended to turn the heating on for longer. The same study also indicates that elderly occupants use heating and ventilation systems more than younger occupants. Urge-Vorsatz et al. (2007) point out that reducing the life-cycle cost of materials will significantly reduce energy consumption and greenhouse gas emissions. Moreover, non-technological approaches can also contribute to energy savings such as behavioural and cultural elements and energy-use patterns. Lee et al. (2013) argue that in order to achieve 60 per cent CO_2 reduction by 2050, it is crucial to emphasise behavioural changes and increase carbon tax. Through investigation of social housing estates in the RfF project, Gupta and Gregg (2016) also state that a low level of communication between professionals and occupants regarding behavioural issues may lead to failure of a project. During the retrofit delivery of large scale social housing estates, contractors are encouraged to communicate with occupants and support them in understanding appropriate methods of operating their homes (if they are not moving out during the energy upgrade). This is supported by Shi et al. (2017).

From a different perspective, Galvin (2014) highlights the 'rebound effect' as a metric that is not precise. Three types of 'rebound effect' are identified in relation to different metrics and employed in empirical studies of three 30-apartment buildings in Germany. They include classic 'rebound effect', 'energy saving deficit' and the 'energy performance gap'. Each metric is used for a specific condition in order to be precise. As there were concerns around the 'rebound effect', energy performance was monitored in the project in terms of energy consumption and CO_2. Sunikka-Blank and Galvin (2012) also argue that behaviour changes (non-technical measures) play a much more important role in energy saving than policies tend to assume. Additionally, it has been reported (TSB 2014) that the RfF Programme finds total investment in the programme is £17 million, of which £20,000 was used to award the 194 best retrofit strategies to stimulate household engagement in social housing sector and promote energy consumption behaviour.

The ‘rebound effect’ has been proved by Ben and Steemers (2014) in a project based in the Brunswick Centre in London. The researchers examined the implication of people’s behaviour in relation to listed buildings being retrofitted. To explore the effects of householders’ behaviour, a physical retrofit model framework was developed at a domestic level, based on a validated energy simulation tool using IES-VE. Factors of occupants’ behaviour are converted to different parameters and taken into account in this model framework. It was found that a lower level of behaviour change effect is associated with a higher retrofit level. As there were certain degrees of retrofit restrictions on the listed buildings, the effect of behaviour change was more obvious. Heating and indoor temperature has the highest saving potential among other sectors in relation to behaviour change.

Wei et al. (2014) carried out dynamic energy performance simulation by taking into account different types of occupant behaviour. They believe that occupant behaviour is one of the key determinants of home energy performance. They found that only part of behaviour-related factors was previously indicated, such as age, gender, culture/race, income, ownership and education level (Wei et al., 2014). Other factors had only been mentioned in limited publications and needed to be further investigated. Wei et al. (2016) then extend their research to the public building sector. By employing the same approach, they suggest that certain behaviour such as heating-related behaviour has a large impact on low carbon retrofit outcomes. Elsharkawy and Rutherford (2015; 2018) conduct a survey questionnaire to investigate householders’ awareness of the relationship between behaviour changes and household energy efficiency. They did this in one pilot area of social housing estates in the Community Energy Saving Programme (CESP) in Aspley, Nottingham. It was concluded that the majority of participants had a basic awareness of energy saving actions such as ‘turn off unwanted lights’, ‘boil only water needed’, ‘unplug unused equipment’, etc. However, the big challenge is still addressing habitual energy consumption. The researchers believe that policies and schemes need to incorporate awareness raising strategies. It was stated that a tenants may consider using electrical appliances and heating systems to suit their lifestyle and gain reasonable value more than utilising them at optimum efficiency (Elsharkawy and Rutherford, 2015; 2018). Other studies also support the findings (Smith and Pett 2005; Pretlove and Kade 2015). Through the investigation of identical low-energy-standard houses in the southwest of the UK, Jones et al. (2016) indicate that buildings with an extremely high degree of insulation may be considered uncomfortably warm. A sample of houses was identified as being susceptible to overheating in the summer period, which was caused by higher insulation and air tightness of the building fabric. However, occupants' energy consumption behaviour such as the use of windows, blinds and ventilation systems may mitigate that influence as it plays an important role in reducing and upsurging indoor air temperature in order to achieve a higher level of thermal comfort.

To move one step further, Hong et al. (2016) try to quantify occupants' energy consumption behaviour and take this into consideration of energy simulation. At first, a few data collection technologies need to be employed, for example, sensors, to gather all necessary behavioural data. Then, the data need to be quantified through the implementation of 'behavioural initiated programmes' such as IEA EBC Annex 66: Definition and Simulation of Occupant Behavior in Buildings. It is indicated (Hong et al., 2016) that due to lack of general scientific standards the model validation technologies are not substantial. At the end, the developed behavioural model can be incorporated into one of the existing Building Energy Simulation (BES) tools such as EnergyPlus, DOE-2, TRNSYS, etc. Several challenges have been identified, such as the requirement of advancements of behavioural data collection and behaviour quantifications processes. With the same purpose, an innovative simulation approach has been developed by Sun and Hong (2017) to take account of occupants' behavioural issues in energy performance. By tackling five important measures; lighting, plug-loads, Heating Ventilation Air Conditioning and Refrigeration (HVACR) systems, openings and thermostats, the potential energy savings affected by behavioural issues is 41 per cent of total energy consumption.

In addition, occupants' behaviour can be determined by many factors. Through a survey of occupants' behaviour in New Zealand, Isaacs et al. (2010) find New Zealanders are comfortable living at a lower temperature than people in the rest of the world. The survey also identifies that New Zealand homes tend to have less heating appliances because central heating systems are not commonly implemented in homes. New Zealanders also seem comfortable heating rooms individually. It is believed that there are certain normative standards or 'pride' factors that drive their energy use patterns. The importance of occupants' energy consumption behaviour on home energy performance are explored in this section. The factors that potentially impact on the way occupants operate their homes are broadly discussed by researchers and scholars. However, to incorporate behavioural factors into the design of retrofit requests further investigation. The approaches applied for doing that are also discussed in the following section.

3.2.2 Mechanisms for investigating energy consumption behaviour

Home energy performance is believed to be significantly determined by energy-related behaviour, which is influenced by household profiles (Santangelo and Tondelli, 2017). Therefore, exploring the interrelationship between home energy performance, occupants' energy behaviour and their socio-demographic characteristics is very important (Steemers and Yun, 2009). The exploration methods of data collection are mainly from questionnaire surveys, interviews, observations and reading statistical data from smart meters or other types of IHDs. A number of instruments are discussed in this section to identify the influential factors of energy consumption.

There is indication that occupants' selection of retrofit measure is determined by a number of socio-demographic characteristics such as age, housing typology, income level and education level (Poortinga et al., 2003). Using a questionnaire survey of 2000 randomly selected households in Netherlands by post, respondents' preferences for a number of retrofit measures were explored in the format of '1-5' Likert Scale questions. The measures range from energy conservation actions to retrofit installations such as 'appliances not on stand-by', 'switch off lights in unused rooms', 'shorter showers', 'house insulation', 'applying radiator insulation', etc. With 455 returned questionnaires, Poortinga et al. (2003) argued retrofit measures are more welcomed than behavioural measures. The latter are applied to reduce indirect energy use. Therefore, they did not have the full awareness of the respondents. Retrofit design needs to be strategic by addressing the identified socio-demographic groups.

Another study (Elsharkawy 2013) identified that as well as the conventional 'top-down' approach the success of low carbon retrofits needs to incorporate a 'bottom-up' approach that focuses on occupants' understanding of energy consumption behaviour. In order to measure this for the CESP scheme in Nottingham, a 'pragmatic' approach was employed with a mixed quantitative and qualitative research methodology. Data was collected by carrying out questionnaires and accessing documents and databases in 2 phases, before and after technical intervention. This was in order to investigate the implications of occupants' behaviour and its influence on the uptake of schemes and policies. The data was analysed by employing SPSS (Statistical Package for the Social Service) to identify the correlation between energy consumption behaviour and change in energy performance. The same approach was applied by Watts et al. (2011) in order to explore the real impact of energy performance certificates (EPCs). They focused on 2000 new homebuyers in Southampton. The questionnaire survey was carried out in the first year the EPCs were released. It found that although the EPCs had been implemented, this did not impact much on occupants' decision-making processes. This shows energy efficiency is not the most significant issue considered by householders. It is suggested that the certification schemes need to be further refined in order to be widespread and meet occupants' interests.

Guerra-Santin (2011) also tried to examine the impact of household profiles and their energy consumption behaviour on home energy performance through a household questionnaire survey that was carried out with 6000 households by the OTB Research Institute in 2 districts of the Netherlands. There were 313 usable questionnaires completed which comprised 5 per cent of the data sample. The reason for low response rate was found to be due to lengthy questionnaires, which required a lot of time to be completed. Additionally, questions relating to respondents' lifestyles and possessions might be too sensitive to answer. The study concluded that energy use in space heating is significantly associated with household profile and behavioural patterns. The efficiency of retrofit programmes is different depending on household groups as their profiles significantly impact on energy use patterns.

Apart from the research methods encompassing questionnaire surveys to collect quantitative data, interviews and other approaches have also been adopted by scholars for the same purpose. Lowery (2012)'s research uses a practical low carbon retrofit case study of a social housing estate in collaboration with Gentoo Group, which was responsible for the project's construction and ownership. Applying a qualitative approach to data collection, interviews were carried out with local householders, covering aspects of their lifestyle patterns and the impact of these on energy performance. This was divided into 2 phases: before technical intervention and after technical intervention. The recorded data was processed and organised by employing template analysis. MAXqda which is used for analysing qualitative and mixed method data was applied to analyse the frequency of occupants' behaviour. Ultimately, an energy-related lifestyle pattern was identified and key energy consumption behaviour pinpointed.

It is noted that mixed methods are widely adopted in this domain to capture data through questionnaire surveys supplemented with feedback of interviewees. Linden et al. (2006) conduct a household questionnaire survey with 600 respondents followed by a focus group interview with 12 households. Similar to Guerra-Santin (2011), the questionnaire was constructed with '1-9' Likert Scale questions in order to explore occupants' environmental attitude and energy consumption behaviour. The addresses of households and birth years were accessed through the energy supplier's database. The selection of a data sample for questionnaire surveys is based on occupants' age groups and housing typologies. As a result, several poor behavioural measures were identified along with suggestions for future policy-making in the aspects of economic measures, administrative measures and user-friendly technologies.

With mixed methods adopted, Pelenur (2013) also explores the impact of occupants' behaviour towards energy performance such as occupants' opinions and motivations. In order to explore the implications of those factors on energy performance, a thematic analysis was employed. The researchers carried out semi-structured interviews on householders' attitudes to retrofits (the motivations and barriers) and home energy consumption. Since the interviews were semi-structured, with multiple responses from a single participant, the single-by-multiple response test was employed, instead of Pearson's chi-square test of association.

Moreover, Gupta (2010) explored how occupants' perception towards an indoor environment and occupancy at pre-retrofit stage impact on the selection of retrofit measures. Differing from conducting a questionnaire survey or interview, empirical tests of several types of short-term and long-term occupant feedback techniques were conducted for two different housing typologies. significant gaps between actual and predicted performance were identified in the aspects of indoor CO_2 level, daylight, indoor temperature and noise transmission. It was shown that the selection of user-centred retrofit measures is significantly determined by those issues which need to be considered by designers of the retrofit programme to optimise time, cost and process. On the other hand, a conceptual framework to identify the most influential factors of energy consumption behaviour before and after occupancy-focused technical interventions was developed by Karatas, et al. (2015). Consequently, suggestions on technical interventions that are targeted to different energy use patterns and household profiles could be provided through the framework. The criteria examined include occupants' perceived retrofit interventions with their levels of involvement, occupants' knowledge in interpreting retrofit measures and energy conservation, and the opportunities of uptake of the programme in terms of availability, accessibility and time.

The determinants of occupants' energy behaviour's influence on home energy performance have been identified looking at a variety of approaches. Understanding of those determinants will help promote occupants' energy consumption behaviour for home energy efficiency. Strategies adopted for effective behavioural intervention are demonstrated in the following section.

3.2.3 Strategies to improve energy consumption behaviour

The impact of occupants' energy behaviour on home energy performance has been broadly discussed in different aspects. It is believed that providing effective strategies to rationalise energy use behaviour is crucial for bridging the BPG. Steg (2008) stated that behavioural strategies can be provided in two ways: informational strategies to directly improve occupants' knowledge, awareness, perceptions and motivation; and structural strategies which aim to create a more attractive context in which decisions are made. The former is conducted through the provision of relevant information or education while the latter is conducted through the improvement of infrastructure or services. Both of the strategies are initiated by designers of a retrofit programme.

To promote occupants' energy consumption behaviour with long-term and sustained change is not easy as ingrained habits may have been adopted for decades. Therefore, the method of regulating occupants' energy consumption behaviour is crucial. Verplanken and Wood (2006) conduct research studies by interviewing householders involved in the Retrofit Reality project that was launched by the social housing provider, Gentoo Group. It is believed that habitual actions are not easily changed, as a habitual action "undermines attention to information of other possible courses of action". It is suggested use should be made of disrupting methods to change people's behaviour such as making specific plans or changes in the living environment (Verplanken et al., 1997; Verplanken and Wood, 2006). The challenge of changing occupants' energy consumption behaviour is noted by Barthelmes et al. (2018), who state change of behaviour requires long periods to internalise and adopt new behaviour. Earlier research (Staats et al., 2000) also highlights the importance of informational interventions when regulating occupants' energy consumption behaviour. An experiment on providing informational interventions for building users was conducted by focusing on a large office building across two consecutive winters. The impact of the interventions were obvious within a short period of time and remained effective after a year.

To cope with the 'rebound effect' and increase domestic energy efficiency, Walker et al. (2014) discuss the possibilities of regulating occupants' behaviour in order to allow retrofitted social housing properties to reach expected energy performance levels. A number of factors have significant impact on occupants' energy consumption behaviour such as occupants' relevant knowledge, their long-term habits, the adopted retrofit measures, quality of installations, conveniences of the measures, thermal comfort and external environments. In order to improve energy consumption behaviour, knowledge and skills need to be delivered along with the implementation of physical installations. In the case under study, providing guidance of necessary knowledge and skills to occupants only worked for heating control and showers but failed to affect the use of thermostats and radiator valves. The approach only seemed effective on existing technologies but not on newly installed technologies. It is recommended (Walker et al., 2014) that an integral approach needs to be adopted by policy makers to help social renters balance various control devices and understand how all parts of the system work. This could be achieved through the interactions provided by end user devices such as energy management applications.

Further, the importance of inhabitants' energy consumption behaviour was emphasised by Baborska-Narozny et al. (2017). Based on a case study of 18 overheated flats in a tower block, they suggested that although overheating in retrofitted dwellings is caused by inappropriate approaches, proper inhabitant behaviour will significantly reduce this issue. Baborska-Narozny et al. (2017) also indicate that the conventional way of providing user guidance and home demonstration tours is proven to have failed. More widespread behavioural practices are those that can be easily seen by neighbours such as opening the windows to mitigate overheating. Additionally, occupants may change their behaviour effectively through monitoring and sensory systems. The monitoring and sensory systems could provide instant feedback of energy use to occupants and remind them to improve their energy behaviour. As a result, a collective approach needs to be carefully designed and implemented.

Failures to provide appropriate and sufficient information and education to end-users has also been argued by researchers. Through analysis of more than 100 retrofit programmes, Moloney et al. (2010) argue that the rational choice model for decision-making which is based on technology and economic measures failed to achieve expected energy efficiency. The reason is that the model does not consider the impact of social context such as systems, standards and norms. Additionally, improvement of energy consumption behaviour through information and education may not be stable as it requires long-term interactions. Owens and Driffill (2008) suggest that mixed messages could generate confusion to occupants. For example, occupants are urged to turn on the ventilation system to improve indoor climate but it is suggested not to do this in terms of utility price at peak hours. Some approaches are also difficult to follow as they conflict with everyday life. Additionally, Owens and Driffill (2008) argue that the system adopted to promote occupants' energy consumption behaviour may not reflect reality. Therefore, a systematic approach needs to be adopted to incorporate complex socio-economic and socio-technical systems.

Moreover, through interviews of middle-class home owners and social housing tenants, Gram-Hanssen and Georg (2018) state that change of policy-making is significant as it needs to be diverted from focusing on building energy efficiency only to the considerations of how new technologies and measures affect indoor comfort and occupants' everyday life. It is argued that implementation of new energy efficiency measures needs to facilitate occupants' behavioural changes and actually reduce energy consumption rather than increase it by adding additional appliances. Gram-Hanssen and Georg (2018) indicate that building characteristics and householders' background need to be taken into consideration to give insights to policy makers for tailored designs.

Apart from promoting occupants' energy consumption behaviour through information and feedback, education is also used as a powerful instrument for behavioural intervention. However, all of these approaches would not work effectively on their own. As previously stated, Moloney et al. (2010) argued that the transition to a low carbon community is significant as it provides a broad sense of system change and shifts the behavioural intervention from simple behaviour changes to a set of sustainable social practices. It is stated (Moloney et al. 2010) that a systematic practice integrating community approaches and its associated technologies, infrastructures and institutions needs to be adopted. The relationship between components of the system needs to be understood. Gram-Hanssen (2010) explored the impact of user-centred approaches on heating consumption by adopting a practice-theory approach. By analysing heating and occupancy patterns of five households with different socio-demographic characteristics living in similar buildings, the indication is that a systematic approach needs to be applied to provide comfort practices for different household typologies. This includes technologies, embodied habits, knowledge and meanings. The advantage of community-based programmes is also highlighted by Heffner and Campbell (2011) as that occupants' awareness of retrofit barriers has highly increased due to multiple benefits possibly achieved in the same environment thus bringing stronger impact. The home energy performance which only represents a single issue in the complex framework needs to be considered together with non-energy measures.

Another possible way of regulating occupants' energy consumption behaviour is to provide them with regular feedback on energy usage (Wood and Newborough, 2003). Energy consumption indicators were installed in 44 UK households for two months. Among these properties, energy savings increased by 10 per cent in 14 properties and by 20 per cent in 6 properties. Barthelmes et al. (2018) also highlight the importance in energy feedback that changes need to be attractive, easy to understand and adoptable on a daily basis. In order to incentivise occupants to change their energy consumption behaviour, real time energy consumption and Indoor Environmental Quality (IEQ) feedback need to be provided in a user-friendly way and supplemented with tailored information campaigns. Further, suggestions on how to optimise energy performance based on feedback ought to be provided.

Based on the review of strategies to improve occupants' energy use behaviour, energy information and education provided by the government or local authorities may be difficult to popularise due to difference in social and technical contexts. However, fully relying on occupants to take the initiative will also prove ineffective. As a result, behavioural intervention through smart technology could be deployed to mediate between the two different methods. The impact of smart technology on occupants' energy consumption behaviour is discussed in the next section.

3.3 Behavioural interventions for home energy conservation

The role of IHDs and energy management applications in behavioural change has been recognised in many studies (Stromback et al., 2011; Schultz et al., 2015; Zhang et al., 2016; Pritoni et al., 2017; Shetty et al., 2015). The important role of smart technology in behavioural intervention relies on the transition of the UK's smart grid energy network and fast development of the Advanced Metering Infrastructure (AMI). This section starts with a brief account of the development of smart technologies and follows with a discussion of the impact of smart meters and energy management applications.

3.3.1 Development of smart meters and energy management applications

During the transition of the UK's energy network in the last few decades, the importance of feedback mechanisms from energy end users has been noted. The UK's new bi-directional energy network requires more installations of smart devices at end users' level to effectively manage energy (Darby, 2010). Other than Building Energy Simulation(BES) tools, which are mainly used by energy experts, energy monitoring and management applications have been widely employed in households. The most distinct motivation for this trend was the mandatory requirement of implementation of smart metering devices by the UK government. The government stated (DBEIS, 2013) that in order to secure affordable, secure and sustainable energy supply, smart metering devices would play an important role in low-carbon energy transitions. The government set up a target that smart metering devices need to be installed in each UK home across the country by 2020 (DBEIS, 2013). Energy companies have been required to lead the roll-out of smart meters.

The benefits that smart meters bring include a series of intelligent functions such as providing near real-time energy use monitoring to occupants, effectively organising energy consumption behaviour, paying exact bills instead of estimated ones, and more flexibly to switch energy suppliers. The smart metering device may also be connected to an in-home display for further detail on energy consumption and credit balance (Cabinet Office, 2011). Energy companies are responsible for installing smart meters taking into account energy consumers' interests in the aspects of privacy, security, product quality and the needs of vulnerable consumers. The smart meter captures near real-time energy consumption of each household and transmits data back to energy companies for monitoring purposes. Traditional manual meter readings and estimated billings are replaced by accurate bills which help energy users avoid energy and financial losses.

The development of the UK's energy network strengthens the relationship between energy management level and energy end users level. It helps energy management diagnose current conditions of energy performance in the domestic sector and more effectively manage energy distribution (Gellings, 2009). Additionally, occupants have much more opportunity to clearly understand their energy usage patterns from a number of end use devices such as smart metering, In-House Displays (IHDs), desktops and smart phone applications (Gellings, 2009). A variety of tools and applications has been evolving for the purpose of improved energy efficiency of new built and retrofit of existing buildings. Amongst those, Building Energy Simulation (BES) tools and energy management applications play imperative roles (Gellings, 2009). The former is widely used by policy makers and designers during the design stage of retrofit programmes in order to understand the conditions of targeted properties and identify problems. It has been asserted in the previous chapter that imprecise building energy simulation is one of the acknowledged barriers for efficient retrofit programmes (Rosenow and Galvin, 2013).

In regard to energy management applications, those are used by occupants to understand their energy usages and improve energy conservation awareness and behaviour. As previously discussed, the manner occupants operate their homes significantly influences home energy performance (Greening et al., 2000; Lee et al., 2013; Sorrell and Dimitropoulos, 2008). Therefore, implementation of energy management applications as a tool to help achieve efficiency of retrofit programmes may be considered a viable solution.

3.3.2 Impact of smart meters on energy consumption

3.3.2.1 Regulating occupants' energy consumption behaviour by smart meters

The implementation of smart meters indicates positive results in Northern Ireland. Through an experimental large-scale case study, Gans et al. (2013) monitored residential electricity consumption since April 2002 when pre-payment meters were introduced. Data collected between 2 different periods (with pre-payment meters and with advanced metering systems) show a 11 to 17 per cent decrease of energy consumption. Stromback et al. (2011) also demonstrate remarkable energy savings by examining 100 pilots in

Europe. Their report also assesses feasibilities of smart meter-enabled programmes such as in-house display, ambient display, website energy feedback and informative billing. As a result, the installation of IHDs shows the most significant savings of 8.68 per cent while the webpage feedback, informative billings and other feedback channels only reflected 5.13 to 6 per cent of savings. The reason for the utmost energy reductions from using IHDs is that they provide the most real-time updates to the occupant, which enables linking real-time behaviour to energy consumption.

Zhang et al. (2016) indicate promising energy savings by implementing smart meters and in-house displays in Shanghai, China. They demonstrate 9.1 per cent energy savings and 11 per cent financial savings in targeted homes with IHDs. However, further work can be done to show how to successfully affect energy performance with IHDs feedback in different national and cultural contexts. The importance of smart meters and the great contribution brought by in-house displays are also recognised by Schultz et al. (2015). To progress further, Schultz et al. (2015) investigate what types of information and feedback framework provided through the IHD will make the most significant impact on the occupants. The research was carried out to monitor energy consumption through an experimental case study in which IHDs with different frameworks were installed. Energy consumption was compared between 2 periods: just after the installation of IHD and after 3 months. This showed that although occupants prefer cost-framed feedback, significant energy reduction was demonstrated in the examples of households with electricity-framed feedback. The electricity-framed feedback displays energy usage by kilowatt hour but cost-framed feedback displays energy usage by amount of energy bills. Further, educational information provided from IHDs may increase knowledge but may not, in effect, help reduce energy consumption. The aspects shown on IHDs are also examined by Stromback et al. (2011), who show that the most effective aspects for energy reduction are up-to-date reporting on consumption, historical feedback and recent bills. The comparison of consumption which was believed effective did not help with energy reduction in the pilot study of this report.

Although the implementation of smart metering is believed an effective method for energy conservation, a number of studies would not advocate applying smart meters. Research in the Netherlands and US find that the negative aspects smart meters bring are more obvious than their advantages due to varying reasons. General reasons include the invasion of privacy, increased energy consumption due to smart technology and general unwillingness of investment in this new device. McDaniel (2009) believes that occupants' privacies have been unintendedly publicised due to the implementation of smart meters, especially information about their habits and energy using signatures. The reveal of private behavioural data is always aligned with financial or political incentives and from the utility companies. He proposes that in order to solve this problem, government needs to set up strict rules for the smart grid on how the data will be collected and with whom data can be shared. By raising the same concern of retaining customers' privacy, Raj Rajagopalan et al. (2011) urge that existing solutions may enhance privacy protection but in doing so sacrifice the benefit of the utility. In order to balance both, a novel privacy-utility trade-off model has been developed and tested on a stationary Gaussian Markov model in order to balance privacy and utility requirements. In detail, the model is able to quantify the utility-privacy trade-off in smart meter data. The guarantee of privacy is defined based on the calculated least information leakage while utility is preserved.

As mentioned, it has been proved (Schultz et al., 2015) that real-time feedback from IHDs may not help to reduce energy consumption effectively in particular circumstances. Petkov et al. (2011) also support the view that although an increased adoption rate of energy monitors and displays is demonstrated, they are not able to increase energy users' motivations by addressing their particular needs. In addition, the interface of current energy monitors lends themselves unengaging and mundane (Petkov et al. 2011). Weiss et al. (2012) put forward that the technical feedback provided by IHDs is dry numbers and intangible units, which are not suitable for most occupants. The same point of view is supported by Carroll et al. (2014). Through an experimental case study in Ireland, it is found that although real-time energy suggestions and educational information can help increase occupants' knowledge and awareness, this fails to reduce short-term energy demand. Carroll et al. (2014) argue that the reason for this is the double-side impact of the IHDs. Real-time feedback can be seen as either a reminder or motivator for occupants. Focusing on a larger scope, Hargreaves et al. (2017) examine the impact of smart home technologies based on the AMI. Through the implementation of smart home technologies in 10 UK homes for 9 months, it is shown that those technologies have not substantially reduced energy consumption. Besides, is the same study highlights that training occupants and making them familiar with new technologies is important but time-consuming.

3.3.2.2 Improving energy management by smart meters

The advantages that smart meters and AMI bring are widely recognised by a number of researchers and scholars (Gans et al., 2013; Stromback et al., 2011; Schultz et al., 2015). However, efforts are not only made towards effectively reducing energy consumption by using smart meters but also towards improving the effectiveness of the energy management system. The challenges of energy load are variable demand and distinct peak loads compared with other periods. Introduction of a smart grid in the UK has meant monitoring and management of electricity load has been improved, commonly benefited by smart meter devices. Other grid-connected devices also have big potential for improving the electricity load (Cetin and O'Neill, 2017).

A new intraday energy load forecasting system was introduced by Quilumba et al. (2015) to replace the conventional aggregated forecasting system at management level. It enhances energy management and operations by identifying groups of occupants with similar energy use patterns before performing the load forecasting. This is supported by others including Haben et al. (2016). The same approach is employed by Hayes et al. (2015) but with an adverse result. Their research demonstrates that there are a few limitations on Short Term Load Forecasting (STLF) using smart meter data. They also indicate similar prediction accuracies between using real-time data and historical data from smart meters.

It is believed that the current electricity load for residential use is highly variable (Perez, 2016), and the fluctuations of the electricity load may lead to financial loss. As the diversified electricity load is influenced a lot by occupants' behaviour, a new modelling and optimisation framework has been developed (Perez, 2016) based on smart meter data to forecast residential electricity demand and improve the efficiency of the energy network. This first applies a nonintrusive load monitoring algorithm to monitor, for example, an air conditioning unit only instead of monitoring a whole building. Further, a smart meter and thermostat are applied to form a simplified model to predicate energy consumption of the air conditioning unit. The end result is electricity load of a whole community will be reduced by shifting a set point of thermostats in each home via a centralised control scheme. One year after their initial research, Perez et al. (2017) explore the correlations between temperature and energy use patterns among different housing typologies. They show that energy-consuming behaviour of air conditioning units will keep steady and low until a certain changing-point of the temperature. Subsequently, a linear increase and an 'energy slope' gradually occur. As a result, this changing-point model can act as a screening tool to compare energy use patterns between different houses and target the ones with the most significant energy slopes. This helps to effectively identify peak load candidates for energy reductions. The impact of smart meters are broadly discussed in terms of regulating occupants' energy consumption behaviour and improving the energy management in this section. As the raised up awareness of smart meters and IHDs, the strategies of engaging them into behavioural intervention is discussed in the following section.

3.3.3 Behavioural interventions for behavioural change

Along with the development of IHDs and energy management applications, interactions between them and humans were predominantly covered in the field of Human-Computer Interactions (HCI). The approach that is applied in order to address climate change and environmental sustainability through HCI is called ‘sustainable HCI’ (DiSalvo et al., 2010). The aim of sustainable HCI is to motivate people to save energy and live in more sustainable environment. Energy management applications which are computerised could potentially motivate people through facilitating the adoption of pro-environmental behaviour. In order to understand people’s motivation for behavioural change, psychological knowledge has also been embedded. It is believed (Bamberg and Moser, 2007) that change of behaviour is based on two psychological models: Rational-Choice Models and Norm-Activation Models, where the former indicates that people tend to change their behaviour to avoid punishment or seek rewards and the later indicates people do so to remain moral or due to personal norms. Specific elements of how energy management applications influence users’ motivations need to be discussed.

Energy management applications may act as an effective media to encourage behavioural interventions to occupants. Several studies (Abrahamse, 2007; Abrahamse et al., 2005) discuss the impact of different types of interventions on stimulating occupants’ energy consumption behaviour in terms of curtailment and investment. There are a variety of intervention strategies that can influence occupants’ behavioural decisions. They are categorised by Han et al. (2013) as ‘antecedent interventions’, ‘consequence interventions’ and ‘structural interventions’. ‘Antecedent strategies’ influence occupants’ energy consumption behaviour at an early stage without the condition of each home’s energy performance being known. These strategies strengthen occupants’ sustainable awareness and help them to be aware of potential energy problems. ‘Consequence strategies’ involve knowing the conditions of energy performance by providing feedback reports or rewards. ‘Structural strategies’ focus on contextual changes such as financial legislation in order to facilitate the improvement of energy consumption behaviour.

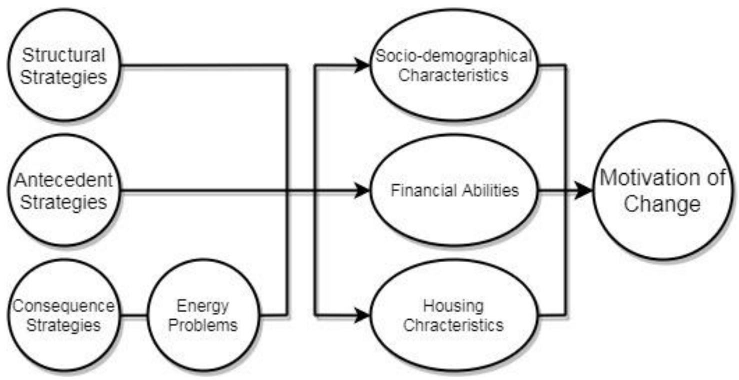


Figure 3. 1. Behavioural intervention strategies model (Adapted from Han et al., 2013).

According to Figure 3.1, both ‘structural strategies’ and ‘antecedent strategies’ only need to take consideration of a series of background information to influence occupants’ motivations. This includes, for example, occupants’ socio-demographic characteristics, their financial abilities and housing characteristics. However, ‘consequence strategies’ impact on occupants' motivations by tackling specific energy problems and providing energy suggestions based on occupants' background. Therefore, occupants are much more aware of the importance of change and alter their energy consumption behaviour accordingly. The current study proposes an energy application that requires the input of current energy performance and users' socio-demographic characteristics and produces output in the form of suggestions and rewards. Hence, it belongs to consequence strategies.

Antecedent Strategies			
Information			
Mass media	Website	Brochure	TV/Radio
Newspaper	Posters	Mobile advertisement	
Demonstration			
Neighbours' performance	Nearby companies	Association ambassadors	Display measures in model
Free products			
Commitment/goal-setting			
With municipality	With home owner association	With own household	With neighbourhood
Consequence Strategies			
Feedback			
Energy use of electronic appliances	Benchmark comparable households	Current energy usage	Behavioural suggestions
Rewards			
Awards/prizes	Tax deduction from land value tax		
Structural Strategies			
Financial legislation			
Price policies	Product tax	Energy tax	Removal tax
Subsidies	Costs measures	Loans	Low rents
Green loan	Legislation	Building regulation	Building performance certificate

Table 3. 1. Possible intervention approaches (Abrahamse, 2007).

According to Figure 3.1, there are several approaches to deliver 'antecedent strategies' such as providing information to occupants through campaigns, demonstrations of better energy consumption behaviour, free energy conservation products and setting up commitments or goals. It is stated (Abrahamse, 2007) that to provide energy-saving information in the manner of a general brief or through mass media is not effective. The information provided needs to be tailored to the particular type of household to actually increase occupants' awareness and strengthen their knowledge (Abrahamse and Steg, 2009). Based on correlating studies of energy consumption behaviour, building technology and energy performance, Zhao et al. (2017) argue that clear and valid information being given to homeowners is significant. Demonstrations are generally effective if they are understandable and meaningful. They will be more effective when combined with rewarding (Han et al., 2012). The same study asserts that providing free energy conservation products to occupants is a passive approach as it only opens an opportunity for them to try out. Further, the larger the scope of the commitment made, the more possible it is occupants will change their behaviour. It was found by Lucas et al. (2008) and Cialdini (2005) that if commitments to energy savings are made in public, participants tend to more effectively regulate their energy consumption behaviour due to expectations of the society.

Consequence strategies' aim to stimulate change of occupants' energy consumption behaviour by showing the relationship between them and energy performance. Energy use feedback is usually provided based on the assumptions of energy performance. Abrahamse (2007) argued that the approach would prove effective if the feedback was frequently provided and especially connected with energy saving commitments. The effectiveness of rewards was proven by Geller (2002) but was thought to be short-lived. In addition, financial legislation is an effective approach to stimulate energy consumption behaviour changes by changing the energy use context. Legislation on dwellings in terms of energy performance certificates and more specific building regulations have been undertaken by the government. It is also most effective to combine financial factors such as subsidies or fines/taxes (Han et al., 2013). Xu et al. (2012) and Zhao et al. (2017) also indicate that the integration of a monitoring system into tax incentive programmes may as well make the approach more robust and impactful.

In addition, energy management applications are developed based on the smart energy management system with metering devices to help occupants better understand their energy consumption and effectively save energy. The energy management applications are mainly developed by major energy companies and have become one of the most important components of today's smart energy management (Darby, 2010). Additionally, scholars and researchers have been working on the development of different types of energy management applications which are driven by occupants' behaviour. The reason for that is because generalised behavioural suggestions based on statistical thermal comfort will not be suitable for each individual case. Thus, energy performance will be improved by compromising an individual's living comfort. The successes and failures of energy management applications are discussed and presented in the below sections.

Raising awareness is needed to make occupants familiar with using energy applications and, in a further step, with the smart energy management system as applications are mainly developed based on it. Further, occupants' energy conservation awareness also needs to be motivated. The first stage of that could be the roll-out of smart meters as this increases interactions between occupants and the energy management system and generates behavioural change (Schultz et al., 2015). A review of energy management applications developed by energy suppliers and other application developers is presented in the next section.

3.3.4 Review of energy management applications

3.3.4.1 Applications from major energy companies

It is asserted that many applications in the current market have employed relatively effective behavioural intervention approaches (British Gas, 2018; EDF Energy, 2018; E.ON UK, 2018; OVO Energy, 2018; JouleBug, 2018; efergy engage, 2018; HomeBeat, 2018). By focusing on application features and impact, a comparison of the existing applications was undertaken in order to inform more effective methods of behavioural interventions. Some of the remarkable features will be identified and quickly demonstrated to participants in the focus group to critically appraise benefits, practicality and feasibility.

Several significant energy management applications developed by major energy companies such as British Gas, EDF Energy and E.ON were selected for comparison (British Gas, 2018; EDF Energy, 2018; E.ON UK, 2018). The majority of the selected tools focus on applications developed by independent application developers as they normally integrate more innovative application features, for example, real-time monitoring, remote control, energy consumption comparison, etc.

Features \ App	British Gas	EDF Energy	E.ON	Volta ware	Wink	Retro fitLab	OVO	Hive Active	Joule Bug	Carbon Calculator	Home Beat	efergy engage	Home selfe
User-friendly interface	•	•	•	•	•	•	•	•	•	•	•	•	•
Gamification design									•		•		
Meter readings (manual)	•	•	•				•						
Meter readings (automatical)				•	•						•	•	
Real-time monitor and control				•	•			•			•	•	
Visualized results	•	•	•	•	•	•	•	•		•	•	•	•
Perspective use						•	•		•	•	•	•	•
Energy consumption comparisons	•		•			•				•	•		•
Energy-related behaviours				•	•				•	•	•		
Energy saving / retrofit advice			•			•				•	•		•
Communication with technical team	•	•	•	•		•	•	•			•	•	
Price compare/ switch supplier	•	•	•	•		•	•						
Voice recognition					•		•	•					
Home security					•								
Rewards			•						•		•		

Developed by energy supplier   Developed by other application developer

Table 3. 2. Comparison of energy management applications in the current market (Source: Author).

According to Table 3.2, energy management applications which are developed by energy companies mostly tend to provide easy and convenient customer experiences in order to increase their customers in the market. Thus, there are many similarities in terms of features and functions. Although some of the energy conservation approaches have been gradually integrated in these applications, they focus more on better user experience and account management for better customer service (British Gas, 2018; E.ON UK, 2018). Besides, most energy management applications developed by energy suppliers, strive to facilitate convenient communication between customers and their technical teams to solve problems and schedule home visits. However, a potential conflict has been identified by Hannon et al. (2013) that Energy Utility Companies (EUCo) makes profit on selling energy units. The models that are developed by EUCo are coupled with their revenue. It may not help towards profits to thoroughly reduce unnecessary energy consumption of clients. On the other hand, more efforts need to be made on facilitating the development of Energy Service Companies (ESCo) because they do not sell energy units.

By contrast, applications developed by independent application developers are more stimulating such as efergy engage, OVO, Voltaware, Wink, RetrofitLab, HIVE Active Heating, Joulebug, Carbon Calculator, HomeBeat and Homeselfe (OVO Energy, 2018; efergy engage, 2018; Homeselfe, 2018). A comprehensive comparison of these applications is carried out by Shi et al. (2017), who believe those tools are more effective than the ones developed by energy suppliers in terms of energy savings by motivating behavioural change. This is also supported by Hannon et al. (2013), who state energy utility companies do not thoroughly help energy reduction as their nature is to make profit. More interesting aspects are found in the more innovative applications such as ‘recommended retrofit scenarios’, ‘tailored behavioural suggestions’, ‘energy saving comparisons’ and ‘energy performance mock-ups’. These applications are compared and hereby discussed.

Although the more innovative and advanced aspects in applications have been recognised (Barrett, 2016), they have not been widely implemented and incorporated into existing energy management systems. Several applications are able to automatically read domestic energy consumption and assign consumption to individual appliances by connecting to a smart meter and associated sensors, for example, Voltaware, Wink, HomeBeat and eferge engage. Users of those applications are able to know real-time home energy consumption in different categories of energy consumed and control the usage of each category remotely (Voltaware, 2018; Wink, 2018’ eferge engage, 2018). Furthermore, behavioural suggestions are constantly given based on thresholds set up by the users. In addition, gamification design is believed to attract more attention and increase motivation for occupants to rationalise their energy use (Aldous and Whitehead, 2016). This has been incorporated into the design of applications such as JouleBug and HomeBeat. In considering disabled people, voice recognition features are incorporated in some applications as well, including Wink, OVO and HIVE Active Heating. Additionally, Wink not only provides remote control for appliances and openings but also ensures a more secure home by providing surveillance and detection services when users are away (Wink, 2018). Moreover, Homeselfe puts the function of energy simulation for energy users first. Energy performance diagnosis is conducted based on entering a number of simple parameters such as building type, heating type and number of occupants. Then, suggestions for potential improvements are provided to users through energy performance optimisation options. Occupants’ knowledge of their home energy performance may also improve during this process.

Many innovative aspects and successes of these applications are identified, but some shortcomings are also recognisable. Several applications focus on real-time energy consumption and remote control of electricity appliances and heating systems. This facilitates energy management but may not be adequate to achieve tangible savings as there is a lack of interaction with users to stimulate incentives (eferge engage, 2018). In some of the applications, users are allowed to set up their preferred energy alert boundaries while they may not have substantial knowledge of good energy performance practice. Thus, the parameters set up by occupants may not be effective. Additionally, gamification design, which potentially increases occupants' motivation, could be utilised better in the future. For instance, gamifying energy saving actions into tasks with points earned and rankings may motivate occupants to adopt more energy saving actions and compete with neighbours or friends.

Due to the rising concern of occupants' energy consumption behaviour, a number of occupant-driven applications are developed to undertake in-depth exploration of occupants' thermal comfort and provide tailored behavioural suggestions accordingly (Konis and Annavaram, 2017; Gupta, 2016). In order to achieve that, occupants' energy use patterns and indoor environment are monitored by sensors for analysis. Discussion of this is presented in the next section.

3.3.4.2 Occupant-driven energy management applications

The behavioural suggestions provided by energy management applications are normally general guidelines which are based on static comfort criteria. It is hard to provide tailored behavioural suggestions to each individual with different thermal comfort requirements (Zhao et al., 2017). D'Oca et al. (2014) argue that standardised parameters and fixed schedules are not reliable to promote occupants' behaviour. The data needs to be obtained from field/on-site measurements. To overcome this hurdle, occupant-driven energy saving strategies have been considered. One of the differences between typical energy management applications and occupant-driven applications is that the latter, not only does it require smart metering devices, but also involves a series of sensors fitted into occupied spaces.

An innovative mobile-based application, Occupant Mobile Gateway (OMG), was developed (Konis and Annavaram, 2017) to first acquire occupants' thermal comfort and consequently provide behavioural suggestions accordingly. By connecting to embedded sensors the application captures and models personal thermal comfort preferences. Potential savings caused by occupants' behaviour are recommended through a data-driven thermal management programme without sacrificing occupants' personal comfort. Following the same research direction, Gupta (2016) developed a new strategy for smart control of indoor air temperature which is based on occupants' feedback on optimal thermal settings. He argues that inherent smart controls of the indoor environment have been independent from occupants' feedback, which lacks consideration of occupant numbers and preferences. The setup range of temperature is mainly subject to the functions of a room. Studies of occupant-driven energy efficiency have been considered in recent years (Pritoni et al., 2017; Shetty et al., 2015; Gupta et al., 2014).

With the same purpose, a programme for providing energy and water advice to social housing occupants based on their energy- and water-related behaviour was developed by Laskari et al. (2016). In contrast to smart phone-based applications, this programme is based on the energy use display interface from a TV screen and designed in the framework of Information and Communication Technology (ICT). Among energy saving measures with different levels of investment, it has been found (Laskari et al., 2016) that the most suitable approaches for low-income social housing households are cost-effective approaches without major interventions in homes. Advice is given on a TV screen with different categories such as electricity, heating, gas, hot water, etc. According to the user experience survey, the most followed energy saving advice is related to electricity use, followed by indoor environmental quality settings, and general user behaviour. Advice about heating and gas was found to be difficult to follow.

Through the review of a number of data-driven models in the world, Hong et al. (2015) develop a framework to represent the influence of occupant energy consumption behaviour with four key elements: drivers, needs, actions and systems (DNAs). They argue that relying technology alone could fail to achieve energy efficiency as a number of aspects involved in energy performance are influenced by occupants' energy consumption behaviours such as building management, operation, design and retrofit. The framework was also expected to be used to standardise the impact of occupant energy consumption behaviour by the international research community. The DNAs framework could be also adopted for the future development of occupant-driven models by researchers and scholars.

Based on the abovementioned examples of occupant-driven energy tools, it can be seen that in order to achieve greater energy savings, the combined approach of utilising both BES and energy management applications has been considered the latest trend. The most advanced strategy is to first capture and measure occupants' personal preferences through mobile apps and then set up tailored approaches accordingly through BES and energy management systems.

3.3.4.3 Other energy management applications

Apart from typical energy management applications developed by energy companies and occupant-driven applications, scholars and specialists also focus on developing more innovative application suites for various purposes. Due to the unengaging formats of current IHDs, a novel and motivation-specific energy management application, EnergyWiz, was proposed by Petkov et al. (2011) in order to provide more effective behavioural interventions to users. EnergyWiz was tested by 17 interviewees through semi-structured interviews. Occupants were actively motivated in different approaches such as energy self-comparisons, energy comparisons with neighbours in the same conditions and the challenge tasks of the competition features. However, the ranking system was only preferred by part of the interviewees. Further, competition with friends was seen as more preferable by the interviewees than with other anonymous users. The energy comparison feature was also valued by Weiss et al. (2012) through the development of the PowerPedia application. This aimed to increase users' energy consumption behaviour through action guiding and visualised feedback rather than traditional feedback with values only. By connecting to smart meters, users are given the opportunity to understand the energy consumption of each individual appliance with a variety of analysis available such as historic energy patterns and accumulated consumption. Petkov et al. (2011) show a ranking system was also developed in PowerPedia in order to show application users how they performed compared with their neighbours. Energy comparison can be conducted at household level or device level. In addition, energy conservation measures may be uploaded onto the application and shared with other users. As a result, application users could clearly understand the energy efficiency levels of their devices and method to improve them. PowerPedia also introduced a socialised platform to energy feedback which has also improved the overall outcome.

According to McKechnie (2015), as a complement of the physical energy monitoring device, EnergyCloud has been developed in Canada to control energy performance in the domestic sector on smart phones. Comparison of energy consumption can be provided on this application, which allows occupants to upload and compare their energy consumption with their neighbours. The same aspect can be also seen from Chai Energy, which provides not only neighbour energy comparisons but also energy tariff comparisons. Additionally, the application separates the energy performance of weekdays and weekends into different scenarios in its data analysis section. What can be noted is that the Chai Energy application analyses feasibilities of installing solar panels on the roof of occupants. Through analysis of local weather, roof area, cost and current tariffs, occupants will be informed if it is a good choice to install solar panels. According to reviews of the abovementioned energy management application, more functions have been developed for occupants' interests.

Recent research (Chou et al., 2017) also indicates an innovative mobile-based application for occupants to be informed of anomalous energy consumption. It is argued that some of the existing approaches failed to rapidly obtain and analyse present data, so do not effectively promote occupants' behavioural changes. However, this framework is able to provide a real-time early warning interface to occupants who lack in-depth technical knowledge. The energy data is then collected by sensors and analysed through an enhanced module of Chou and Telaga (2014) to understand users' normal energy use patterns. Then, predictions will be displayed through a smartphone application to forecast unusual energy uses and alert users. The records of anomalous data will also be shared with building managers for further improvement and retrofit strategies. Some of the newly developed application features which used to be only considered for professionals have now been applied to normal energy users, for example, feasibility analysis of solar panel installations. Though, this trend also indicates that more efforts need to be made to optimise this function and cover as many retrofit approaches as possible. A few of the most effective energy applications which were developed by application developing companies have been selected for in-depth discussion in the following paragraphs. Their successes and failures are criticised in order to form the design of an energy management application for the research.

3.4 Conclusion

This chapter focused on the impact of occupants' behaviour on home energy performance. It first continues the discussion of the barriers of the retrofit programmes in the UK. As discussed in Chapter 2, there are several issues identified during the design and delivery stage of a programme. In addition, the way that occupants operate their homes after the handover of the programme also significantly impacts on energy performance. One of the major issues is also the 'rebound effect' and BPG. Although there has been an awareness of this for several decades, it has not been fully addressed. In a number of case studies, the results of energy conservation following retrofit may have not met expectations that were set up in the planning stage. The reason for this is that home energy performance is subject to a wider range of variables such as technical, social and behavioural. However, occupants' behaviour, energy use patterns and socio-demographic characteristics have not been thoroughly explored. It is crucial to consider and incorporate these factors in the design stage of projects as the way that occupants operate their homes will significantly impact on home energy performance.

In addition, approaches adopted to address occupants' behavioural issues and improve retrofit efficiency are also discussed. One of the effective approaches is through implementation of smart meters and energy management applications. As the importance of smart meters has been gradually realised in the UK and Europe in the last decade, a series of policy and regulatory documents have been published to facilitate their implementation. The impact of smart metering devices on occupants' energy consumption behaviours and home energy performance is also explained through a number of experimental case studies. However, invasion of occupants' privacy has been flagged as the main concern. Researchers and scholars are making efforts on improving the AMI with thorough protections on occupants' privacy. Further, a few innovative approaches based on smart meters are introduced to further increase the effectiveness of energy performance.

A review and analysis of energy management applications is presented. The tools that are mostly applied have been developed by the major UK energy companies such as E.ON, British Gas, EDF Energy, Scottish Power and NPower. In addition, there are a number of energy management applications developed by specialising companies. These tools will normally have some innovative aspects in contrast to those developed by the major companies. In general, as the tools are designed for energy users, their aspects show huge variation in comparison to BES tools. Energy management applications have relatively simple tool structures, user-friendly interfaces and visualised simulation results to attract energy users' attention. There are some innovative aspects found in the tools but they have not been widely spread, for example, comparison scenarios, behavioural suggestions and voice recognition. Due to the nature of application audiences, the energy management applications focus primarily on being concise, straightforward, convenient and interactive.

Through examination of energy management applications, this chapter has explored the potential opportunities to contribute to domestic energy conservation in a new and innovative direction. Review of the applications helps to identify gaps and inform the research questions on how to provide more effective behavioural interventions through energy management applications as a potential solution. The next chapter addresses gaps in the current research field based on a comprehensive literature review and explains the rational of the research, including the design and process of data collection and analysis.

Chapter 4. Research Methodology

4.1 Introduction

The background of the research was discussed concerning the barriers to energy efficiency in the UK retrofit programmes and the impact of behavioural interventions on improving occupants' energy consumption behaviour. Based on a comprehensive literature review, a few gaps in the current body of knowledge have been identified, such as the impact of occupant energy consumption behaviour, occupancy patterns, and socio-demographic characteristics on energy performance, as well as the lack of comprehensive behavioural interventions that support and encourage energy conservation. Hence, studies of current energy management applications have been conducted in order to examine their feasibilities. The majority of applications, with limited innovative features, fail to make effective influences on occupants' energy behaviour. To tackle this, implications between occupants' behavioural factors and home energy performance were investigated through different methodological approaches, such as a questionnaire survey and focus group interview. The users' preference for energy management application was also investigated in a focus group interview.

This chapter identifies the methodological approaches adopted in the research by stating the research aims based on the current gaps, and research objectives to accomplish the research aims. This is followed by the probing research questions and process of designing the research methodology to collect, present and analyse essential data to address the research questions in an attempt to achieve the research aim. The reasons and justifications for the research design, research methods, data sources, data collection and analysis techniques adopted are explained in detail in the following sections.

4.2 Rationale for the research

Based on the review of literature and case studies in Chapters 2 and 3, the research examines the current conditions of low carbon retrofit projects in the UK and highlights their successes and failures. Several underlying reasons as to why retrofit programmes may not meet expectations have been thoroughly investigated. Among a variety of issues, the impact of occupants' energy consumption behaviour, their socio-demographic characteristics and occupancy patterns have not been thoroughly studied due to difficulties in measuring and calculating (Pelenur, 2013; Gupta and Gregg, 2016; Gram-Hanssen and Georg, 2018). D'Oca et al. (2018) also indicated that human dimensional relating to energy behaviour are often ignored or simplified by stakeholders. Thus, these factors need to be significantly considered in order to meet the gap in the current research field. Additionally, traditional low carbon retrofit projects are generally driven by the government with a series of supportive energy policies and schemes but lack interactions with energy end users. Furthermore, it is believed that occupants' energy consumption behaviour and awareness could be potentially influenced by IHDs and energy management applications. In this research, a specification of energy management application was proposed based on the research findings. It will help the development of physical application in the future.

The research aims to strengthen the government's 'top-down' approach by providing suggestions to policy makers with respect to improving occupants' energy related behaviour. In the context of 2 social housing estates, the research aims to develop viable interventions for reducing operational energy post retrofit in the UK social housing sector that could potentially benefit to better retrofit outcomes.

By working in collaboration with one of the London boroughs, access to 2 social housing estates was facilitated for the research. To accomplish the research aim, the research objectives are to:

- Understand housing characteristics, households' profiles and energy performance with respect to occupants' energy consumption behaviour and occupancy patterns.

- Explore correlations between housing characteristics, occupants' socio-demographic characteristics and energy performance of their homes.

- Investigate correlations between occupants' energy consumption behaviour, occupancy patterns and energy performance of their homes.

- Study occupants' attitudes towards smart technologies, as a possible strategy to reduce home energy consumption.

- Identify particular implications for energy conservation in UK social housing estates and provide evidence-based recommendations.

The research questions are designed as below:

- Which socio-demographic characteristics and housing characteristics have significant impact on energy performance in social housing estates?

- What are the occupants' energy consumption behaviours that may have significant impact on energy performance in social housing estates?

- How can smart technology help improve occupants' energy consumption behaviour through behavioural interventions?

- How can this study contribute to and inform the effective building energy operation that can benefit to the future retrofit programmes in the UK social housing sector?

The sections below demonstrate why the methodological approaches were deployed and how they were developed in order to fulfill the research aims and objectives, and answer the research questions. Detailed explanations are given for the case studies employed, the design of survey questionnaire, planning of the focus group and the original contribution of the research.

4.3 Research case studies

In the UK, 18.25 per cent of the housing tenure was social rented by 2016. London has a correspondingly high composition of social rented households that makes up 22 per cent of all housing tenures (House of Commons, 2017). With more than 500 social housing tower blocks built between 1950s and 1970s in London (GLA, 2015), the capital accommodates 21 per cent of the social rented households in England (Tunstall and Pleace, 2018). Therefore, in collaboration with the local council, the study was conducted using two social housing tower blocks in one of the boroughs in London as exploratory case studies. The research has been undertaken in order to research the impact of 'live' retrofit projects on energy consumption behaviour. This collaboration holds significant impact on the research design, philosophical approaches and methodology deployed. Therefore, it is important to outline the case studies that have been investigated.

4.3.1 Estate A

Estate A was built as affordable housing with low rents for people struggling with housing costs. The tower block comprises 11 storeys with 44 flats in total. The planned retrofit interventions were to be conducted by the estate's contractor. The first phase of the refurbishment focusing on the building interiors was started by the beginning of 2016 and completed by the end of 2016, and the second phase of the work focusing on upgrading exterior insulation was started by April 2017 and completed by the January 2018.

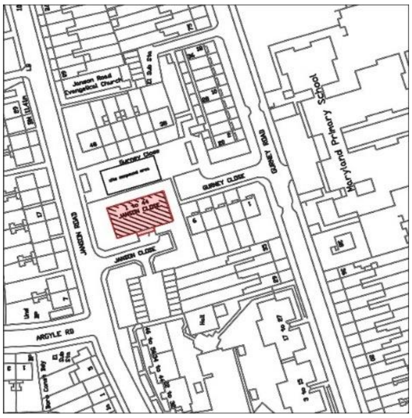
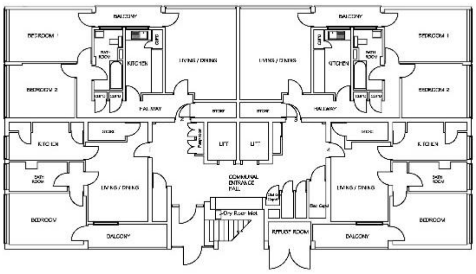


Figure 4. 1. Site location (Google map, 2018). Figure 4. 2. Site of Estate A (Source: Author).

The tower block is located to the north of the town centre within 10 minutes walking distance from the main train station. It is part of a large residential area surrounded by terraced houses and 2 blocks of 5-storey flats. Based on conversations with local residents, the area has had some social problems, such as stranger invasions and crime. There are 4 flats located on each floor: 2 one-bed properties and 2 two-bed properties. The properties on each floor generally follow the same layout with some differences on the ground floor. As additional spaces are required for elements such as pump rooms, refuse rooms and storage, the two-bed flats on each side have relatively smaller living rooms (Permarock, 2017).

The block does not have a basement floor but has a roof terrace. It has been reported that each property is suffering from a certain degree of issues with the indoor environment. Additionally, occupants living on the top and ground floors suffer more mould and dampness issues due to having less insulation.



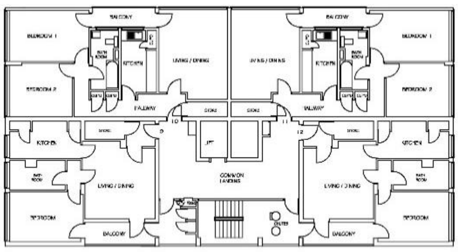


Figure 4. 3. Ground floor plan (Permarock, 2017). Figure 4. 4. Upper floor plan (Permarock, 2017).

The first phase of the retrofit intervention included renewing the balcony balustrades and refurbishing internal communal areas where re-decoration, replacement of fire doors, replacement of mains and the relocation of electricity wires were conducted. Windows in communal areas were also replaced by units with lower U-Values. Additionally, lifts were refurbished and a new cold water system was created including an external pump room (Permarock, 2017). The second phase of the retrofit intervention was due to include the rendering of external walls and insulations of building envelops.

Figure 4. 5. Site investigation: mould issue at Estate A (Source: Author).

Based on site investigations shown in Figure 4.5, the major problems had already been identified by the constriction team of the Council: mould was very serious in the corners between walls and ceilings in each property, especially in the top floor flats; and leaking was indicated in specific flats due to lack of maintenance. As there were a few properties that had been purchased by occupants, the council would not be able to cover the cost of retrofit for those flats. If the private owners did not agree with the budgets proposed by the authority, the construction team would leave those properties un-retrofitted. However, the private owners were likely to be convinced as they had already been involved in the first stage of the retrofit interventions.

2.3.2 Estate B

Estate B was built also as affordable housing completed in 1967 and comprises 22 storeys with 109 flats.

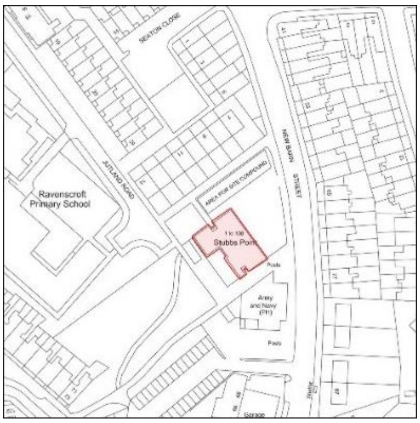


Figure 4. 6. Site location (Google map, 2018).

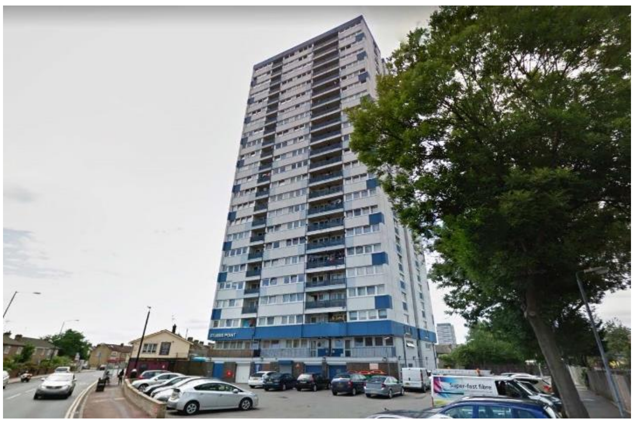


Figure 4. 7. Site of Estate B (Source: Author).

As a high rise building, it is very distinct in its urban context and forms part of a large residential area of terraced housing. A large car park space is also dedicated to Estate B at the back.

Externally, the building is clad in asbestos cement panels painted in shades of blue. The external panels of the tower block were jet-washed in 2012 for health and safety purposes. However, this was contrary to the latest Asbestos Regulations as there was little risk posed. Jet-washing would have taken away the original paint finish and the outer surface of the panel, potentially releasing microscopic harmful asbestos fibres (Newham Homes, 2007). Jet-washing would also have damaged any seal that existed between the panels providing a path for water to penetrate the concrete structure behind during periods of driving rain (John Rowan and partners, 2016).

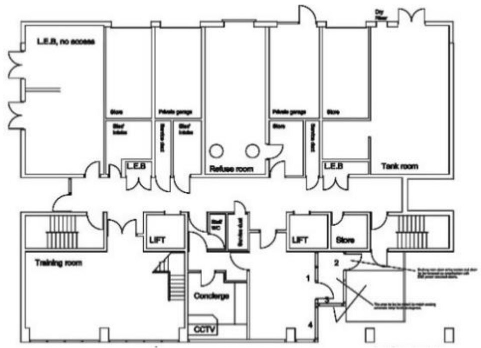


Figure 4. 8. Ground floor (Newham Homes, 2007).

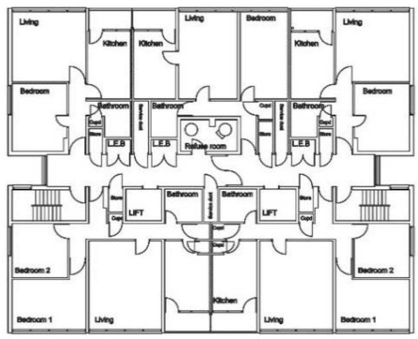


Figure 4. 9. Upper floor (Newham Homes, 2007).

There are no flats located on the ground floor of estate B. Instead, the ground floor fit out comprises a concierge reception area, staff WC, tank room, training room, garages and service rooms. The residential properties are located from the first floor onwards. There are 3 properties located on the first floor and 5 properties located on the second to twenty-second floors with the same layouts as shown in Figure 4.9. On each floor, there are 3 one-bed flats, 2 two-bed flats, 2 lifts and 2 staircases.

Figure 4. 10. Problems in Estate B (Source: Author).

Figure 4.10 shows housing issues captured during the site investigation where damp and mould occurred partially due to water penetration into the flats. This had damaged internal plaster inside one property. The second image in Fig 4.10 shows the condition of the cladding panels in a corner with gaps existing on both the internal and external corners. The third image in Fig 4.10 shows defective mastic seals between the window and wall panelling. The problems at Estate B were recognised by the local authority which prompted the plans for refurbishment in the near future.

4.4 Research design: a mixed methods approach

4.4.1 Strategy of inquiry

To explore the relationship between occupants' energy consumption behaviour, their socio-demographic characteristics and energy performance in the samples of UK social housing tower blocks through a systematic research investigation, a mixed methods approach is adopted for the research design. The research design is defined as "the plan of action that links the philosophical assumptions to specific methods" (Creswell and Clark, 2007). As the research aims to measure and explore potential correlations between the abovementioned factors and domestic energy performance, data were collected by using both quantitative and qualitative research methods.

Household profiles, housing characteristics, energy performance and participants' preferences of energy consumption behaviour in the questionnaire survey are acquired by employing quantitative methodological approaches. Additionally, occupants were asked about their attitudes and awareness of energy conservation through mainly quantitative questions but supplemented with a few open-ended questions to probe into more detail. Further, to help interpret the data collected during the questionnaire survey and inform the development of innovative energy management application, an in-depth interview was also conducted in a focus group to understand the current conditions, barriers and perceptions concerning diverse application features. As a result, the sequential explanatory design was employed for the research investigation.

Figure 4. 11. Sequential Explanatory Mixed Methods Designs (Adapted from Creswell and Clark, 2007).

As stated by Creswell and Clark (2007), there are 5 main research designs when using a mixed methodology: the convergent parallel design, exploratory sequential, explanatory sequential, embedded design and transformative design. The current study employs a sequential explanatory mixed methods design, as the qualitative data collected is used to help in explaining the findings of the quantitative study in this research. The same research methods are commonly adopted in investigating the impact of occupants' behavioural factors (Steemers and Yun, 2009; Pelenur, 2013; Linden et al., 2006). The research comprises an initial phase of quantitative data collection and analysis, followed by and complemented with the second phase of qualitative data collection and analysis (Figure 4.11). The approaches together inform the interpretation and inferences deduced from the sequential explanatory research process.

To answer the research questions, a number of research methods have been employed to collect and analyse the research data. It has been realised that energy consumption patterns are complex and involved in technical and socio-cultural phenomena. Crosbie (2006) argued that methodological approaches for this issue were comparatively emergent. Hence, a series of quantitative and qualitative research methodologies are considered and designed as demonstrated in Table 4.2, where the research questions guided the choice of research methods to generate both quantitative and qualitative data.

Research Questions	Research Methods	Data	Reason of the Research Methods
Q1. Which socio-demographic characteristics and housing characteristics may have significant impact on the energy performance in social housing estates?	Literature review Questionnaire survey Focus group interview	Qualitative Quantitative Qualitative	To obtain accurate and objective data of housing issues and occupants' socio-demographic information. Identify the correlations between those factors and energy performance.
Q2. What are the occupants' energy consumption behaviour that may impact on energy performance in social housing estates?	Literature review Questionnaire Survey Focus group interview	Qualitative Quantitative Qualitative	To obtain accurate and objective data of occupants' energy consumption behaviour and their occupancy patterns. Identify the correlations between those factors and energy performance.
Q3. How can smart technology help improve occupants' energy consumption behaviour?	Literature review Review of energy apps. Focus group interview	Qualitative Qualitative Qualitative	To identify the most effective and preferred application features according to interviewees' feedback. Develop the design specification of the proposed energy management application.
Q4. How can this study contribute and inform the design of future low carbon retrofit programmes in the UK domestic sector?	Questionnaire survey Focus group interview	Quantitative Qualitative	Mixed interpretations of research findings in both phases.

Table 4. 1. Data required for the thesis research questions (Adapted from Creswell and Clark, 2007).

The research methods, employed in this research design, aim to answer each research question. The main approaches adopted include a literature review, questionnaire survey, and focus group interview. The questionnaire contains mainly close-ended questions augmented with a few open-ended questions. As well as including questions on house character, household profile and occupants' lifestyle patterns. Probing questions are asked to investigate the participants' perspectives on the reasons behind significant changes in energy performance and how much they were involved in the low carbon retrofit. Each approach employed has particular advantages and disadvantages. Crosbie (2006) and Lopes et al. (1997) argued that household energy monitoring is the only way to precisely record energy consumption patterns as it is not affected by self-report bias. However, due to limited access to energy data, quarterly electricity and gas bills were used instead of energy consumption data, which are held by energy companies.

It is noted that response bias for the data acquired will arise during the questionnaire survey, because respondents may want to manage the impressions they give regarding social responsibilities and morality (Brace, 2018). In order to offset the possible bias, occupants were asked to complete questionnaire surveys according to their actual bills received. The questionnaire survey was also employed in order to capture the data of housing characteristic and occupants' socio-demographic information required, as this method has been widely used to analyse statistical relationships between energy performance and socio-demographic characteristics (Kavousian et al., 2013; Gram-Hanssen, 2014). For the same reason, the questionnaire survey was used to answer the research question 1 and 2 regarding the relationships between energy performance, occupants' energy consumption behaviour and their socio-demographic characteristics.

The questionnaire, with both structured questions and open-ended questions, is aimed to collect quantitative data through standardised means and qualitative data for probing details of particular questions. For instance, in a recent project, Fylan et al. (2016) investigate the main barriers to the expansion of retrofit schemes by carrying out unstructured interviews with an inductive research design. The inductive approach to research is adopted to generate new theory based on the data collected and usually combined with unstructured or semi-structured surveys. The interview only had one open-ended question. On the other hand, the failures of questionnaire surveys need to be carefully avoided. This has been stated by Robson (2002), who comments that bias may occur during the process of concluding findings into self-report. The bias of self-report comes from the structure of a questionnaire and the interpretations based on that. Moreover, the number of participants responding to a survey could be much lower than expected. It is also important to note that survey questions need to be refined to avoid misinterpretation.

In order to optimise research findings, a focus group was designed as the supplement to the questionnaire survey for the research questions 1 and 2. Besides, it was also designed to obtain interviewees' preferences for proposed application features in order to answer the research question 3. The interviewees were asked to express their opinions concerning the key issues identified during the questionnaire survey, such as 'Do you pay similar bills across the years?', 'Do you think you can pay less if you change the way of using the energy?' and 'Did you try to change the way of using electrical appliances, windows, fans, heaters in recent years? If yes, was it successful?'.

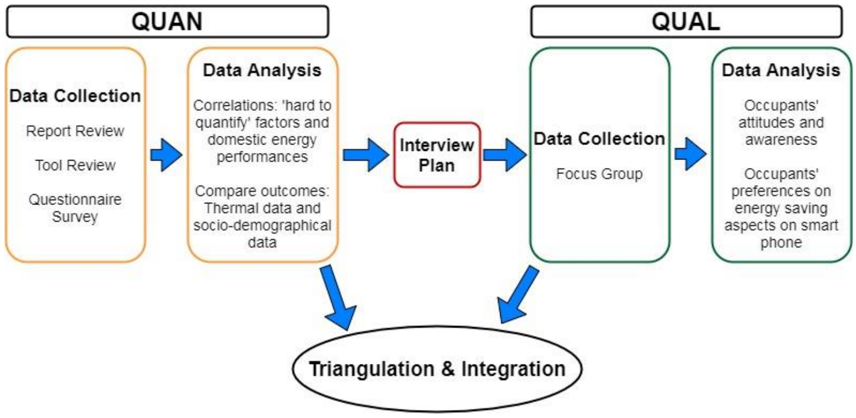


Figure 4. 12. Diagram of Research Methodology (Source: Author).

According to Figure 4.12, quantitative approaches are firstly conducted to capture the majority of the data and qualitative approaches followed to help explain data acquired from the first stage. Thus, a sequential explanatory research design is adopted in this research. The review of literature helped to understand the socio-demographic conditions and cross-validate households' socio-demographic characteristics on the questionnaire survey with the UK social housing sector. The comparison helped to ascertain the representativeness of the research. It also helped to identify potential behavioural interventions for energy conservation both at the government's level and the energy end users' level. The possible recommendations for future retrofit programmes and proposed energy management applications aim to stimulate occupants' behavioural changes. The review of energy management applications in the market helps to identify gaps and propose novel application features, which were examined by interviewees during the focus group interview.

Besides, the focus group is taken as an extended investigation of the questionnaire survey regarding the questions about energy management tools. It helps to gain a thorough understanding of what energy application aspects are preferred or not preferred by occupants and cross-validate the data obtained from the questionnaire survey, such as the implementation of smart meters and occupants' attitudes towards application features. In general, the quantitative methods delve into the complexity of housing, socio-demographic and energy use issues. On the other hand, qualitative methods focus more on occupants' awareness, opinions and attitudes. The data from both methods are combined and interpreted. The data gathered during the qualitative phase of the study informs the findings of the quantitative phase. Similarly, the quantitative results demonstrate the outcomes related to perceptions and experiences shared by participants, assisting in the findings of the qualitative data. Additionally, the cross-validation process helped to insure the validity of the data collected from different sources.

The collected data from the questionnaire survey was analysed by using Statistical Package for the Social Sciences (SPSS) in order to find potential correlations and identify the significance of correlated variables through correlation coefficient factors. There are a number of benefits that the research findings brought. The general findings and correlations generated from the questionnaire survey and in-depth interview may help inform future programmes for policy makers and local authorities. The correlations and suggestions from the interview help inform the development of an innovative energy management application which is connected with smart meters and the AMI. The development of the application will help regulate occupants' energy consumption behaviour and feedback unexpected energy usage to the energy management level for further action.

4.4.2 Survey questionnaire

4.4.2.1 Aim of survey questionnaire

The purpose of designing a questionnaire is to effectively extract data from respondents (Hague, 2006) through different approaches such as 'face-to-face', postal mail, emails or telephones. Defranzo (2012) states that there are 4 main reasons to conduct a questionnaire survey, which include uncovering answers, evoking discussion, making decisions and comparing results. It has been stated that in order to obtain meaningful and honest answers, the survey environment needs to be non-intimidating to protect participants' privacy (Defranzo 2012). In the current study, a number of themes were explored during the questionnaire survey such as household energy performance, housing characteristics, occupants' energy consumption behaviour, their occupancy patterns and socio-demographic information. The survey questionnaire aims to uncover the answers and understand the current conditions of the above-mentioned aspects. Further, as the significant part of the research design all of the quantitative data and some qualitative data were expected to be obtained from the questionnaires. The open-ended questions allow participants to freely express their ideas not restricted by the questionnaire structure. The results obtained were widely compared with relevant studies as the research also aims to bring discussions into a wider scope. Finally, by analysing quantitative data, the research results obtained may have an impact on decision-making processes.

4.4.2.2 Questionnaire design

Case study questionnaire design

To ensure the successful development of the questionnaire, similar approaches in relevant fields were thoroughly studied. The pros and cons of each approach were discussed and demonstrated. Lawrence and Keime (2016) undertook surveys of occupants in two higher education buildings in Sheffield in order to investigate the relationships between dwellers' thermal comfort, energy consumption and environmental design strategies. The survey form designed is very explicit and focused, where it included only 5 questions in relation to personal information and 13 questions in relation to the participants' perceived comfort at various points in a year, and in various locations within the building. The scale of the project was relatively small, as it only focused on environmental control within the dwellings. In a similar study, Gupta and Gregg (2016) investigate why an institutional building failed to achieve its energy and carbon performance targets. This was conducted using systematic and socio-technical approaches including the Building Use Study (BUS) questionnaire. A BUS questionnaire is commonly used to evaluate occupants' satisfaction in relation to different designed aspects such as living comfort and services provided. The collected quantitative data can then easily be compared with the BUS national benchmark database. Another example that employed participant satisfaction surveys (before and after a retrofit project) is from Thomsen et al. (2016). As well as monitoring and comparing dwellings' performance, this participant satisfaction survey was carried out to investigation occupants' experiences at the project processing stage and the 'new building' stage. Using the same format as Lawrence and Keime's (2016) project, participants were asked to choose a degree of satisfaction from a degree bar (1 to 25) in relation to aspects of living comfort such as air temperature, view, daylight, air quality, etc.

Another study undertook a questionnaire with a sample size of only 2 UK homes (Gupta and Greg 2016). The research aimed to cover every aspect of the dwelling, including air permeability, relative humidity, daylight, CO_2 levels, etc. The questionnaire focused on occupants' feedback on the retrofit installation process, ways of operating the dwelling and thermal comfort, employing semi-structured questionnaires. The difference between Gupta and Gregg's project and the current research is that their project focused on general issues leading to the failures of low carbon retrofit. By contrast, this research specifically examines the links between dwellings' energy performance and people's energy consumption behaviours. It was also asserted that Gupta and Gregg's project cannot provide strong informative guidance to the UK's current RftF programme as it is mainly based on social housing. From a different angle, Marchand et al. (2015) carry out a 2-stage semi-structured questionnaire survey involving financially-supported Green Deal participants. The questionnaire was composed of different types of questions that include single choice questions, multiple choice questions and rating scale questions. As well as closed-ended questions, some of the questions were open-ended to allow participants to precisely express their opinions if they could not find a place for their answers in the given options. Although the research did not focus on the efficiency of retrofit projects, it stemmed from Green Deal policymaking and implied participants' scheme awareness. The questionnaire was designed to be very explicit and easy to understand. Additionally, the questionnaire was designed to be completed within 10 minutes to improve the response rate. At the design stage of the questionnaire, the data analysis process was taken into consideration to ensure that the data could be easily processed.

Elsharkawy and Rutherford (2018) also adopt a two-phase questionnaire survey in order to explore the impact of occupants' energy consumption patterns and awareness of policy initiative intended outcomes. The pre-retrofit and post-retrofit questionnaire surveys containing quantitative and qualitative questions were conducted for 150 households in the Aspley ward of Nottingham. The first phase of the survey targeted the potential candidates of the CESP retrofit scheme whose homes were identified as energy inefficient. The second phase of the survey targeted the homes that had been retrofitted. Thus, the respondents of both phases were not been the same. In order to mitigate any skews of the results, the selection of respondents followed robust criteria: to have the same dwelling conditions, tenancy status and socio-demographic characteristics. Similar approaches have been adopted to explore occupants' attitudes, awareness and behavioural factors and home energy performance (Elsharkawy and Rutherford, 2015; Watts et al., 2011).

There are several issues that need to be considered when participants' lifestyle patterns are focused, such as the differences between weekdays and weekends occupancy profiles. Wei et al. (2014) undertake a case study on a mid-terraced house in the southwest of the UK to investigate the relationship between occupants' behaviour and dwellings' energy performance. The most influential behaviour was identified through the implementation of a dynamic BPE combined with different types of occupants' behaviour. Survey questionnaires were carried out to obtain the occupants' lifestyle patterns and their energy consumption behaviour. In the lifestyle pattern section of the questionnaire, occupants were asked how long they spent in each room on weekdays and on weekends. The study also took into consideration the differences between tenants and homeowners. The design of this questionnaire inspired the design of the survey in the current study.

In order to get a thorough understanding of occupants' lifestyle and heating usage patterns, the questionnaire covers the number of hours that occupants spend in each room and the number of hours for which the heating system is on. Jones (2013) also administered a survey to investigate how socio-demographic characteristics and ways of using electricity appliances contribute to electrical energy demand. In his structured administered survey, occupants were asked about their electrical appliance patterns of usage. Different types of questions were asked according to different appliances and scenarios: weekdays and weekends. For example, participants were asked about the number of hours they spend watching television per day, the number of times they loaded their washing machine every week, among other questions.

Based on the review of recent studies with similar research methods adopted, the design of the questionnaire and approaches applied are incorporated into the design of the questionnaire survey in this study. This helps to acquire information which then informs the design of the focus group interview. Further, the lessons learned from previous projects are considered in the current study such as the low response rate and lower patience of the participants.

Question types

Certain types of data and research purposes can be responded to by employing certain types of questions in a questionnaire survey. There are 2 types of questions: close-ended and open-ended. Close-ended questions are suitable for large data samples and collecting quantitative data. Open-ended questions are suitable for comparatively small data samples and collecting qualitative data. A questionnaire survey with combined close-ended questions and open-ended questions is more suitable for investigative studies and collecting both quantitative and qualitative data (Taylor-Powell, 1998). In this research, both close-ended questions and open-ended questions were employed to investigate each dwelling's physical conditions, household profiles, and energy consumption behaviour.

Key principles were followed when developing the questionnaire. First, it was identified that there were four aspects that the questionnaires would cover: physical characteristics of the dwellings, household profiles and occupant's attitude and awareness towards low carbon retrofits, and their energy consumption behaviour. Second, the initial questions were drafted and revised for each topic of the questionnaire. Third, the structured questionnaire includes questions with expected formats of answers such as numbers, judgemental answer (Yes or No), degrees or percentages. The matrix questions to explore occupants' preferences and feelings belong to close-ended questions. The contingency questions, that are used to explore the reasons for specific answers, are designed as open-ended questions in the questionnaire. The layout of the questionnaire was decided on by refining and considering a logical sequence of sections and associated questions.

Survey questionnaire

Different types of survey questions were developed in order to capture a wider range of research data. In the context of the case study, with planned low carbon retrofit interventions in the borough, initial interviews were held with the Council representatives in order to understand what the problems and barriers are in current low carbon retrofit projects in the light of national plans to improve the efficiency of the programmes. The questionnaires were designed to address the research aims and simultaneously address some of the Council's concerns. The respondents or participants are the occupants who live in the properties to be retrofitted. The questionnaire was designed as explicitly as possible to avoid response bias generated from the researcher's side. This increases the possibility that the occupants will answer the questions truthfully and express what they actually think. In addition, the researcher tried to simplify the questions as much as possible. Some of the necessary questions were removed from the questionnaire where the information could be obtained directly from the Council or contractors. As the research outcome will help to improve the efficiency of energy performance and generate financial savings for each household, the benefit of the project was briefly explained to the occupants through a cover sheet in order to increase their incentives in participating in the survey.

The initial visits to the case studies cover the number of rooms, room types, building services, walls, roof and openings. Additionally, any physical damage to dwellings was recorded in the site survey. As demonstrated in Table 4.2, different types of questions were developed in order to collect different types of data.

Section	Composing Questions
1. Housing characteristics	Tenancy status & living length
	Secondary heating systems
	Housing issues: cold, damp, mould
2. Behavior patterns	Energy supplier/plan & Energy bills
	Heating patterns
	Use of heating controls
	Temperature set on the wall thermostat
	Use of windows/extractor fans/trickle vents, etc.
	Sustainable activities
	Ability to understand the bill

3. Attitudes of energy management application features	Smart meter installation
	Use of energy management applications
	Preferences of application features
4. Basic information	Gender, number of members & age group
	Economic status & income
	Education level
	Health condition

Table 4. 2. Design of survey questionnaire (Source: Author).

The housing characteristics section was designed to record the current condition of the dwellings, issues experienced and understand the physical changes that came about due to any technical intervention. The occupants' energy consumption behaviours and occupancy patterns. Occupants' attitudes concerning energy management applications and their current situations with smart meter implementation were acquired within one of the sections of the questionnaire. Finally, the basic information section was designed to collect socio-demographic data related to gender, age and number of occupants, education level, employment status, and income level.

In the housing information section, occupants were asked to provide their 'tenancy status', 'living years' and 'quarterly energy bills'. The researcher also investigated whether they 'have previously received energy advice' and 'changed their energy suppliers/plans'. In addition, the type of 'secondary heating systems' equipped and 'housing issues' occupants have been experiencing were also asked. In the energy use behaviour section, detailed energy use behaviour on heating systems, ventilation and energy conservation were explored. Occupants were asked to map their 'energy use patterns in each room of their dwelling during weekdays and weekends'. Further, they were asked how frequently they 'open their windows', 'trickle vents' and 'turn on extractor fans' in winter. In addition, several 'effective energy saving approaches' were listed on the questionnaire. Respondents were asked to indicate how frequently they take those actions normally. A few open-ended questions were also incorporated: occupants were asked to 'provide the reason if they believe they spend more on energy than they should to have a more comfortable home'. In the section of occupants' attitudes towards energy management applications, the researcher tried to find out if 'they have smart meters installed at their homes', if the respondents are 'familiar with using applications for energy management', if they 'have smart meters installed at their homes' and 'how frequently occupants are using use energy management applications to adjust energy consumption'. Additionally, several options of 'application features' were listed in order to understand occupants' preferences. In the basic information section, socio-demographic information for each household was requested such as 'age group', 'economic status', 'ethnicity background', 'total household income', 'level of education' and 'health condition'.

The final questionnaire form consists of 4 pages with 4 different sections: housing information, energy use behaviour, attitudes towards energy management applications and household profiles. The pilot questionnaires were pre-tested by handing to a few non-academic colleagues with different socio-demographic characteristics. The detailed questionnaire form is illustrated in Appendix I.

4.4.2.3 Pilot questionnaire

Design of the questionnaire is subject to the types of data needed in order to respond to the research questions. It is important to run a pilot test of the designed questionnaires before collecting data. The reason for this is that it helps to identify the questions that are difficult to understand or any problem which could lead to biased answers (Brace, 2018). A number of types of pilot surveys are recommended by Brace (2018) such as informal pilots, cognitive interviewing, accompanied interviewing, soft launches, large-scale pilots and dynamic pilots. In this research, informal pilots were undertaken with people with a variety of backgrounds such as non-academic colleagues, academic colleagues and stakeholders of the project. Ultimately, the questionnaire was developed through a series of consultations between the researcher, the research supervisory team, the collaborating council before being piloted with a few participants. Their suggestions also helped to improve and finalise the questionnaire form.

Questions which were not necessary or considered not stand for the stakeholders' interests were taken off the questionnaire. For example, questions regarding 'primary heating systems' was taken off as that information could be provided directly by the local authority. Some questions regarding housing physical conditions, such as the leaking, physical damages and conditions of service systems, were suggested to remove due to the consideration of negative impact of the local authority. Then, the researcher was advised by stakeholders to the researchers to simplify questions and minimise the pages of the questionnaire to maintain the patience of respondents. These included that the 9-level Likert Scale bar in the questionnaire was too complicated and it was recommended to simplify with a 5-level Likert Scale. The questionnaire was also reduced from 6 pages to 4 pages. Additionally, the table asking for occupancy patterns and energy use patterns during weekdays and weekends was recommended to be simplified as occupants' could easily lose their patience when completing the complicated questions. In order to encourage participation, the local authority suggested to stress in the cover letter that information given from the survey remain independent from the council and does not imply any upcoming works.

The updated questionnaire was also trialled with a number of non-academic colleagues after taking advice from academic colleagues and the local authority. This aimed to test whether the questionnaire is in 'lay terms' and clearly presented without any confusion for people without relevant knowledge. As a result, although a majority of the questions could be easily understood, a few concerns were raised. Most participants felt that it was difficult to remember the timeslots of using heaters and thermostats during weekdays and weekends. Besides, heating patterns might be too fragmental to be recorded. In this case, the respondents were asked to answer the hours of use in total instead of different time slots to avoid complexity. In addition, a few people did not understand the meaning of thermostats and trickle vents. However, they understood as soon as a description was provided in the questionnaire. Lastly, the information leaflet was also included in the pilot study in order to test its clarity and legibility.

4.4.2.4 Data collection and analysis

There are several reasons that may lead to the failure of questionnaire distribution such as improper questionnaire distribution approaches, formats and/or questions. Elsharkawy (2013) indicates that the approaches developed at the design stage may need to be changed to tackle new challenges when the project is ongoing. In her study, an alternative approach was employed in the second phase of the questionnaire distribution, as the door-to-door approach seemed less effective than when applied in the first phase of the study. Hence, survey forms with pre-paid envelopes were posted to the participants followed by phone calls to remind the participants to complete the form. This proved relatively successful as an alternative distribution and collection approach. Lessons learned from other studies has been considered in this study, hence the process of the questionnaire survey distribution and collection is hereby described.

Before the launch of the questionnaire survey, leaflets describing information about the research project and the potential benefits participants could get were pinned up in the communal areas and the corridors of each floor in order to draw occupants' attention. Follow-up leaflets were also distributed to each flat in both estates to prompt occupants about deadlines and update them on the project progress. Although the questionnaire distribution at both social housing estates was in the manner of 'leave and collect', the approaches carried out were slightly different. As stated previously, the local contractor at Estate A held coffee mornings regularly in order to consult and receive feedback from the occupants regarding the upcoming retrofit interventions. The questionnaire distribution took place during the coffee mornings, which helped to collect the completed questionnaires more effectively. The engagement of the contractor and the upcoming construction work drew more attention from the occupants. Although coffee mornings effectively helped with the data collection, a 'door-to-door' approach was also applied in order to continue collecting completed forms between the coffee mornings.

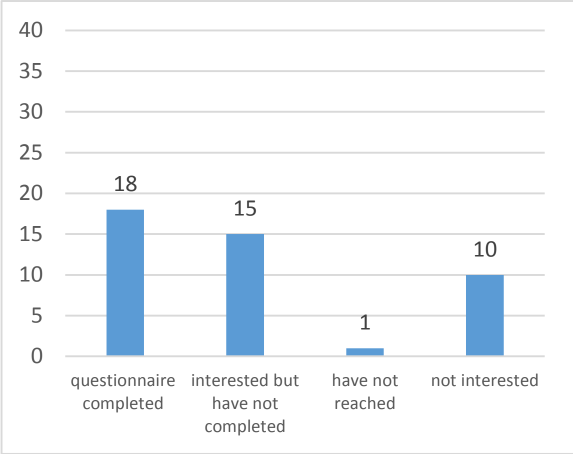


Figure 4. 13. Response rate of questionnaire survey at Estate A.

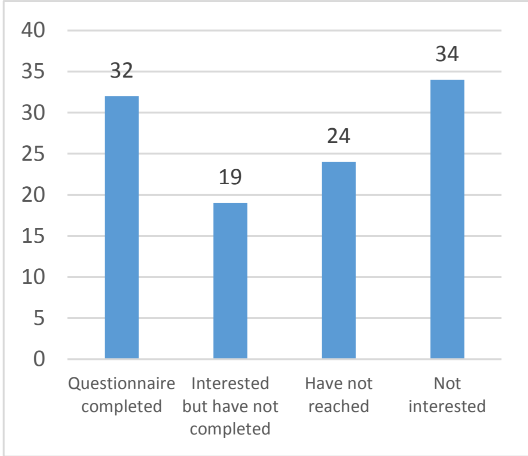


Figure 4. 14. Response rate of questionnaire survey at Estate B.

There were 10 attempts made to chase up progress and maximise the response rate of the questionnaire distribution at Estate A. There were 19 questionnaires completed out of 44 flats with a response rate of 40.9 per cent, as shown in Figure 4.13.

As for Estate B, the progress was relatively slow and a number of households immediately indicated they were not interested. A lot of participants were not able to complete all the questions although the questionnaire was developed in 'lay terms'. Due to the unfamiliarity of the questionnaire, it always took more time than expected. The form was expected to be completed within 15 minutes; however, respondents asserted they took more time to understand and respond to the questions. Additional help was also requested by some of the respondents to further explain particular questions. Based on the above concerns, the researcher tried to be available in the communal area and speak to the occupants passing by instead of approaching them door by door. With a relatively large number of flats, 18 attempts were made to maximise the response rate of the questionnaire distribution. As indicated in Figure 4.14, there were 32 questionnaires returned out of 109 flats with the response rate of 29.6 per cent. It is also indicated that although different timeslots were tried in order to approach as many households as possible, the occupants were still not available at those instances. A few participants who were previously not interested during the 'door-to-door' approach changed their mind and completed the questionnaire in the communal area at a later time.

Collected data from the questionnaire survey were transcribed into Excel spreadsheets at first for initial data analysis in order to draw a general picture regarding the current conditions of the case studies and identify potential variables for correlations analysis. Consequently, the data in Excel was coded and imported into SPSS for correlation analysis and ANOVA tests. Correlation statistical analysis was conducted in order to investigate the potential relationship between occupants' energy consumption behaviour, socio-demographic variables and housing energy performance. Due to the large variance of occupants' feedback towards the housing conditions between 2 social housing estates, the correlations analysis was separated if those variables are involved. Otherwise, the data collected from both social housing estates were combined during the investigation. ANOVA tests were also run for the unordered categorical data with the same purpose. It should be noted that all the research data were kept confidential and only shared within the research team. The findings aim to shed light on the influential factors of energy performance in the domestic sector in relation to energy consumption behaviour and socio-demographic characteristics of households.

4.4.3 Focus group

4.4.3.1 Aim of the focus group

Based on the questionnaire survey during the first stage of the research, smart technologies such as smart meters and energy management applications have not been widely implemented within both estates under study. However, research indicates that regular monitoring of home energy consumption may effectively improve occupants' energy consumption behaviours in the UK domestic sector (Stromback et al., 2011; Schultz et al., 2015). To investigate this further, a focus group was considered in order to probe into more details of occupants' experiences on using energy applications, and whether they would consider using them if they have not already. As previously discussed, major energy companies such as E.ON, British Gas and EDF Energy all developed their own energy applications for their customers. Additionally, some software developing companies create innovative energy management applications to influence occupants' energy consumption behaviour. A selected number of application features were demonstrated in the focus group in order to acquire detailed feedback from participants.

In order to develop the relationship between energy end users and energy management tools, a systematic approach is suggested based on the findings of the questionnaire survey (first phase) followed by the proposed focus group (second phase). Occupants' behavioural and socio-demographic characteristics were considered within the research in order to explore the potential correlation between them and energy performance. Design features of an energy management application are developed according to the research findings which will detect household inefficient energy consumption and feed the information back to energy companies and/or local authorities for further action (i.e. advice, information, support, engineer services, etc.). In addition, significant correlations identified from the questionnaire survey are incorporated into the design of the application. The focus group also helps the researcher to identify smart and effective options and features and develop the application design guidelines accordingly.

4.4.3.2 Design of the focus group

A focus group is designed to obtain qualitative data but has also proven effective amongst physical sciences research areas (Rabiee, 2004; Steward and Shamdasani, 2014; Reddy et al., 2015). The size of a focus group is relatively small but needs to be demographically diverse in order to capture comprehensive responses. Furthermore, the background of group members and characteristics of the group will influence interactions and response patterns. The size of the focus group is based on but not limited to the responses provided from the questionnaire survey as a number of respondents expressed interest in taking part in the focus group following from the questionnaire. In order to secure a sufficient number of attendees, the local council's support is sought to communicate with a wider range of potential participants. The candidates were carefully considered based on the characteristics of the group such as gender, age, occupation, ethnicities, etc. The focus group is carried out within a group interview setting (Frey and Fontana, 1991). A group interview can be carried out as a formal interview with structured questions and strategy or informal interview where the researcher tries to stimulate the session with specific topics.

Potential participants of the focus group are selected to cover a diverse range of backgrounds and socio-demographic features. An informal interview is preferred in order to create a relaxed atmosphere and make participants freely express their opinions. Responses are audio recorded for the data analysis. The questions asked in the interview were outlined by the researcher in order to steer the interview. The questions in the research include interviewees' current awareness of smart meter implementations, their energy consumption behaviour and preferences for energy management applications. Participants are asked to express their feelings after demonstrating some examples and illustrations of existing and proposed applications features in the form of videos, PowerPoint slides and images.

The focus group interview script included a variety of questions covering different themes were asked (See Appendix III). To probe into details of key issues raised in the questionnaire survey, interviewees' energy consumption behaviours were firstly discussed such as 'Did you change your method of using electrical appliances, windows, fans, heater in recent years? If yes, was this successful?' and 'Do you pay more or less the same amount of bills in the same period of years?'. The questions are designed to examine if occupants tend to consistently follow the same energy consumption patterns in the long-term and how difficult is it to improve behaviours. In addition, the barriers of energy conservation were also explored by asking 'Do you know that you can save your energy for free such as 'go out to avoid heating' and 'put on a jumper instead of heating'? And how do you feel about doing these?'. Then, a number of select application features were demonstrated for interviewees' feedback such as 'Would you be more interested if you and your neighbours were on the same platform to learn from and compete with each other on energy savings?', 'How would you feel if you know somebody else in your tower block has paid much less in bills than you?' and 'What are your thoughts on the illustrated features – rewarding systems?'. Interviewees were also asked to summarise what the most important issue was during the discussion. At the end, interviewees were asked to complete a short socio-demographic questionnaire in order to understand their socio-demographic characteristics and analyse the impact on a wider scope.

A number of issues raised from the review of energy management applications were demonstrated during the focus group in order to contribute to the proposed energy management application: the benchmark of real-time behavioural suggestions is currently based on historic energy use patterns, which may not be effective as occupants' behaviours are long-term habitual actions. The benchmark setting with consideration of occupants' socio-demographic background was discussed during the interview; currently, applications are able to provide real-time energy analysis and control for individual electricity appliances. However, window- and ventilation-related behaviours may also impact on energy performance and need to be integrated into energy management applications; gamification features in the application will effectively stimulate occupants' incentives but may generate negative influence without ensuring a fair playing field with strict supervisions.

4.4.3.3 Data collection

In order to help interpret the data collected from the questionnaire survey and inform the proposal of energy management applications, a focus group interview was arranged with the occupants of Estate A and Estate B according to potential participants' availability and permission from the local authority. Prior to the interview, leaflets were placed on the display board in the estates' communal areas and distributed a few times to the flats to entice more contributors to participate. Twenty-two occupants initially expressed their interest but only 9 occupants attended the interview.

To ensure the successful delivery of the focus group interview, a number of elements were considered. An interview script was drafted to ensure that the event would run according to the set structure. The interview questions and illustrations which help interviewees to better understand the questions were presented on a PowerPoint presentation (Figure 4.15). Audio recorders were used to capture the conversation during the interview. At the end, interviewees were asked to complete a short demographical survey form, which was used to explore the diversity of the participants and potential correlations with the opinions expressed. Refreshments were served in order to comfort interviewees and facilitate the event.

Figure 4. 15. Interview day (Source: Author).

Participants were firstly welcomed and introduced with the aim of conducting the focus group interview. The approximate length of the event, 90-100 minutes, was indicated to the participants and permission to use audio recorders was agreed by all interviewees. Then, the researcher assured interviewees that the discussion would be anonymous and the collected data kept safe and destroyed after transcription. In addition, guidelines for the interview were clearly explained. Occasionally, it was found that the discussion may diverge from the main topic during the interview. In this situation, the researcher had to steer it back to the intended route. The researcher also needed to maintain a protocol for the discussion as more than one interviewee speaking simultaneously may create confusion and reduce the quality of the recording.

4.4.3.4 Data analysis and reporting

A number of focused topics were planned for the discussions. They include understanding and current conditions of the smart meter implementations, interviewees' energy consumption behaviour and their experiences and preferences towards a number of energy application aspects. The interviewees' knowledge and awareness of energy saving actions and their attitudes towards the current and proposed applications were thoroughly explored in the interview. Interviewees provided very fruitful discussions on the day and their conversations were recorded for further analysis. Harding (2013) suggested that data acquired from focus group interviews need to be analysed by using the generic data analysis method for qualitative data. Sometimes, interviewees easily agree with other people's ideas without thinking. Therefore, the researcher needs to be careful that responses given by interviewees may be influenced by others due to the interactions between each other. Thus, it is vital to understand the full context of the interview context (Harding, 2013).

NVivo software, developed by QSR International, and commonly used for qualitative and mixed research analysis, was adopted to analyse the data from the focus group (Gibbs, 2002). This allows users to import the record of an interview in a wider range of formats such as text, video, audio and images. It is very convenient to process the data in NVivo as the text can be marked and annotated with interesting information, and images and footnotes can be highlighted in the audio and video sources. Following this, and based on the marks and footnotes, the data can be coded as ‘nodes’ in NVivo for in-depth analysis (Gibbs, 2002). The nodes could be a single word or a whole sentence. This allows for gathering related material in one place to search for emerging patterns and ideas. Nodes can be created and organised themes or 'cases' such as people or organisations. In addition, NVivo provides a variety of approaches to analyse the data, for example, the frequency of words occurring, re-categorisation analysis, visualisation analysis and ideas and generation of charts and diagrams for reporting.

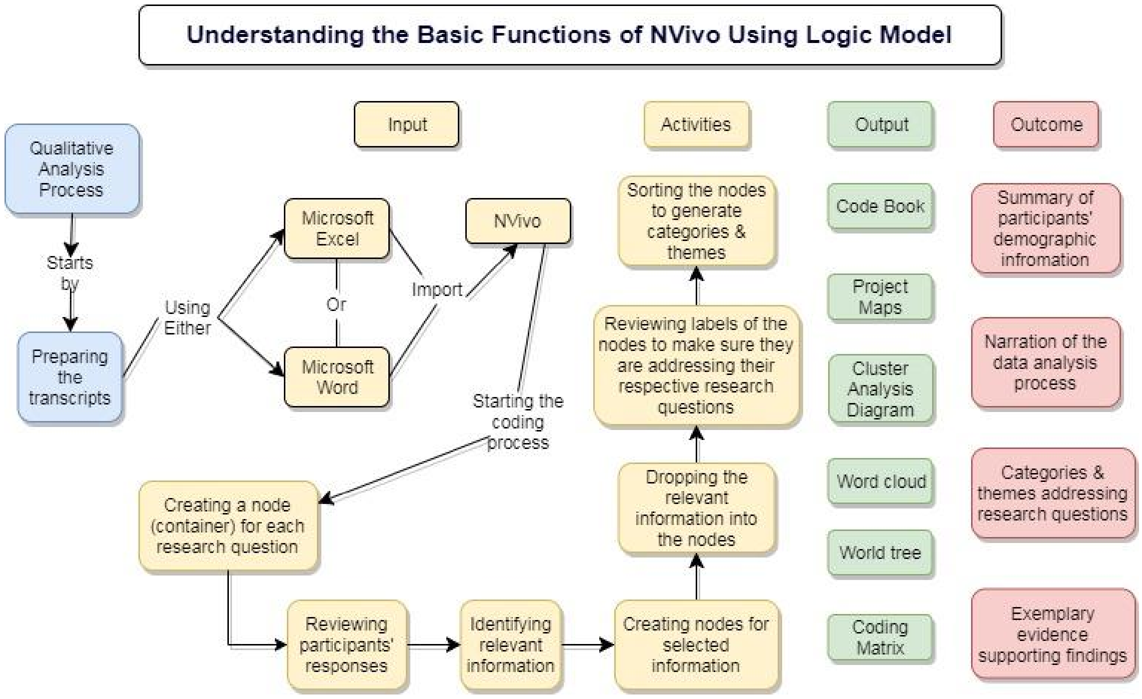


Figure 4. 16. NVivo function model (Adapted from Adu, 2017).

Figure 4.16 shows how qualitative analysis is conducted using NVivo in this research. In essence, comments obtained from the interview are carefully read and understood by considering the conversation context. Then, the data is transcribed using Microsoft Word and imported into NVivo for coding. As the interview is conducted by following a pre-designed script with a number of questions, responses given by the interviewees stay in order. So nodes are created for each question by following the interview template. Sub-nodes are also created according to the different points of view under each question. Following this, relevant information is dropped into its associated nodes. In addition, nodes are refined and sorted to generate categories and themes. It has been noted that the same ideas may have transpired for different questions. Further, themes are concluded based on identified ideas. In the data analysis, ideas expressed by interviewees are used as a ‘quotation’ to illustrate the themes. Furthermore, the research findings need to be described in an engaging narrative and compared with relative studies in the field. The research findings of the focus group interview are presented in Chapter 6.

4.5 Conclusion

This chapter systematically explains the research methodology and approaches adopted in order to fulfill the research aims and address the research questions. It started with a summary of knowledge gaps in the research field, followed by the research aims and objectives designed to tackle the gaps. Then, the research questions were raised with the aim of fulfilling the research aim and objectives. A series of methodological approaches were proposed in order to answer the research questions. The research adopts a sequential explanatory mixed methods design where the questionnaire survey with the collection of quantitative data contributed to the majority of the research supplemented with the collection of qualitative data through the focus group interview to further explain the quantitative data and in-depth understanding of a number of key issues. The functions of those approaches and similar studies were explored to ensure the successful design of data collection and analysis methods.

In collaboration with the local authority, the research was conducted using two social housing estates in one of the London boroughs as the case studies. Abundant information was returned during the questionnaire survey from both social housing estates. Additionally, fruitful discussions were provided by 9 interviewees during the subsequent focus group. There are also a number of interesting findings identified in the general survey findings and correlations analysis of the questionnaire survey. The lessons learned from the data collection have also been discussed to inform future studies. The following chapter describes and discusses the research findings from the survey questionnaire, focusing on the impact of occupants’ energy consumption behaviour, occupancy patterns and socio-demographic characteristics on home energy performance.

Chapter 5. Data analysis: Questionnaire survey

5.1 Introduction

The survey questionnaire was conducted in order to explore the potential relationships between energy performance in both social housing estates and a number of factors, such as housing issues, occupants' energy consumption behaviour, occupancy patterns and socio-demographic characteristics. The questionnaire was split into four sections exploring the issues affecting social housing energy performance, such as housing conditions, energy use patterns and behaviour, the attitudes of energy management applications, as well as occupants' socio-demographic characteristics. The chapter starts with the descriptions of current conditions of the two social housing estates in a variety of aspects through presenting the general survey findings. The data analysis is reported with the complied results of both case studies. Then, the correlations analysis was conducted towards the different variables. It is found that a number of energy consumption behaviour and socio-demographic characteristics potentially influence building energy performance. The research findings may help to form a set of evidence-based recommendations for policy makers to promote occupants' energy behaviour and improve retrofit delivery. It also helps develop recommendations for energy management application which provides behavioural intervention directly on energy users' level. The detailed research findings from the questionnaire survey are demonstrated below according to the different sections and corresponding questions.

5.2 General survey findings

5.2.1: Basic information and housing conditions

This section aims to draw an overview picture of the research sample with results by tackling a few key issues such as their occupancies, tenancy status, energy bills and the housing conditions. This information is fundamental for the data analysis.

<u>Tenancy status & living years</u>

According to Figure 5.1, social renters form the majority of the participating households comprising 76 per cent of overall tenancy status. Owner occupied properties comprise 16 per cent of the overall tenancy status and housing association renters only make up 9 per cent of it.

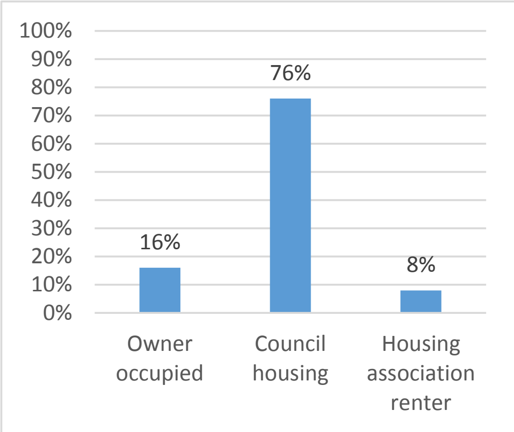


Figure 5. 1. Tenancy status.

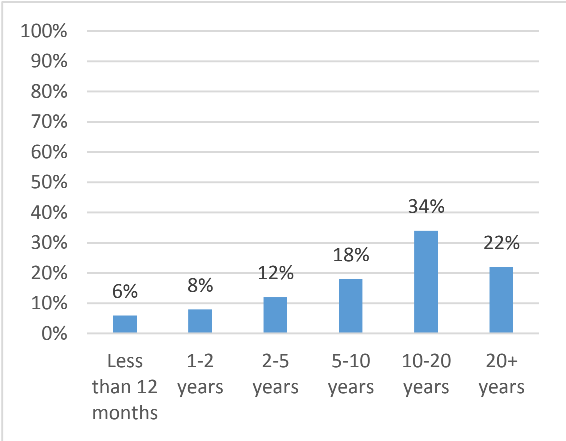


Figure 5. 2. Living years.

According to Figure 5.2, there are 6 per cent of households living in their current property for ‘less than 12 months’, 8 per cent of households living there for ‘1 up to 2 years’, 12 per cent of households living there for ‘2 to 5 years’, 18 per cent of households living there for ‘5 to 10 years’, 34 per cent of households are living there for ‘10 to 20 years’, and 22 per cent of households living there for ‘more than 20 years’. The result shows an increasing trend of number of households along with the increase of the living years. Households living in their current properties for ‘more than 10 years’ form 56 per cent of all respondents. De Castella (2013) stated that most people decide to rent a property only if they have to do it with relatively high mobility than private rental sector. However, the distinct difference of social rental sector indicates that financial issue is the most significant factor among social renters as they pay much lower rentals and are exempt from the costs of housing upgrades and retrofits.

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 pay almost the same amount on electric and gas bills. In general, households’ gas bills may slightly higher due to high gas demands in the winter.

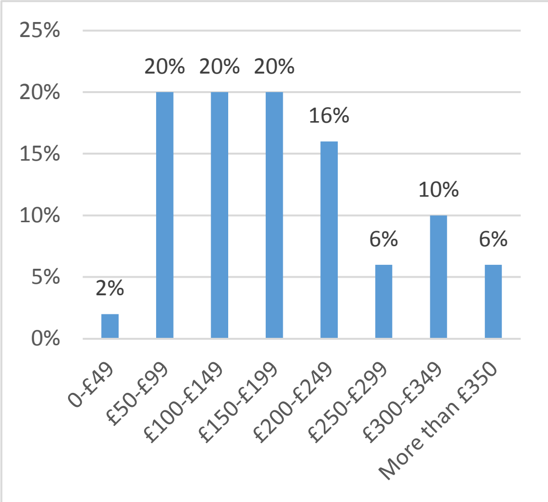


Figure 5. 3. Quarterly electricity bills.

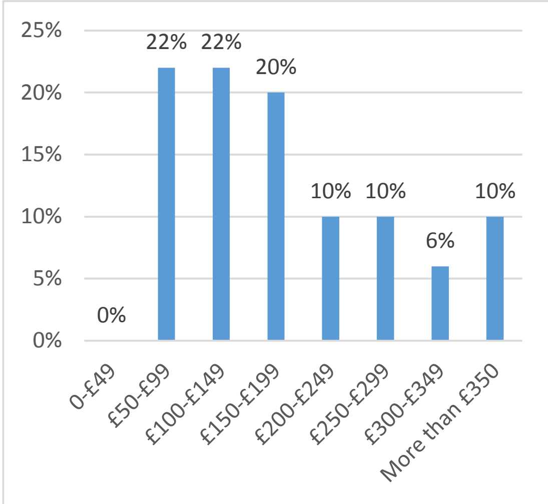


Figure 5. 4. Quarterly gas bills.

According to Figure 5.3, among the participants, 2 per cent of them had their quarterly electricity bills between '£0-£49'; 20 per cent of the households each paid their quarterly electricity bills between '£50-£99', '£100-£149' and '£150-£199'; 16 per cent of the households' quarterly electricity bills were between '£200-£249'; 6 per cent of them spent '£250-£299' on their quarterly electricity bills; 10 per cent of them spent '£300-£349' on their quarterly electricity bills; and 6 per cent of the households tended to spend 'more than £350' on their quarterly electricity bills. According to Figure 5.4, 22 per cent of the participating households each paid their quarterly gas bills between '£50-£99' and '£100-£149'; 20 per cent of them paid '£150-£199' for their quarterly gas bills; 10 per cent of the households paid '£200-£249' on their gas consumption; 10 per cent of them paid their quarterly gas bills between '£250-£299'; 6 per cent of the respondents paid their quarterly gas bills between '£300-£349'; and 10 per cent of them paid 'more than £350' on their quarterly gas bills.

The fuel poverty is defined as the households which need to spend more than 10 per cent of its incomes on fuel. By 2013, the DECC (2013) re-defined its definition as fuel poverty households need to meet two criteria: their fuel costs are above national median level, and their incomes are below official poverty line after deducting the fuel costs. According to Annual fuel poverty statistics report, 2018 (2016 data) (DBEIS, 2018), the highest proportion of fuel poverty appears in private rental sector which forms 19.4 per cent in England. It follows by social housing sector that 16 per cent of the properties in England is fuel poor.

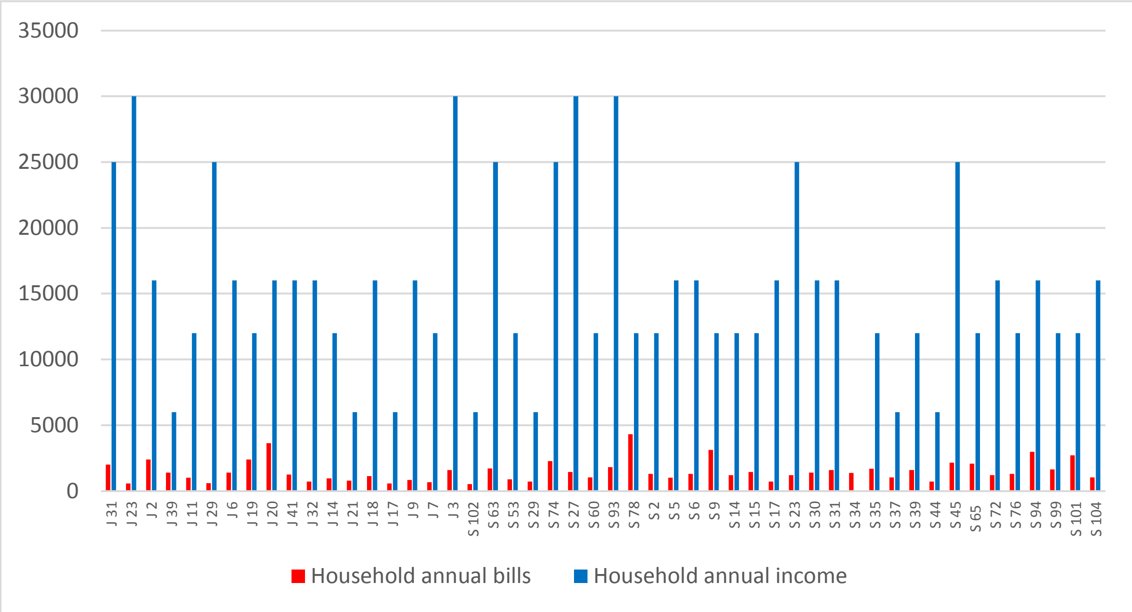


Figure 5. 5. Household annual incomes and annual bills

In the research, Household annual bills were calculated based on quarterly bills shared by the respondents. Annual household incomes were determined by using the average of income level indicated by the respondents. By comparing the households' annual incomes and their corresponding energy bills by each household (see Figure 5.5), 38.7 per cent of the households in the data sample needs to spend more than 10 per cent of annual household incomes for their bills. Therefore, they are on the risk of fuel poverty. As the annual bills were estimated based on the winter season, the actual bills could be less. However, it shows that the fuel poverty is found more significant in the research case study than the national level.

Energy advice

In the questionnaire, it investigated if occupants have obtained sufficient support on energy conservation from local authority, energy suppliers or other sources. According to Figure 5.6, 40 per cent of the households had previously received energy advice and 60 per cent of them were not told how to save their energy from the energy companies or local authorities before.

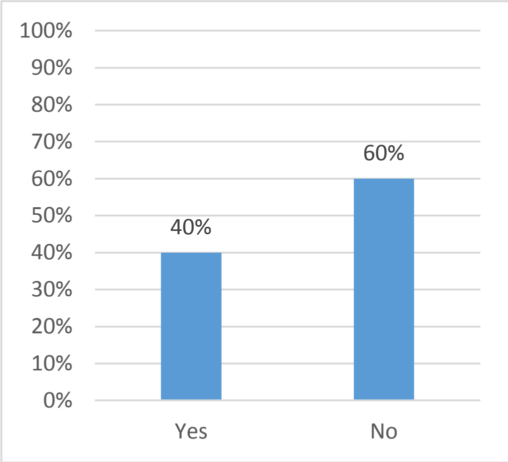


Figure 5. 6. Have you received energy advice?

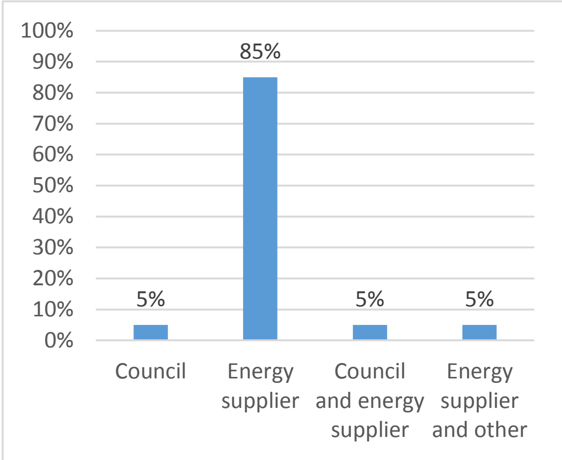


Figure 5. 7. Where did you receive advice from?

The sources of energy advice received were indicated in Figure 5.7. Among the respondents who have received energy advice, 5 per cent of them only received energy advice from ‘the council’; another 5 per cent of them has received energy advice from ‘both the council and the energy suppliers’; 5 per cent of them received energy advice from ‘the energy suppliers and other sources’; another 85 per cent of them expressed that they have received energy advice from ‘the energy suppliers’ only. It shows that energy company is currently taking the major responsibility on informing and educating occupants. However, local authorities, communities and other organizations need to work together to maximise the influence of energy conservation.

Have you changed your energy supplier/energy plan?

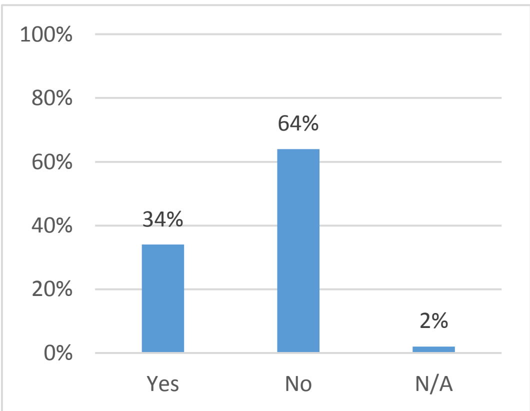


Figure 5. 8. Have you changed suppliers/plans?

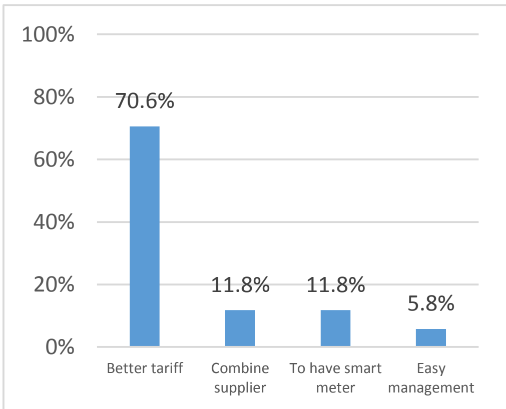


Figure 5. 9. Why did you change it?

According to Figure 5.8, 64 per cent of the respondents had not considered changing energy suppliers or plans; 34 per cent of the participants had previously changed their energy supplier/energy plans; 4 per cent of them expressed that they wished to do so but had not started. It shows that the respondents who have previously changed energy suppliers or energy plans may have certain levels of energy awareness and may be willing to save energy. The reasons of changing energy tariffs and plans were also explored and indicated in Figure 5.9. 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 either 'plan to do it' or 'have tried but not successful'. The results indicate that financial saving is the dominant reason for occupants to make changes to current energy tariffs. Other reasons that could increase occupants' motivations to make changes also include the meter upgrades and easy energy management. Occupants expressed that they would like to change their energy suppliers if the new supplier could offer them the installations of smart meters. Besides, they would like to do it if their gas and electricity supplies could be unified under same suppliers to save hassles.

<u>How often do you experience issues (cold, mould, damp, etc.) below in your home?</u>

It was also believed that issues within the internal environment may have a significant impact on the home energy performance. Hence, the issues occurred inside the properties were also investigated in the questionnaires, such as cold, damp, mould, draught and condensation. Participants were asked to report on how frequently they experience those issues in their homes. Notably, a significant variance has been indicated in the results of the two cases under study which is shown below:

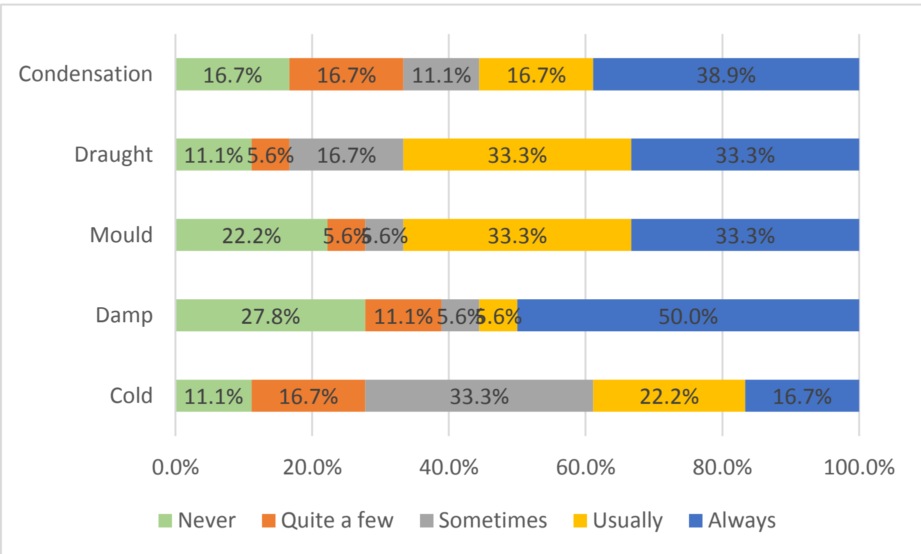


Figure 5. 10. Housing conditions at Estate A.

As shown in Figure 5.10, 'draught' and 'mould' are the most experienced housing issue as 66.6 per cent of the respondents 'always or usually' experience them at their homes in Estate A; 'condensation' is the second most experienced housing issue at Estate A as 55.6 per cent of the respondents expressed that they 'always or usually' experience it at their homes. On the other hand, 'cold' is the least problematic issue at Estate A as only 38.9 per cent of the participants 'always or usually' feel 'cold' inside their dwellings; 'damp' is also not too obvious at Estate A as 38.9 per cent of the participants 'never or quite a few' feel it at their homes and only 33.3 per cent of them will 'always' feel 'damp' at homes.

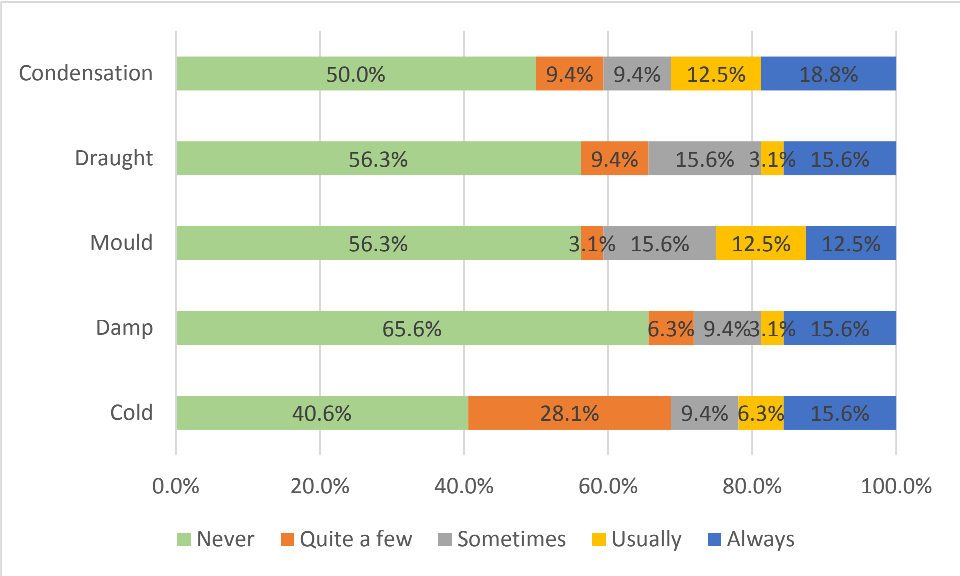


Figure 5. 11. Housing conditions at Estate B.

On the other hand, as shown in Figure 5.11, 'condensation' is the most experienced housing issue at Estate B as 31.3 per cent of the respondents expressed that they 'always or usually' experience it at their homes; the second problematic housing issues are 'mould' where 25.0 per cent of the participants 'always' feel it at their homes; the percentages that respondents experience 'cold', 'damp' and 'draught' are 21.9 per cent, 18.7 per cent and 18.7 per cent. Hence, 'draught' and 'damp' are the least problematic issues at Estate B.

Variations were indicated between the 2 social housing estates regarding to the level of housing problems experienced: the average percentage of respondents who had 'never or quite a few' experienced all housing issues at Estate A is 28.92 per cent. On the other hand, there were 65 per cent of the respondents expressed that they had 'never or quite a few' experienced all housing issues at Estate B; the average percentage of respondents who had 'always or usually' experienced all housing issues at Estate A is 56.48 and 23.12 at Estate B. As a result, the housing conditions at Estate B is much better than at Estate A. That explains why the local authority decided to retrofit Estate A prior to Estate B. The distinct differences of housing conditions at both estates informed that the correlation analysis which is related to 'housing problems' need to be conducted separately.

5.2.2: Energy consumption behaviour and energy use patterns

Occupants 'heating and occupancy patterns

In order to explore the implication of occupants' occupancy and heating patterns on home energy performance, the hours that occupants occupied their flats and the hours that heaters were turned on were asked in the questionnaire survey. As recording the occupancy and heating patterns requires large amount of detailed information, the respondents could not remember the details in every room of their flats. As a result, the occupancy and heating patterns in the 'living room' as the most complete answer is used to the analysis in the future.

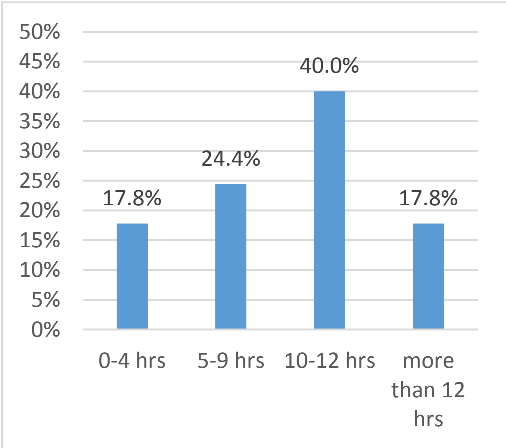


Figure 5. 12. Hrs occupied in weekdays (living room).

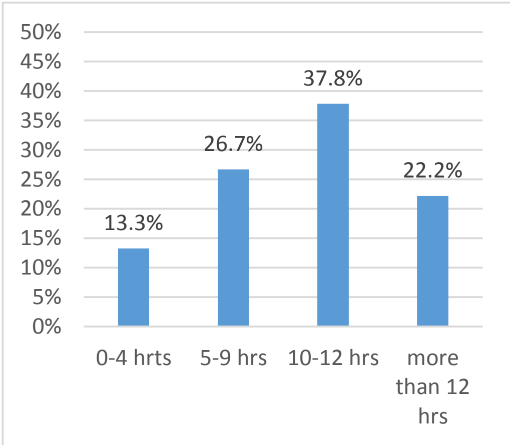


Figure 5. 13. Hrs occupied in weekends (living room).

According to Figure 5.12, the occupants who spent '0-4 hrs' in the living room during the weekdays comprises 17.8 per cent of the overall respondents; the ones spending '5-9 hrs' in the living room during the weekdays comprises 24.4 per cent of the overall respondents; the ones spending '10-12 hrs' in the living rooms during the weekdays comprises 20.0 per cent of overall respondents; the rest of 17.8 per cent of respondents would spend 'more than 12 hrs' in their living rooms. On the other hand, their occupancy patterns in living room during weekends were also explored. According to Figure 5.13, the occupants who spent '0-4 hrs' in the living room during the weekdays comprises 13.3 per cent of the overall respondents; the ones spent '5-9 hrs' in the living room during the weekdays comprises 26.7 per cent of the overall respondents; the ones spent '10-12 hrs' in the living rooms during the weekdays comprises 37.8 per cent of overall respondents; the rest of 22.2 per cent of respondents would spend 'more than 12 hrs' in their living rooms. The results showed different occupancy patterns in the living room between weekdays and weekends. The occupancy is generally higher during the weekends than the weekdays. It may imply that the employed family members spend less time at their homes during weekdays but more time during weekends.

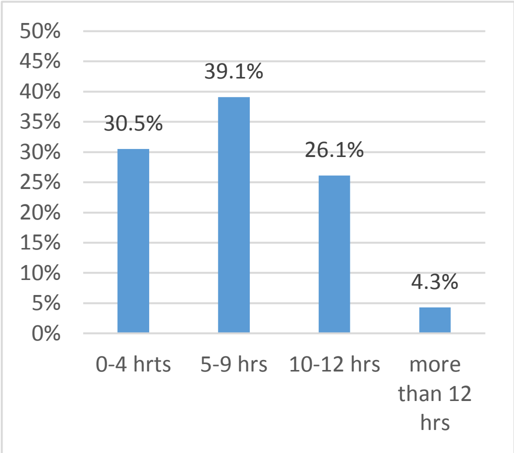


Figure 5. 14. Hrs heaters on in weekdays (living room).

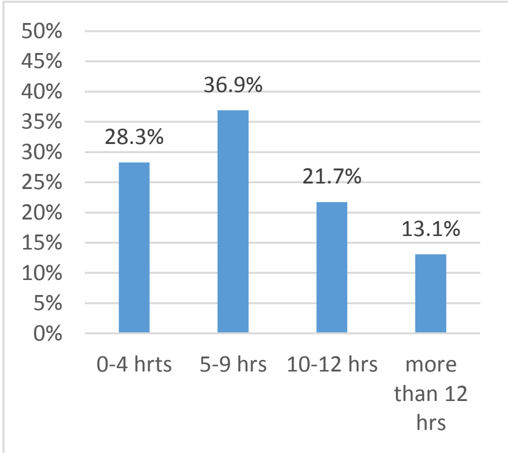


Figure 5. 15. Hrs heaters on in weekends (living room).

Apart from respondents' occupancy patterns, their heating patterns in living room during weekdays and weekends were also explored. According to Figure 5.14, the occupants who would turn on the heaters for '0-4 hrs' in the living room during the weekdays comprises 30.5 per cent of the overall respondents; the ones that kept the heating turned on for '5-9 hrs' in the living room during the weekdays comprises 39.1 per cent of the overall respondents; the ones with heating turned on for '10-12 hrs' in the living rooms during the weekdays comprises 26.1 per cent of overall respondents; the rest of 4.3 per cent of respondents would turn on the heaters for 'more than 12 hrs' in their living rooms. According to Figure 5.15, the occupants who would turn on the heaters for '0-4 hrs' in the living room during the weekdays comprises 28.3 per cent of the overall respondents; the ones that kept the heating turned on for '5-9 hrs' in the living room during the weekdays comprises 36.9 per cent of the overall respondents; the ones with heating turn on for '10-12 hrs' in the living rooms during the weekdays comprises 21.7 per cent of overall respondents; the rest of 13.1 per cent of respondents would turn on the heaters for 'more than 12 hrs' in their living rooms. The different heating patterns are indicated between weekdays and weekends. It may imply that the employed family members who spend more time at their homes during weekends will also use the heating systems more frequently.

Heating controls 1:

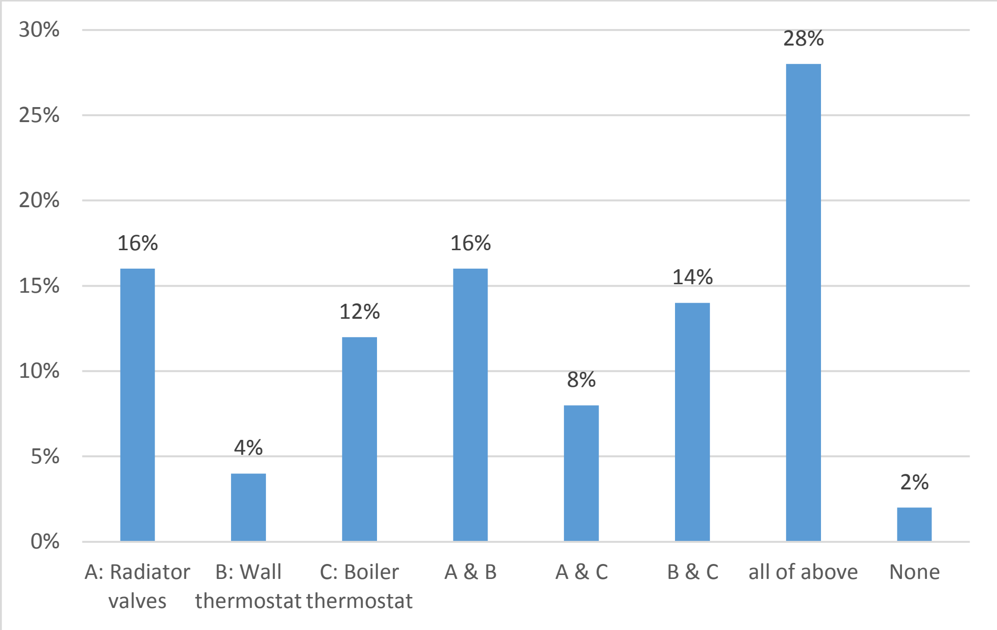


Figure 5. 16. What heating controls do you have at home?

According to Figure 5.16, 32 per cent of the participants expressed that they only have one type of heating control in their homes: 16 per cent of the households have 'radiator valves' only, 4 per cent of the households have 'wall thermostat' only and 12 per cent of the households have 'boiler thermostat' only at their homes. Besides, 38 per cent of the participants expressed that they have two types of heating controls at homes: 16 per cent of them have 'both radiator valves and wall thermostat' in their properties, 8 per cent of the households have 'both radiator valves and boiler thermostat' in their properties and 14 per cent of them have 'both wall thermostat and boiler thermostat' at homes. In addition, 28 per cent of the households claimed that they have 'all three heating controls' at their homes. Two per cent of the participants expressed that they 'do not have any heating controls' in their properties. According to the discussions with local authority, all of the radiator valves, wall thermostat and boiler thermostat were equipped at each property of both estates. Except small proportion of the them whose heating controls might be broken, the majority of them should have all of them in working conditions. The results indicate that respondents generally do not have sufficient knowledge regarding to the functions of heating systems. Hence, the heating controls might be ignored when operating the homes.

Heating controls 2:

It is noticed that the majority of the respondents knew that they have heating controls at homes. Hence, their use patterns of the heating controls were also investigated in order to explore its impact on energy performance.

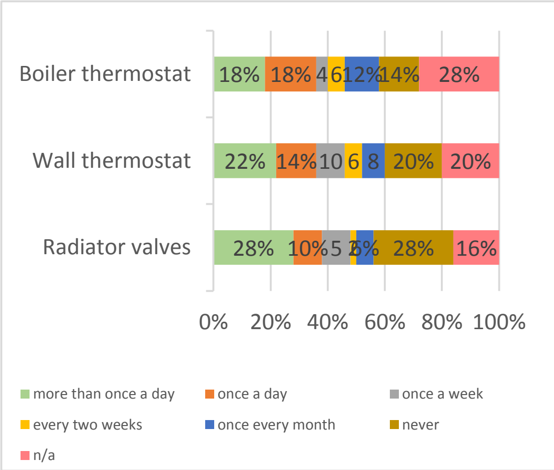


Figure 5. 17. How often do you use your heating controls?

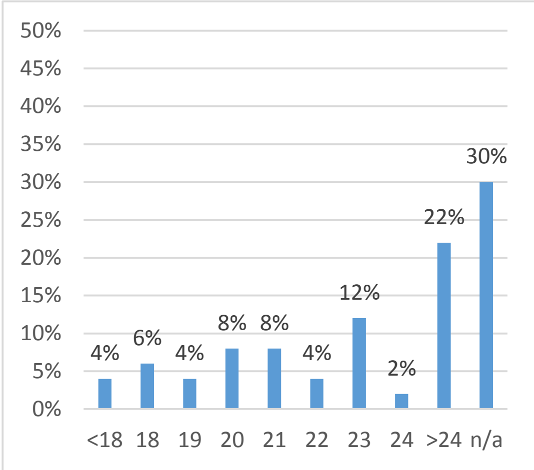


Figure 5. 18. What temperature do you set thermostat?

Occupants were asked how frequently they use each heating control at their homes. According to Figure 5.17, 36 per cent of the respondents used their 'boiler thermostat' at least 'once a day'; 36 per cent of the participant would use their 'wall thermostat' at least 'once a day'; and 38 per cent of them used 'radiator valves' at least 'once a day'. On the other hand, 64 per cent of the participants used 'wall thermostat' at most 'once a week'; 64 per cent of them would use 'radiator valves' at most 'once a week'; and 62 per cent of the households used 'boiler thermostat' at most 'once a week'. In general, around 36.67 per cent of respondents used their heating controls at least once a day, which may imply that occupants understood the significance of the heating controls to a certain level. This indicated that occupants need to be further educated and advised in order to appreciate the functions and operations of heating controls at their homes better.

According to Figure 5.18, the room temperatures that occupants set on their wall thermostats demonstrated that they tended to set up relatively high temperature for a number of reasons that were explored in the later sections. Forty-eight per cent of the respondents tended to set their wall thermostat 'more than 21 °C' which may not be necessary. The respondents (24 per cent) who have set their room temperature at more than 24 °C could encounter the cardiovascular diseases risk (Saeki et al, 2014). The reason of this is that high temperature could lead to the change of human body signs, such as blood pressures, blood viscosity and the heart rate. The high indoor temperature in winter also enlarges the temperature differences between inside and outside. Hence, it increases the risk of cardiovascular diseases (Gasparrini et al., 2015). Recent reports (Gram-Hanssen, 2014) also stated that the main causes of high heat consumption are relatively high indoor temperatures, extensive infiltration due to poor building physical conditions and hot water over-consumption.

<u>How often do you open the windows in winter and for how long?</u>

It is believed that opening the windows will effectively increase the air circulation within the properties and improve indoor air quality and comfort in a natural approach (Stazi, 2017). Besides it may also help to solve the condensation, mould and damp experienced inside. However, opening windows for longer hours may reduce the indoor temperature thus requiring more heating (Stazi, 2017). The frequency of opening the windows in the winter and the hours the windows are opened have also been investigated.

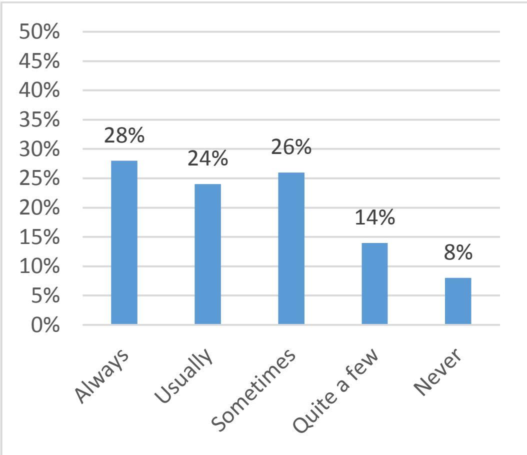


Figure 5. 19. Frequency of opening the windows in the winter.

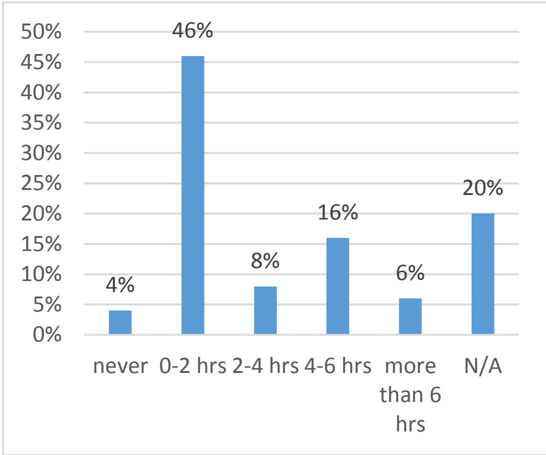


Figure 5. 20. Hours windows opened in the winter?

According to Figure 5.19, 28 per cent of the participants expressed that they 'always' open their windows in the winter for a certain time; 24 per cent of the occupants would 'usually' open their windows in the winter; 26 per cent of them would 'sometimes' open their windows in the winter; 14 per cent of them opened their windows 'quite a few times' in the winter while 8 per cent of the occupants would 'never' open their windows in the winter.

According to Figure 5.20, 4 per cent of the respondents would never open their windows in living room when they were at home; 46 per cent of the occupants tended to leave their windows open 'less than 2 hours' in living room; 8 per cent of them left their windows open for '2 to 4 hours' in living room; 16 per cent of the households would leave their windows open for '4 to 6 hours in average in winter in living room; and 6 per cent of the households would leave their windows open for 'more than 6 hours' in living room; and 20 per cent of them could not remember how many hours they tended to leave their windows open in living room during the winter. Although some occupants did not like opening the windows very frequently but the hours they left their windows open are relatively long. On the other hand, although some occupants may open their windows every day in the winter, they tended to leave their windows open for a very short time. These different patterns of opening the windows will significantly affect their energy consumption and issues experienced. The potential relationships were demonstrated in the findings of the correlations in 'Section 5.4: Correlation results and analysis'.

How often do you turn on the extractor fan and for how long?

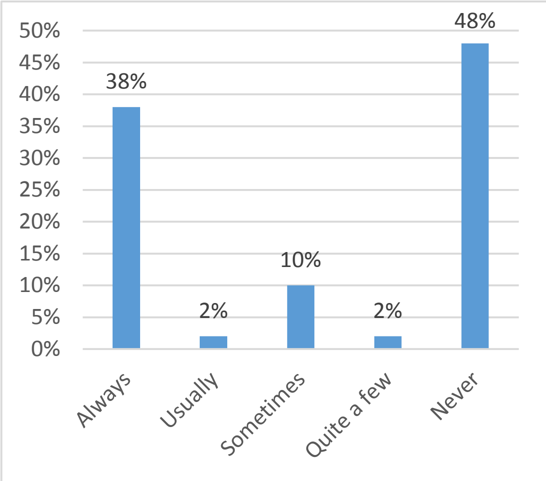


Figure 5. 21. How often do you turn on the extractor fan?

According to Figure 5.21, 38 per cent of the participants expressed that they 'always' turned on the extractor fans when taking a shower; 2 per cent of them would 'usually' turn on the extractor fan when taking a shower; 10 per cent of the occupants would 'sometimes' turn on the extractor fans; 2 per cent of them would turn on the extractor fan 'quite a few times' when taking a shower; and 48 per cent of the participants 'never' turned on the extractor fans when taking a shower which may dramatically increase the possibilities of mould, condensation and damp in their properties.

How often do you keep the trickle vents open and for how long?

A trickle vent is a line of small slots in the window to allow air to filter into the indoor spaces even when the window is closed (Designing buildings, 2015). Occupants can control it when needed. 58 per cent of the participants expressed that they are familiar with the purpose of the trickle vent. However, 42 per cent of them did not know the purpose of it. Among the occupants who are familiar with the purpose of trickle vents, they are asked how the trickle vents in their homes are operated.

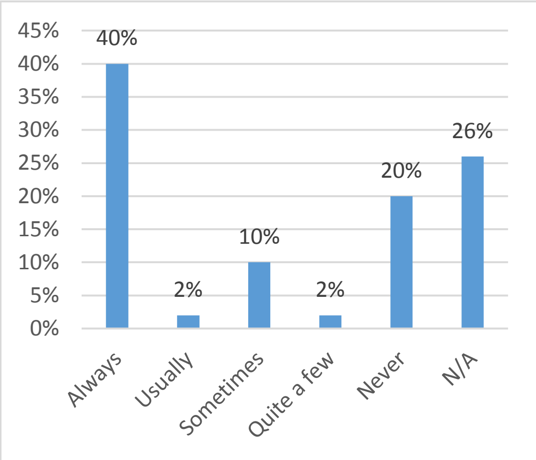


Figure 5. 22. How often do you keep trickle vents open?

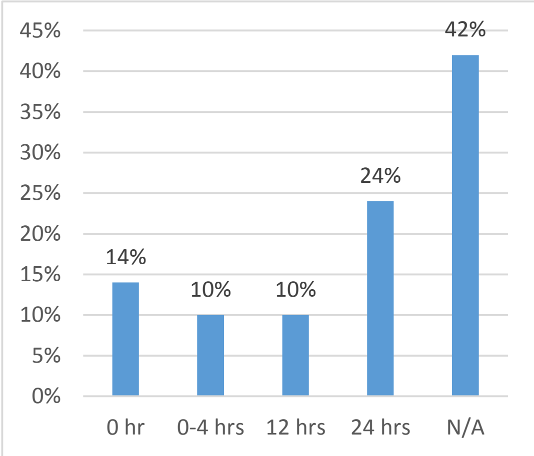


Figure 5. 23. How long do you keep the trickle vents open?

According to Figure 5.22, 40 per cent of the participants ‘always’ kept the trickle vents open; 2 per cent of them ‘usually’ kept it open; 10 per cent of the occupants would keep it open ‘sometimes’; 2 per cent of them only kept it open for ‘quite a few times’; 20 per cent of participants ‘never’ kept the trickle vents open; and 26 per cent of them ‘did not answer’ as they have no idea what the trickle vent is. Therefore, they either leave the trickle vents open or close all the time.

According to Figure 5.23, 14 per cent of them have ‘never’ kept it open'; 10 per cent of them would keep the trickle vent open for ‘less than 4 hours’; 10 per cent of participants would leave it open only during the daytime for ‘12 hours’; 24 per cent of occupants would always keep the trickle vent open all day ‘24r hours’; and 42 per cent of the participants ‘did not answer’ as they did not deal with the trickle vents and consequently do not know if it is closed or open. Occupants’ behaviours of using trickle vents need to be considered as it is used to maximise the indoor temperature while keeping the spaces ventilated. It showed that 82 per cent of respondents would leave it closed all the time, leave it open all the time or ignore it. As a result, the guidance on how to properly operate trickle vents should be provided to the occupants.

How frequently do you do the following activities?

It is recognized that apart from physical conditions of the properties and the uses of appliances, a series of factors also impact on energy performance, such as occupants’ energy consumption behaviour and occupancy patterns. A number of energy-related approaches were proposed and incorporated into the questionnaires. Occupants were asked to provide the information on how often they do a few energy-saving activities as part of their lifestyle.

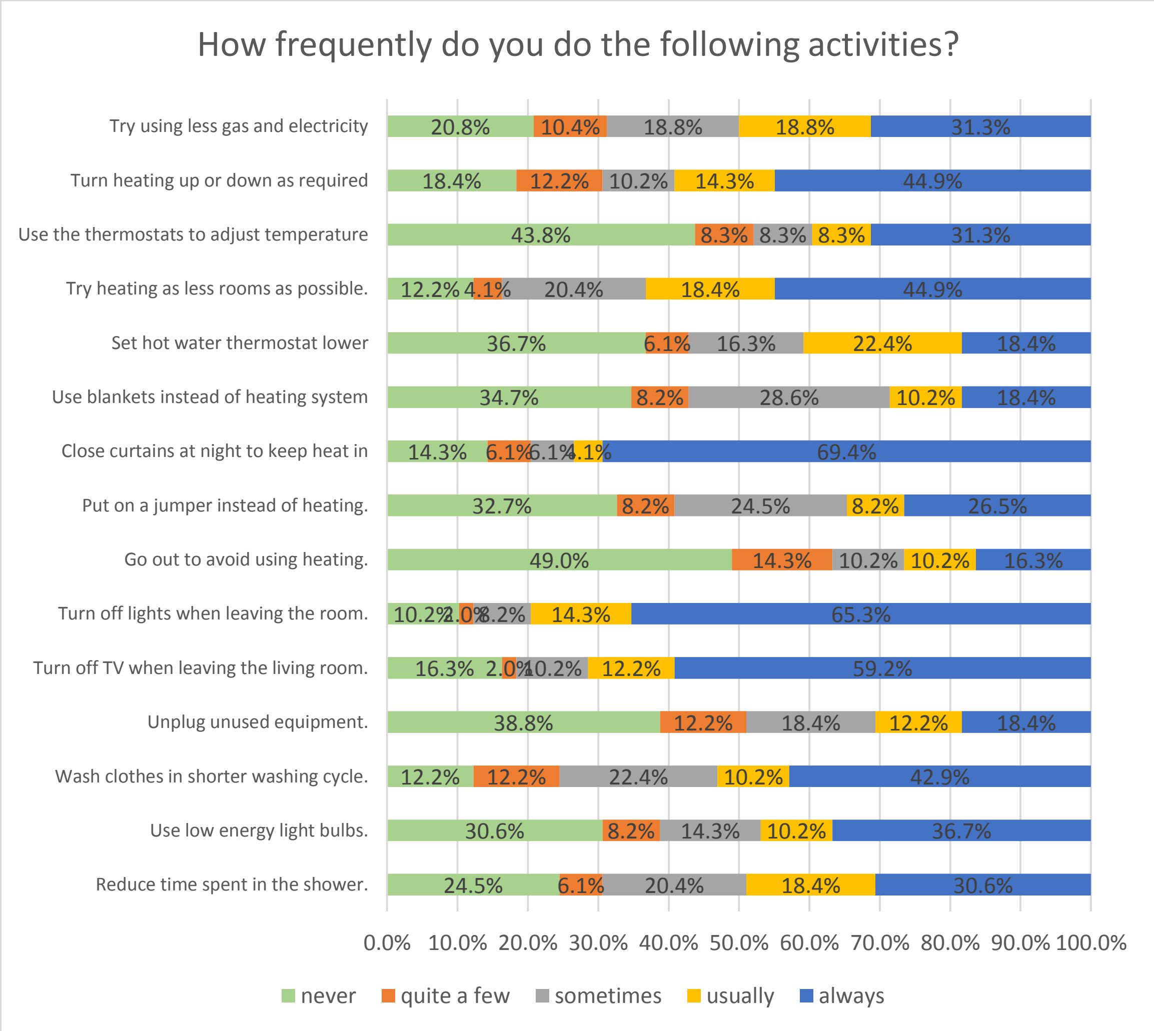


Figure 5. 24. Occupants' preferred energy saving behaviors.

According to Figure 5.24, occupants 'always or usually' saved their energy through more conventional ways, such as 'turn off lights when leaving the room' (79.6 per cent), 'close curtains at night to keep heat in' (73.5 per cent), 'turn off TV when leaving the living room' (71.4 per cent) and 'try heating as less rooms as possible' (63.3 per cent). However, the energy saving behaviour that require more knowledge and skills were not well adopted among the participants: 52.1 per cent of the occupants would 'never' or 'quite a few' 'adjust their wall and hot water thermostat', and 42.8 per cent of them would 'never' or 'quite a few' 'set hot water thermostat lower'. Besides, people did not want to saving energy by compromising their comfort, that is why 63.3 per cent of the participants would 'never' or 'quite a few' 'go out avoid using heating', 40.9 per cent of them would 'never' or 'quite a few' 'put on a jumper instead of heating' and 42.9 per cent of them would 'never' or 'quite a few' 'use blankets instead of heating system'.

Do you think you use more energy than you should to sustain a comfortable home?

Occupants may over consume energy due to lack of knowledge and aspiring to achieve a more comfortable living environment. According to figure 5.25, respondents' perception of energy use was explored. As a result, 46 per cent of the respondents believed they use more energy than they should to have a comfortable home. On the other hand, 54 per cent of the respondents do not think they used more energy than they should.

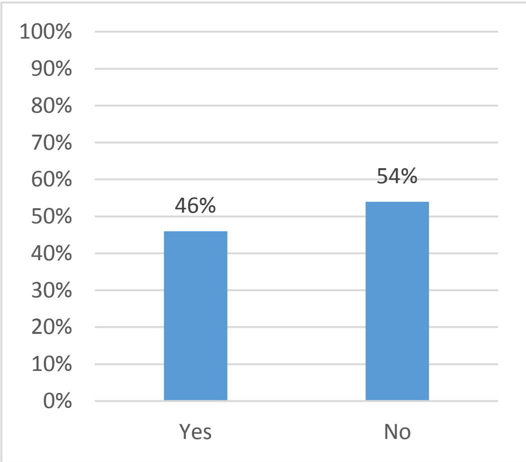


Figure 5. 25. Do you use more energy than you should?

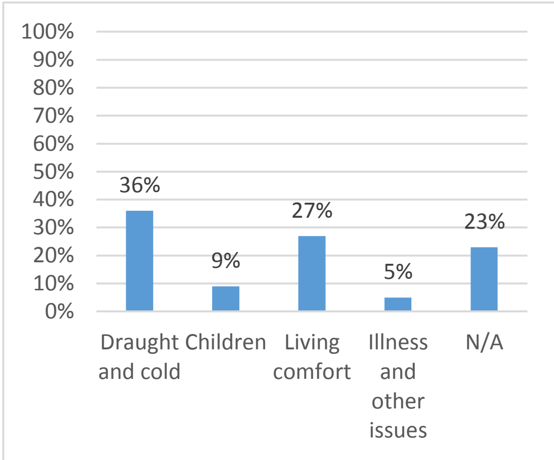


Figure 5. 26. If you use more energy than you should, why?

To further explore the reason behind this, the occupants were asked why they thought they used more energy than they should through an open ended question. Their answers were categorised with different themes and shown in Figure 5.26. Among the respondents who thought they used more energy than they should, 36 per cent of them claimed that the reason of energy over consumption is due to the draught and cold experienced in their flats; 9 per cent of them needed to provide warmer homes to their children; 27 per cent of them did it for their own comfort and satisfaction; 5 per cent of the respondents had to consume more energy due to illness; while 23 per cent of the respondents did not answer this question. This shows that occupants may consume more energy for children's need, personal comforts and illness (Abrahamse and Steg, 2009; Neuhoff et al., 2011). The poor housing condition also lead to the energy overconsumption.

5.2.3 Attitudes towards saving energy through energy management applications

<u>Does anyone of your household have a smart phone and comfortable to install and use applications?</u>

According to figure 5.27, 86 per cent of the respondents asserted that they or their household members have smart phones; only 14 per cent of the households did not have it.

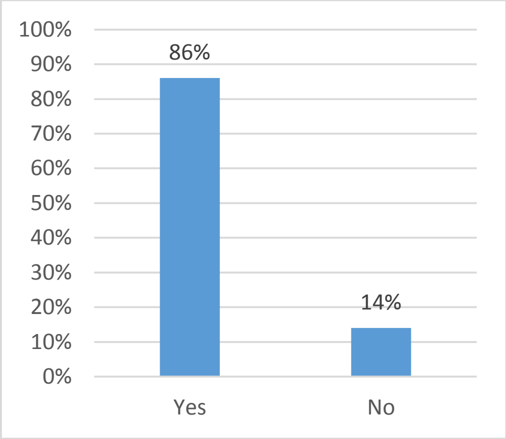


Figure 5. 27. Do you have a smart phone?

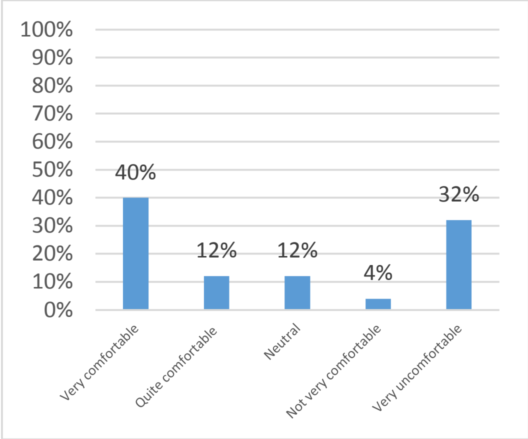


Figure 5. 28. How comfortable do you like to use app on it?

According to Figure 5.28, 32 per cent of the respondents expressed that they are 'very uncomfortable' to use application on smart phones; 4 per cent of them felt 'not very uncomfortable' to use applications on their smart phones; 12 per cent of them feel 'neutral' to use application on their smart phones; 12 per cent of them felt 'somewhat comfortable'; and 40 per cent of the respondents felt 'very comfortable' to use application on their smart phones. It is noticed that there were large proportion of the respondents did not feel very comfortable to use the application. It because of the large proportion of elderlies and carer-needed person living in the social housing estates. They would feel very difficult to adopt the smart technologies and applications.

Do you have a smart meter installed at home and how often do you read your smart meter and adjust energy use accordingly?

According to Figure 5.29, only 20 per cent of the households have smart meters installed in their homes and 80 per cent of the households do not have smart meters installed. It is noticed that although the roll-out of smart meters was set up by the government and committed to finish by 2020 by the energy companies, it is still a long way to equip smart metering devices in all homes, especially social housing and housing association estates. Blackman (2017) stated the pace of smart meter implementation and its implications of fuel poverty for in social housing are behind the schedule.

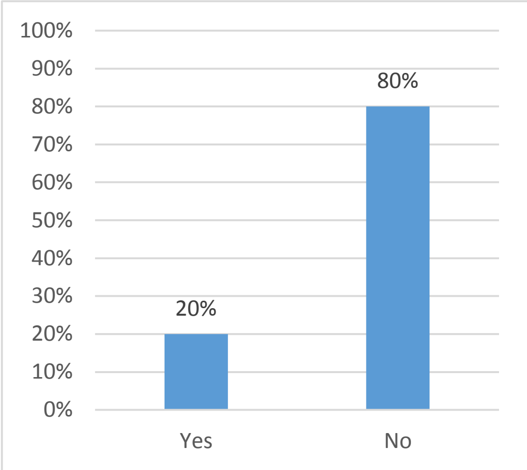


Figure 5. 29. Do you have smart meter at home?

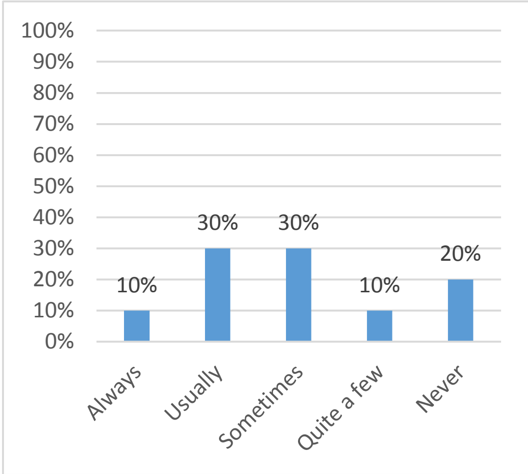
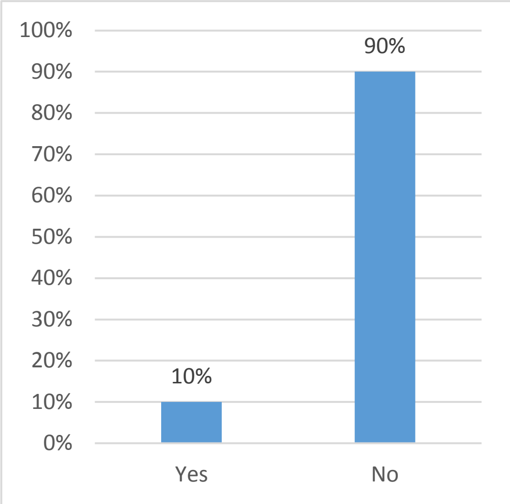


Figure 5. 30. How often do you read smart meters?

According to Figure 5.30, among the ten respondents who have smart meters installed at their homes, 10 per cent of them 'always' read smart meters and adjust energy use accordingly; 30 per cent of them 'usually' did it; 30 per cent of them will do it 'sometimes'; 10 per cent of the respondents only read the smart meter and adjusted energy use 'quite a few' times; and 20 per cent of them never did it although the smart meters are at homes. It shows that 70 per cent of the respondents who have smart meters installed at their homes will 'always, usually or sometimes' adjust their energy uses according. It is much more than the frequency of using 'heating controls' and 'extractor fans' among all of the respondent regardless of smart meter installation. Therefore, the result shows positive influences of smart meters on improving occupants' energy behaviour. The low implementation rate of smart meter was further explored during the focus group interview and discussed in the following section.

<u>Do you have energy management application on your smart phone and how often do you use it and adjust energy use accordingly?</u>

It has been found that the number of occupants who have smart meters installed to monitor their energy use accordingly was very low. The smart control of energy consumption through energy management application was also investigated. According to Figure 5.31, 10 per cent of the respondents indicated that they had energy management applications on their smart phones while 90 per cent of the respondents did not.



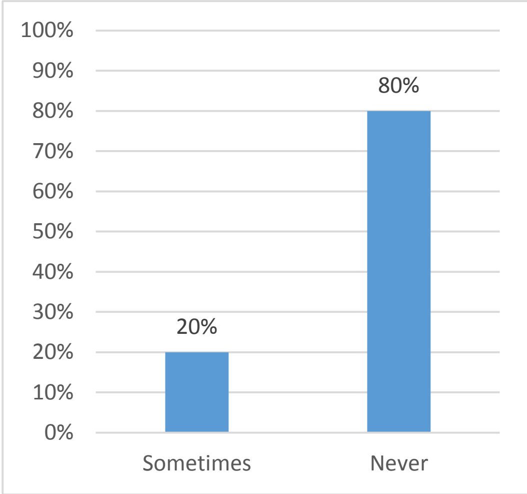


Figure 5. 31. Do you have energy management app on your phone?

Figure 5. 32. How often do you use it?

According to Figure 5.32, Among the respondents with energy management applications on their smartphones, only 20 per cent of them would 'sometimes' give attention to it and adjust energy use accordingly, the rest of them (80 per cent) would never do that. The results showed that the adoption of energy management applications have not been thoroughly approached to the energy end user's (occupant) level.

Preferred energy saving features in an energy application

This section aims to explore which features on the energy management applications may mostly attract people's attention and raise their engagement. A series of potential application aspects for energy saving were incorporated according to the literature review and current energy management applications in the market.

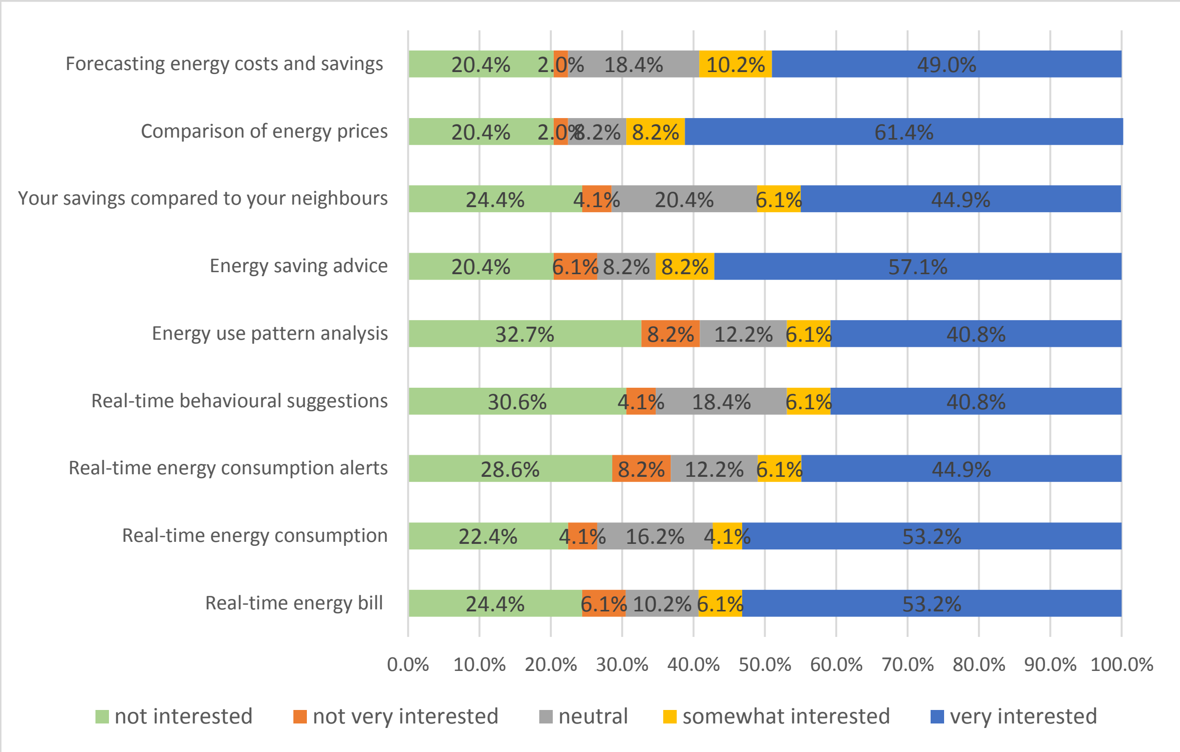


Figure 5. 33. Preferred smart application aspects.

According to Figure 5.33, occupants rated their preferences of a number of application features which they felt would help them to reduce home energy consumption in the case study social housing estates. 50 respondents all have answered this question. Although many of them have not experienced those application feature, they all expressed their opinion about them. Respondents had expressed they are 'very interested' in some application features, such as 'comparison of energy prices' (61.4 per cent), 'energy saving advice' (57.1 per cent), 'real-time energy bill' (53.2 per cent) and 'real-time energy consumption' (53.2 per cent). However, some features did not raise interest from the participants. For example, respondents were 'not interested' in a few other application features, such as 'energy savings compared to your neighbors' (24.4 per cent), 'real-time behavioral suggestions' (30.6 per cent), 'energy use pattern analysis' (32.7 per cent), and 'real-time energy consumption alerts' (28.6 per cent). In order to make occupants familiar with those innovative energy saving aspects, energy suppliers and the council need to initiate more pilots within their boroughs. In the research produced by Ehrhardt-Martinez et al. (2010) and Hargreaves et al. (2010)'s, they both indicated that households with comparative feedback displayed in the 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 community' level. This question also directly informs the design of focus group to probe more into details of the reasons of occupants' preferences.

5.2.4 Socio-demographic characteristics

Members in household and age group

According to Figure 5.34, 15 participating households are occupied by 1 person which make up 30 per cent of overall households; 24 households are occupied by 2 or 3 persons which make up 48 per cent of overall households; 9 participating households have 4 or 5 people living in the properties that corresponds to 18 per cent of overall households; and 2 of the households are occupied by 6 or 7 people which make up 4 per cent each of overall households.

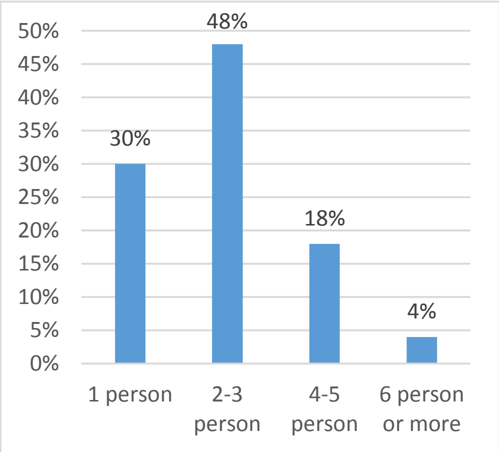


Figure 5. 34. Number of family members.

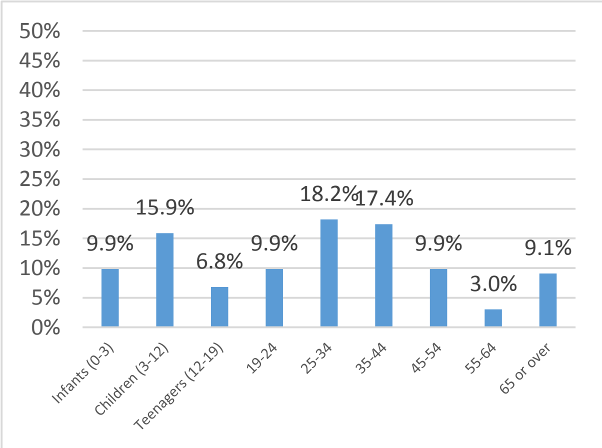


Figure 5. 35. Age band of family members.

The age band of each family member was also explored in the questionnaire. According to Figure 5.35, there are 13 'infants (0-3 yrs)' which make up 9.9 per cent of overall family members in participating households; 21 'children (3-12 yrs)' which make up 15.9 per cent of overall members; 9 'teenagers (12-19 yrs)' that corresponds to 6.8 per cent of overall family members; 13 adults between '19 and 24 yrs' that corresponds to 9.9 per cent of overall family members in participating households; 24 adults between '25 and 34 yrs' that take 18.2 per cent of overall family members; 23 adults between '35 and 44 yrs' that make up 17.4 per cent of overall family members in participating households; 13 adults between '45 and 54 yrs' that make up 9.9 per cent of the overall family members; 4 adults between '55 and 64 yrs' that take 3.0 per cent of overall family members; and 12 adults with '65 yrs or over' which corresponds to 9.1 per cent of the family members in the participating households. From the result, the dominant age groups in participating households are 'infants and children' (25.8 per cent), 'adult (25-34)' (18.2 per cent), and 'adult (35-44)' (17.4 per cent), whilst 'adult (65 or over)' comprised 9 per cent of the total household residents.

In national level, properties occupied by 1 comprise 42.3 per cent of overall social housing sector, properties occupied by 2 to 3 people comprise 37.7 per cent of overall sector, the ones with 4 to 5 people comprise 16.6 per cent of overall social housing sector, and properties with 6 or more persons comprise 3.4 per cent of overall sector (DCLG, 2017). In this research, the composition of 1 person properties is a little lower, composition of 2 to 3 person properties is slightly higher, and the compositions of other categories are more or less the same as the DCLG report. It showed that the research sample generally represents the condition of social housing estates in terms of number of occupants. The representativeness of the data sample is further discussed in 'Section 5.3: Representativeness of the research'.

Household economic status

Occupants' economic status were investigated in the questionnaire survey as it may closely relate to energy saving awareness and the degree of knowledge and perceptions. Therefore, it may impact on occupants' energy use patterns and affect home energy consumption (Zahiri and Elsharkawy, 2018).

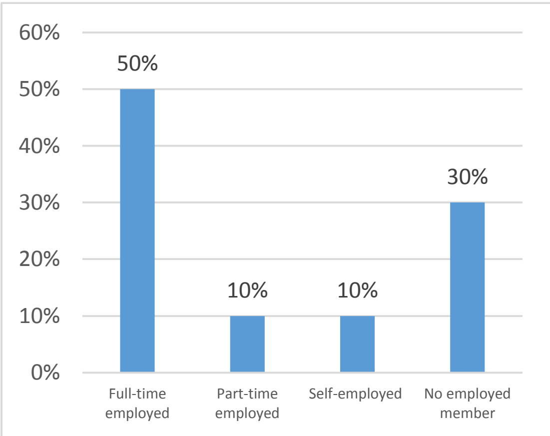


Figure 5. 36. Economic status.

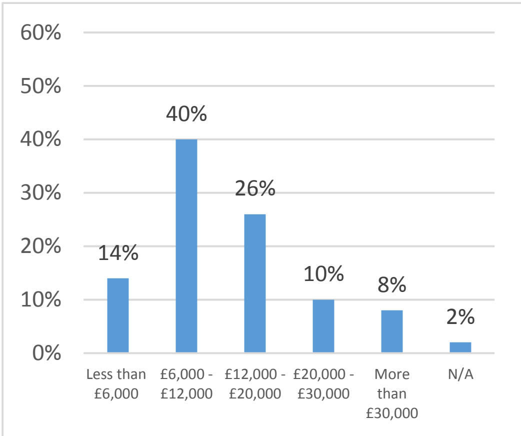


Figure 5. 37. Total household income level.

The economic status statistics are based on the percentage of households with different options of employability. According to the Figure 5.36, households with full-time employed family members comprised 50 per cent of overall participating households; 10 per cent of the households had part-time employed family members only; 10 per cent of them had self-employed family members only, and 30 per cent of them indicated that all of their family members were not able to work. According to Figure 5-37, the majority (54 per cent) of the households earned less than £12,000 per year which are considered lower than the UK's minimum wage rate for full year work (Gov.uk, 2018). This also increases the possibilities of fuel poverty. Among these households, 17.5 per cent of them earned less than £6,000 total annual income.

Ethnic background:

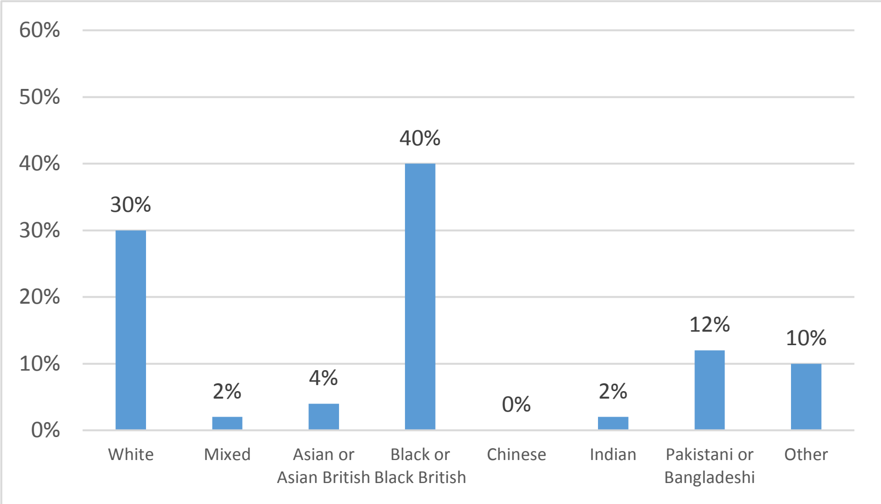


Figure 5. 38. Ethnic background.

The mapping of participants' ethnic background helps to explore if it is correlated with energy performance in later stage. According to Figure 5.38, twenty respondents are Black or Black British which comprises 40 per cent of all respondents; fifteen respondents are white British which makes up 30 per cent of overall participants; six respondents are Pakistani or Bangladeshi that make up 12 per cent of overall participants; five of them are from other ethnicity background including Arab, Turkish and Jamaican that corresponds to 10 per cent of respondents; two respondents are Asian or Asian British which corresponds to 4 per cent of all respondents; one respondent is mixed ethnicity which makes up 2 per cent of overall participants; and one respondent is Indian which comprises 2 per cent of the data sample. It shows that 'white' and 'black or black British' are the dominating ethnicity groups in the case study.

Level of education and health condition:

Occupants' education level may influence perceiving the knowledge and environmental awareness. According to Figure 5.39, 30 per cent of the respondents had no degree; 20 per cent of them held secondary (GCSE) qualifications; 10 per cent of the participants held A. AS Level; 6 per cent of them held Diploma, teaching, nursing; 2 per cent held Level 5 certificate; 24 per cent of them expressed that they had obtained Degree with honours; and 8 per cent of them held Masters or PhD degree qualifications.

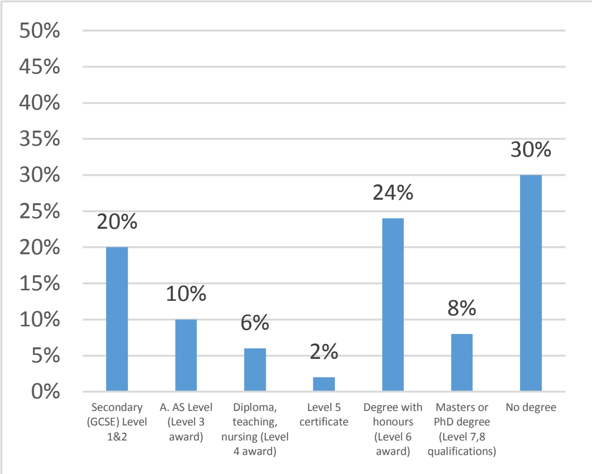


Figure 5. 39. Level of education.

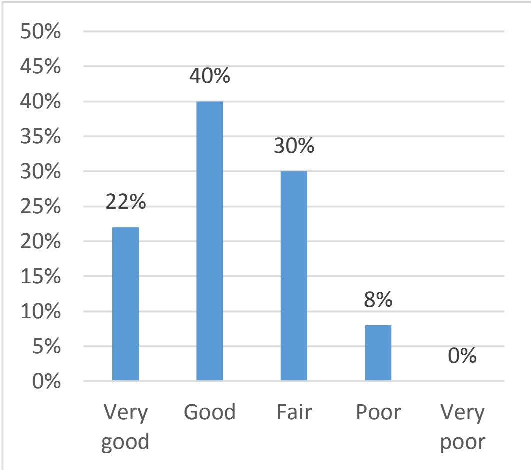


Figure 5. 40. Health condition.

Finally, participants' health conditions were investigated as it may potentially impact on home energy consumption in the case study social housing estates. According to Figure 5.40, 22 per cent of the respondents believed they are very good in health; 40 per cent felt that they were good in their health; 30 per cent of the respondents felt fair; 8 per cent of the participants felt that they were in poor health condition; and nobody felt very poor in health. In general, 62 per cent of the participants felt either 'very good' or 'good' concerning their health conditions, while 38 per cent rated their health as 'fair' or 'poor'.

5.2.5 Summary of the general findings

The previous section demonstrated the general survey findings of both case studies in the aspects of housing characteristics, occupants' energy consumption behaviour, occupancy patterns and their socio-demographic information. It draws the current conditions of 2 particular social housing estates in one of the London boroughs and how occupants operate their homes. The important findings are summarised below.

As stated from the above sections, the majority of the households are currently renting the properties either through the council (76 per cent) or Housing Association (8 per cent). Although local authority allows occupants to purchase these properties by offering relatively cheap prices, only a small proportion of them (16 per cent) bought these properties. However, it does not mean that occupants do not have a long-term living plan in social housing as 52 per cent of respondents expressed that they have been living in their homes for more than 5 years. With its distinct characters, the mobility of renters in these 2 social housings is low. According to DBEIS (2018), the average quarterly electricity bill applying standard electricity tariffs supplied by home energy supplier was £154.75 per quarter in 2017. The average quarter gas bill was £157.5 in 2017. In the research, the majority of the households (68 per cent) tend to spend their electricity and gas within a reasonable range (£0-£99 and £100-£199) in the winter. Occupants also tend to spend same on both electricity and gas bills. However, 30 per cent paid their quarterly electricity and gas bills in between £200 and £400. Some of them (2 per cent) even paid more than £400 for their quarterly bills which is unrealistically high. The reason for that will need to be further investigated. Around half of the respondents (46 per cent) expressed that they have previously received energy advice and this is mainly from energy companies (90 per cent). The council also provided energy support (10 per cent) to the local occupants. Only one-third of them have changed their energy suppliers/energy plans before for financial savings and other promotions such as installation of smart meters. In addition, huge variation of housing conditions was identified between Estate A and Estate B and occupants were more satisfied with their living conditions at Estate B rather than Estate A. This also helps to explain the reason that the council decided to carry out retrofit interventions at Estate A first. It also informed that the further correlation analysis was conducted separately regarding to these variables.

Although 34 per cent of the respondents expressed that they only have one heating control at their homes among radiator valves, wall and boiler thermostats; according to the local authority, most of them have all heating controls equipped unless some of these heating controls are not in service. It showed that occupants may not be aware of the existence of these heating controls, thus ignore using them in their daily routines. Besides, less than 20 per cent of them will use their heating controls at least 'once a day' which may contribute to inefficient energy consumption. Fifty-two per cent of the respondents will 'always' or 'usually' open their windows during the winter which could help to relieve 'mould', 'damp' and 'condensation'. Forty-six per cent of them will open their windows for less than 2 hours in winter for each time but some of them (6 per cent) will keep their windows open for more than 6 hours or always keep it closed (24 per cent). These behaviours may lead to energy over consumptions and more problematical housing issues as using heating controls more frequently may effectively reduce heating demands. Lack of ventilation may cause mould and condensation in the flats and consequently impact on indoor environment. It is worth mentioning that 46 per cent of the respondents will never open extractor fans at homes when taking showers. Local authorities need to make sure extractor fans are installed at every home. Additionally, although trickle vents play important role on indoor living environment where 40 per cent of respondents tend to 'always' leave it open and 20 per cent of them tend to 'never' open it. Another 20 per cent of the respondents did not know what the trickle vent is, thus never turn it on or off accordingly. Furthermore, occupants tend to save their energy through conventional approaches without compromising their living comfort: 46 per cent of respondents thought they use more energy than they should for a variety of reasons such as children's need, illness and comfort.

In both social housing estates, there are 14 per cent of the respondents who do not have smart phones and only 20 per cent of the households have smart meters installed. Smart technology is deeply involved into people's life and significant on helping occupants to achieve energy efficiency through interactions. Besides, among the ones with smart phones, only 10 per cent of them have energy management applications installed on it where only 2 per cent of the occupants will actually use the application.

The results indicate that occupants' energy conservation awareness is relative low and need to be further educated. Therefore, the interventions need to be adopted through a variety of ways to improve occupants' energy consumption behaviours and increase their energy awareness. By focusing on the government's level, making more effective policies and schemes may stimulate society's incentives for energy saving and consequently improve the behaviours. The energy consumption behaviours could also be improved by increasing interactions between occupants and energy management systems, such as IHDs and energy management applications. The influences of them are discussed in 'Chapter 6' and 'Chapter 7'. In addition, more advanced energy saving approaches need to be introduced to the occupants for more efficient energy uses such as using thermostat, increasing ventilation and installing energy monitoring and management devices. On the other hand, the support given need to be increased due to low take up rate of smart meters and low energy saving awareness. Energy suppliers are currently the major provider of energy advice and guidance. Additional, support need to be provided by local authorities, communities and other organizations.

A significant number of participating households (30 per cent) have only 1 family member where majority of them are single elderly. 30 per cent of the households do not have any employed family members which leads to low household income and fuel poverty where 14 per cent of households earn less than £6,000 annual income. The majority (54 per cent) of them identify their annual income levels between £6,000 and £12,000. Besides, the education level in these housing estates are relatively low: half of the respondents have 'no degree' or only 'GCSE level 1 and 2' and 32 per cent of the respondents have degree qualification or above. Their educational background may be a factor affecting their income levels and may also impact on the way that they operate their homes. The potential correlations are explored on the follow chapters.

5.3 Correlation results and analysis

5.3.1 Sample size and the validity of the results

As the results, there were 18 questionnaires returned from Estate A and 32 questionnaire returned from Estate B. Among those returned questionnaires, one questionnaire reflects unrealistic energy consumptions that were consumed by single occupant with high energy knowledge and sustainable awareness. As this does not follow the general pattern of the whole data set, it was taken off from the sample. Therefore, the data set in the research is 49. However, some analysis might be based on less number of variables due to the missing answers. The number of variables will be detailed in the following sections if they were less than 49. Before running the correlation analysis, the validity of the data sample is discussed. To examine if it is an appropriate data set, comprehensive studies adopting correlation analysis using statistical tests are presented below.

Technically, correlation coefficient can be calculated from 'n=2', where 'n' means number of data set. However, with the increasing number of data set, more valuable data will be collected with more accurate prediction during the analysis of correlation coefficient. According to Weaver and Koopman (2014), when 'n<3' in a data set, 'p value' and 'coefficient intervals' are not computed; when 'n<4' in a data set, 'coefficient intervals' is not computed; when 'n<10' in a data set, normal approximation is poor. Hence, a data set with more than 10 is recommended. Besides, Bonett and Wright (2000) recommended that in order to run valid Pearson, Kendall and Spearman correlation tests, the sample set need to be equal or superior to 25. Field (2009) also suggests that the sample size for running correlation tests need to be at least 30 for accurate predictions. Same point of view was also suggested by Pajula and Tohka (2016) in their study. They found that 20 subjects in a data set may be converged close to a large data set that comprises 120 subjects. A notable improvement was seen if the data set is increased from 20 to 30 or more. This indicates that a data set of 49, as in the current study, is capable to produce sufficient and accurate predictions for the study.

5.3.2 Correlation between occupants' 'energy consumption behaviour', 'socio-demographic characteristics' and energy consumption

As previously stated, various kinds of aspects were investigated through the questionnaire survey. It is believed that those aspects potentially influence home energy consumption, such as housing issues, occupants' energy consumption behaviour, occupancy patterns and their socio-demographic information. Thus, all of the collected data were put into correlation analysis in SPSS to explore those influences. According to the nature of data acquired, analysis of variances (ANOVA) was also employed as the most appropriate test to further explore the potential relationships between unordered categorical data (mixed discrete data) and ordered data (Leon and Zhu, 2008). As a result, a significant number of interesting findings were identified and demonstrated below.

5.3.2.1 'Energy advice' and the 'energy consumption behaviour'

The research firstly investigated whether the occupants who have previously received advice on how to reduce their energy bills will perform better than the others on using heating controls, ventilation and energy saving behaviour.

Q4.1 Have you received advice on how to reduce bills?	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q10.2. How often do you use your wall thermostat? (in winter)	0.257*	0.048	49
q10.3. How often do you use your boiler thermostat? (in winter)	0.334*	0.011	49
q16.1. Try using less gas and electricity	0.339**	0.010	48
q16.2. Turn your heating up or down as required	0.273*	0.038	49
q16.5. Set hot water thermostat lower	0.326*	0.013	49
q16.12. Unplug unused equipment	0.401**	0.002	49
q16.14. Use low energy light bulbs	0.260*	0.048	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 1. Correlation between 'Have you received energy advice?' and the 'energy related questions'.

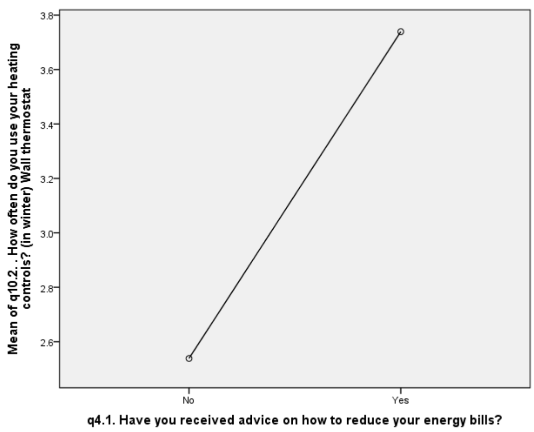
According to Table 5.1, significant and moderate correlations were identified between 'Have you received advice on how to reduce your energy bills?' and a number of energy related variables at both 0.05 and 0.01 levels. As a result, respondents who expressed that they 'have previously received energy advice' tend to use 'wall thermostat' (0.257*, $p<0.05$) and 'boiler thermostat' (0.334*, $p<0.05$) at homes in winter more frequently; people who 'have previously received energy advice' also tend to 'try using less gas and electricity' (0.339**, $p<0.01$), 'turn heating up or down as required' (0.273*, $p<0.05$), 'set hot water thermostat lower' (0.326*, $p<0.05$), 'unplug unused equipment' (0.401**, $p<0.01$), and 'use low energy light bulbs' (0.260*, $p<0.05$) more frequently.

Dependent Variable	**F**	**Sig.**
q10.2. How often do you use your heating controls? (in winter) Wall thermostat	4.377	0.042

q10.3. How often do you use your heating controls? (in winter) Boiler thermostat	7.478	0.009
q16.1. Try using less gas and electricity	8.446	0.006
q16.2. Turn your heating up or down as required	5.336	0.025
q16.5. Set hot water thermostat lower	6.905	0.012
q16.12. Unplug unused equipment	11.023	0.002
q16.14. Use low energy light bulbs	4.912	0.032

Table 5. 2. ANOVA test between ‘Have you received energy advice’ and the ‘energy related questions’.

The correlation analysis can easily identify correlations among numerical data and ordinal data that have ordered series or ranking sequences among categories, such as different ‘frequency’ or ‘satisfaction degrees’. However, if the analysed information belongs to binary or nominal data which are not in ordered series, ANOVA test need to be adopted in order to help interpret the established correlations. According to Table 5.2, significant differences of ‘frequency of using boiler thermostat’, ‘try using less gas and electricity’, ‘turn your heating up or down’, ‘set how water thermostat lower’, ‘unplug unused equipment’ and ‘use low energy light bulbs’ have also been identified with different categories of ‘Have you received advice on how to reduce bills?’. The ‘means plot’ diagram below clearly presents the significant differences between a number of variables and different categories of the chosen factor: ‘have you received advice on how to reduce your energy bills?’.



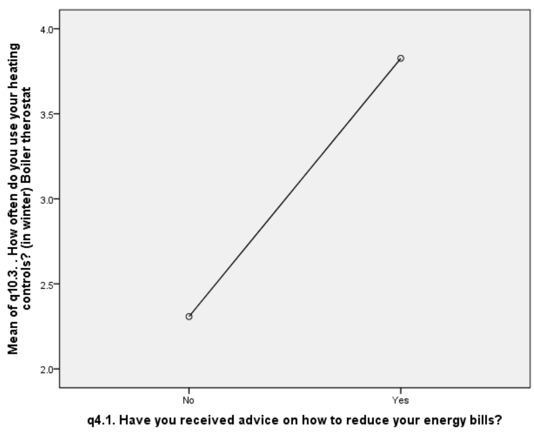


Figure 5. 41. ANOVA test: energy advice and use of wall thermostat. Figure 5. 42. ANOVA test: energy advice and use of boiler thermostat.

According to Figure 5.41 and Figure 5.42, occupants who have received advice on how to reduce energy bills tend to use wall thermostat and boiler thermostat more frequently. On the other hand, the occupants who have not received energy advice tend to use wall thermostat and boiler thermostat less frequently.

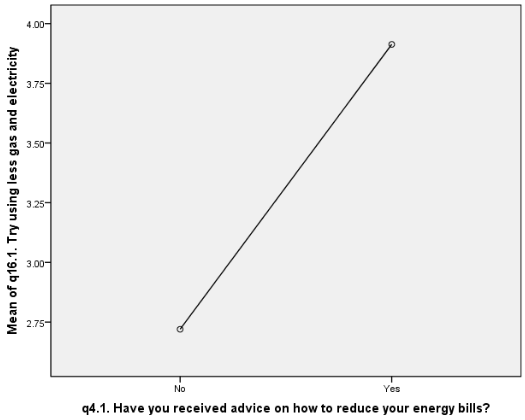


Figure 5. 43. Energy advice and try use less gas and electricity.

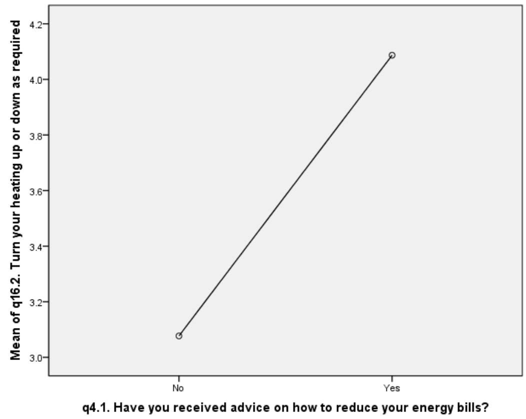


Figure 5. 44. Energy advice and adjust heating as required.

According to Figure 5.43 and Figure 5.44, occupants who have received advice on how to reduce energy bills tend to follow the energy conservation actions more frequently, such as 'try using less gas and electricity' and 'turn heating up or down as required'. On the other hand, the occupants who have not received energy advice tend to follow the energy conservation actions less frequently. The rest of identified energy conservation actions also follows the same trends. The positive influence of energy information and advice were also highlighted in recent studies (Gupta and Gregg, 2016) that communications with occupants regarding the way of operating the homes is crucial for the improvement of home energy performance.

5.3.2.2 'Change of energy suppliers/plans' and 'energy consumption behaviour'

The research also investigated whether the occupants who have 'previously changed their energy suppliers or energy plans', will perform better than the others on using heating controls, ventilation and energy consumption behaviour. The analysis was based on 48 variables due to missing answers.

q5.1. Have you changed your energy supplier/energy plan?	Correlation Coefficient	Sig. (2-tailed)	N
q16.5. Set hot water thermostat lower	0.328*	0.023	48
q16.9. Go out to avoid using heating	0.397**	0.005	48

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 3. Correlation between 'Have you changed energy suppliers/plans?' and the 'energy related questions'.

According to Table 5.3, significant and moderate correlations was indicated between 'Have you changed your energy supplier/energy plan?' and a number of energy related variables at both 0.05 and 0.01 levels. As a result, occupants who 'have previously changed their energy suppliers/plans' tend to 'set hot water thermostat lower' (0.328*,

$p<0.05$) more frequently. Besides, people who 'have changed energy supplier/plan' tend to 'go out to avoid using heating' (0.397**, $p<0.01$) more frequently. The analytical result indicated that people who 'have previously changed energy suppliers/plans' may have stronger awareness on energy saving.

Dependent Variable	F	Sig.
q16.5. Set hot water thermostat lower	5.552	0.023
q16.9. Go out to avoid using heating	8.631	0.005

Table 5. 4. ANOVA test between 'Have you changed energy plans/tariffs' and the 'energy related questions'.

As 'Have you changed energy supplier/energy plan' is a binary question, ANOVA test was also adopted to clarify the correlations. As a result, significant differences in 'set hot water thermostat lower' and 'go out to avoid using heating' have also been identified with different categories of 'the change of energy supplier/plan'.

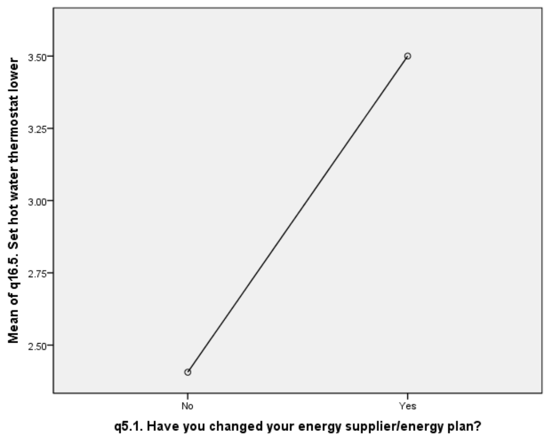


Figure 5. 45. Change of supplier/plan and set thermostat lower.

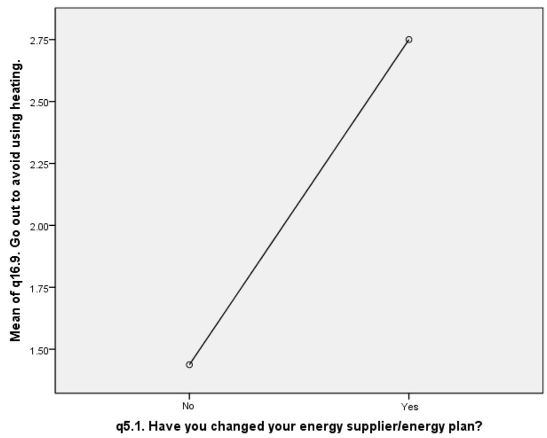


Figure 5. 46. Change of supplier/plan and go out to avoid using heating.

According to Figure 5.45 and Figure 5.46, occupants' who have previously changed energy suppliers or energy plans tend to follow energy conservation actions more frequently, such as 'set hot water thermostat lower' and 'go out to avoid using heating'. On the other hand, the occupants who have not received energy advice tend to follow energy conservation actions less frequently. It shows that although a few energy saving actions are influenced by the 'change of energy supplier/plan', it is not as effective as 'receive energy advice'. The reasons of the correlation were also explained by the respondents from the questionnaire survey that 'because I am looking for less to pay' and 'received a smart meter'. It indicated the willingness of energy conservation from the occupants but simply changing energy plan/tariff does not fundamentally improve occupant's energy consumption behaviors as it requires long-term informative communications provided by suppliers, communities and local authorities.

5.3.2.3 'Energy advice' and 'energy bills'

The research investigated whether the occupants who have previously received energy advice, changed their energy suppliers or energy plans, will pay less electricity and gas bills than others.

q4.1. Have you received advice on how to reduce your energy bills?	Correlation Coefficient	Sig. (2-tailed)	N
q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	-0.340**	0.005	49
q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	-0.352**	0.004	49

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 5. Correlation between 'Have you received energy advice', and 'quarterly electricity and gas bills'.

According to Table 5.5, significant correlations between 'have you received energy advice?' and 'quarterly electricity and gas bills' were identified at 0.01 level. It shows that respondents who 'have previously received energy advice' tend to spend less on the 'quarterly electricity bills' (-0.340**, $p<0.01$) and 'quarterly gas bills' (-0.352**, $p<0.01$). On the other hand, correlations between 'have you changed energy tariffs/plans' and 'quarterly electricity and gas bills' were also analysed but nothing was indicated. As a result, it implies that the way of operating the homes more effectively will significantly impact on home energy performance.

Dependent Variable	F	Sig.
Q3.1 How much do you pay for the electricity bill each quarter approximately?	7.568	0.008
Q3.2 How much do you pay for the gas bill each quarter approximately?	6.084	0.017

Table 5. 6. ANOVA test between 'Have you received energy advice' and the 'quarterly electricity and gas bills'.

ANOVA analysis was also conducted to further interpret the correlations between numerical and categorical data. According to Table 5.6, significant differences in 'quarterly electricity bills' and 'quarterly gas bills' have also been identified with different categories of 'energy advice'.

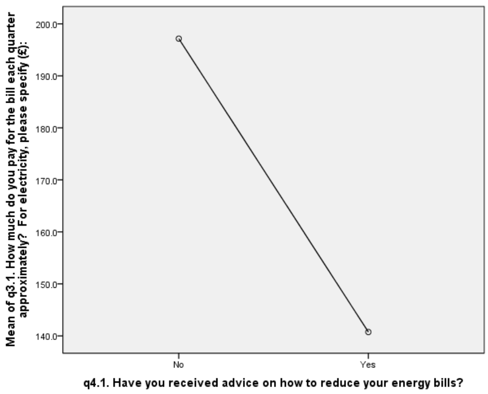


Figure 5. 47. ANOVA: 'energy advice' and 'electricity bills'.

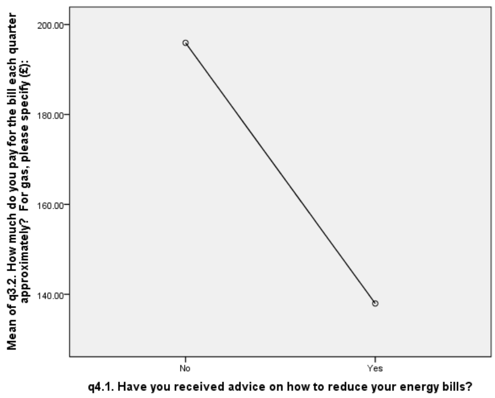


Figure 5. 48. ANOVA: 'energy advice' and 'gas bills'.

According to Figure 5.47 and Figure 5.48, the relationships between different answers of 'energy advice' and the average of 'quarterly electricity and gas bills' were demonstrated. It showed that occupants who received energy advice tended to spend much less on 'quarterly electricity and gas bills' than the ones who had not received energy advice. This is supported by Simpson et al. (2016) that occupants' energy consumption behaviours need to be improved through education.

5.3.2.4 'Energy bills' and the 'energy consumption behaviour'

The research also explored whether the occupants who used more heating controls, ventilation and energy consumption behaviour, will spend less on their electricity and gas bills than others. The analysis of 'number of hours that window opened', 'frequencies and houses trickle vents opened', 'try using less gas and electricity' and 'use the thermostats to adjust temperature' were based on less variables (see Table 5.7 and 5.8) due to missing answers.

q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	Correlation Coefficient	Sig. (2-tailed)	N
q10.2. How often do you use your wall thermostat? (in winter)	-0.372**	0.001	49
q11. At what temperature do you set your wall thermostat? (in winter)	0.224*	0.036	49
q12.1. How often do you open your windows in winter?	-0.229*	0.038	49
q12.2. Please specify the number of hours that the window opened: (hrs)	0.269*	0.017	43
q16.1. Try using less gas and electricity	-0.373**	0.001	48
q16.3. Use the thermostats to adjust temperature	-0.283*	0.012	48
q16.9. Go out to avoid using heating.	-0.287*	0.010	49
q16.12. Unplug unused equipment.	-0.222*	0.043	49

q16.14. Use low energy light bulbs.	-0.328**	0.003	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 7. Correlation between 'quarterly electricity bills' and the 'energy related questions'.

According to Table 5.7, the significant and moderate correlations were indicated between occupants' 'quarterly electricity bills' and a number of energy related variables at both the 0.01 and 0.05 levels. As a result, occupants who spend more on 'electricity bills' tend to 'use wall thermostat' (-0.372**, p<0.01) less frequently in winter and set their 'wall thermostat' (0.224*, p<0.05) higher. The importance of using thermostat was highlighted by Herring (2006) that energy demand could be reduced by lowering heating levels through turning down thermostat levels. According to ASHRAE Standard 55-2013, approximate acceptable indoor air temperature is between 67 and 82 °F (19.4-27.8 °C) depending on location and relative humidity. The Public Health England (Bone, 2014) suggests that occupants should keep their indoor temperature at least 18 °C and 21 °C for the recommendations. Ahn and Park (2016) demonstrated the correlation between occupants' active action to control heating/cooling system and energy performance. Scholars who also support it include Yun and Steemers (2011) and Guerra-Santin (2011).

Besides, respondents who spend more on 'electricity bills' tend to 'open windows' (-0.229*, p<0.05) less frequently. However, the 'hours that windows opened' (0.269*, p<0.05) tend to be longer during the winter. Home energy consumption does not only relate to how often the windows are opened but also to the degree of openings (Fabi et al., 2012). The correlation between the hours that window opened in living room (p < .05) and energy performance were identified in Guerra-Santin (2011)'s research. Fabi et al (2012) also stated that opening the windows could improve the indoor climate by increasing air exchange rate and mitigate housing problems, such as 'mould', 'damp' and 'condensation'. Hence, it decreases the heating demand. Furthermore, respondents who pay more 'electricity bills' tend to 'try using less gas and electricity' (-0.373**, p<0.01), 'use the thermostats to adjust temperature' (-0.283*, p<0.05), 'go out to avoid using heating' (-0.287*, p<0.05), 'unplug unused equipment' (-0.222*, p<0.05), and 'use low energy bulbs' (-0.328**, p<0.01) less frequently.

q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q10.2. How often do you use your wall thermostat? (in winter)	-0.314**	0.004	49
q11. At what temperature do you set your wall thermostat? (in winter)	0.468**	0.001	49
q12.1. How often do you open your windows in winter?	-0.353**	0.001	49

Q13.1 How often do you turn on the extractor fan when take the shower?	-0.354**	0.002	49
q15.1. How often do you keep the trickle vents open when it is cold?	0.318*	0.016	37
q15.2. Please specify the number of hours	0.332*	0.022	37
q16.1. Try using less gas and electricity	-0.371**	0.001	48
q16.12. Unplug unused equipment.	-0.317**	0.004	49
q16.14. Use low energy light bulbs.	-0.494**	0.000	49
q8.1.2. Living Room Hrs heaters on (weekdays)	0.256*	0.018	46
q8.1.2'. Living Room Hrs heaters on (weekends)	0.306**	0.004	46

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 8. Correlation between 'quarterly gas bills' and the 'energy related questions'.

According to Table 5.8, significant correlations were also found between occupants' 'quarterly gas bills' and a number of energy related variables at both 0.05 and 0.01 levels. As a result, respondents who pay more 'quarterly gas bills' tend to use 'wall thermostat' (-0.314**, $p<0.01$) and 'open windows' (-0.353**, $p<0.01$) in winter less frequently. Occupants tend to spend more on 'quarterly gas bills' with higher 'temperature set on wall thermostat' (0.468**, $p<0.01$). Besides, occupants who 'turn on the extractor fan' (-0.354**, $p<0.01$) more frequently tend to pay less on 'quarterly gas bills'. Occupant who pay more 'quarterly gas bills' would 'leave the trickle vents open' (0.318*, $p<0.05$) more frequently 'with longer hours' (0.332*, $p<0.05$). The reason of this is that the hours that trickle vents opened is much longer than windows and extractor vents according to the survey findings. Thus it decreases the indoor temperature and increases the heating demand. In addition, respondents who expressed that they pay more 'quarterly gas bills' tend to less frequently 'try using less gas and electricity' (-0.371**, $p<0.01$), 'unplug unused equipment' (-0.317**, $p<0.01$) and 'use low energy light bulbs' (-0.494**, $p<0.01$).

Moreover, households who pay more 'quarterly electricity bills' tend to have longer 'heating patterns' during 'weekdays' (0.231*, $p<0.05$) and 'weekends' (0.230*, $p<0.05$). Same finding also indicated between 'quarterly gas bills' and 'heating patterns' during 'weekdays' (0.256*, $p<0.05$) and 'weekends' (0.306**, $p<0.01$). This indicates that longer heating patterns may result in more energy consumption and consequently increase the energy bills.

5.3.2.5 'Energy bills' and 'Socio-demographic characteristics'

The research explored whether households with different socio-demographic characteristics, such as family size, tenancy status or economic status, will impact on their quarterly bills.

q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q1. Tenancy status	-0.356**	0.003	49
q29.2. Members of household children (3-12 yrs)	0.302**	0.009	49
q29.5. Members of household 25-34 yrs	0.291*	0.012	49
q31.5. Economic status of each family member Retired.	-0.247*	0.040	49
q31.6. Economic status of each family member Student	0.255*	0.029	49
q35. How is your health in general?	0.239*	0.034	49
qII. Number of Occupants	0.306**	0.005	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 9. Correlation between 'quarterly electricity bills' and the 'socio-demographic characteristics'.

According to Table 5.9, significant and moderate correlations were indicated between occupants' 'quarterly electricity bills' and a number of socio-demographic variables at both 0.05 and 0.01 levels. As a result, occupants with 'owner occupied' status tend to spend more on their 'quarterly electricity bills' and 'social renters and 'Housing association renters' tend to spend relatively less on it (-0.356**, $p<0.01$). Based on the questionnaire survey, the average annual income for social renters is £13,097.6 and £21,375.0 for private renters. Higher incomes may imply more energy consumption. Guerra-Santin (2011) also argued that the high 'energy-intensive' of using large appliances and spaces at home appeared to home-owners with high incomes. An opposite view was held by Kavousian et al. (2013) that there was no correlation found between income level and energy performance based on their research.

The 'quarterly electricity bills' is found to be significantly or moderately correlated by the household profiles, such as the households with more 'children (3-12yrs)' (0.302**, $p<0.01$), 'adult (25-34yrs)' (0.291*, $p<0.05$) and 'student' (0.255*, $p<0.05$) tend to spend more on 'quarterly electricity bills'. On the other hand, households with more 'retired' (-0.247*, $p<0.05$) people tend to spend less on their 'quarter electricity bills'. Similar findings were also indicated by Kavousian et al. (2013) that individuals over 55 recorded lower energy consumption. It is also supported by Guerra-Santin (2011) that the presence of elderlies has strong negative impact ($p < .001$) on energy performance. The 'number of occupants' (0.306**, p<0.01) increases while the household 'quarter electricity bills' increases. Conan (1981) also identified correlation between winter energy consumption and number of occupants based on the questionnaire survey. The correlations between household profiles and energy consumption were also identified by Guerra-Santin (2011) that the presence of both children and elderlies hugely influence heating and ventilation patterns. Larger families also tended to use large electricity appliances more frequently and consequently consume more energy. In addition, occupants with better 'health conditions' (0.239*, p<0.05) tend to spend less on 'quarterly electricity bills'. Nicholls and Strengers (2017) emphasized the correlation between occupants' ill, health and high cost of utility bills through interviews. Moreover, poor health condition increases the occupancy pattern at home for recovery.

Apart from the correlations between 'quarterly electricity bills' and socio-demographic characteristics, the correlations between 'quarterly gas bills' and the same variables were also conducted and demonstrated below:

q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q1. Tenancy status	-0.275*	0.020	49
q29.3. Members of household Teenagers (12-19yrs)	0.396**	0.001	49
q31.6. Economic status of each family member Student	0.244*	0.037	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 10. Correlation between 'quarterly gas bills' and the 'socio-demographic characteristics'.

According to Table 5.10, significant and moderate correlations were indicated between occupants' 'quarterly gas bills' and a number of socio-demographic variables at both 0.05 and 0.01 levels. As a result, occupants with 'owner occupied' tenancy status tend to spend more on their 'quarterly gas bills' (-0.275*, p<0.05). Similar findings were also identified by Elsharkawy (2013) that moderate correlations (r = 0.465, P < 0.005) between 'social tenancy' and 'average monthly gas bills' were found in the Community Energy Saving Programme (CESP) survey. The households with more 'teenagers (12-19yrs)' (0.396**, p<0.01) and 'student' (0.244*, p<0.01) tend to spend more on their 'quarterly gas bills'.

q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):

Dependent Variable	F	Sig.

q1. Tenancy status	4.555	0.016
q35. How is your health in general?	3.298	0.044

q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):

Dependent Variable	F	Sig.
q1. Tenancy status	3.343	0.028

Table 5. 11. ANOVA test between 'quarterly bills' and 'socio-demographic characteristics'.

As 'tenancy status' and 'health condition' are unordered categorical data, the ANOVA test was also conducted to further explore the correlations. According to Table 5.11, significant differences in 'quarterly electricity bills' and 'quarterly gas bills' have also been identified with different categories of 'tenancy status' and 'health conditions'.

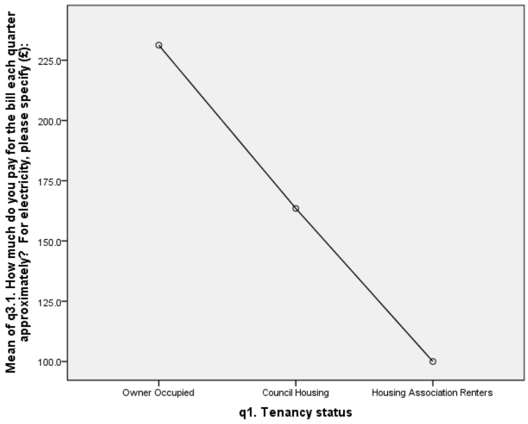


Figure 5. 49. ANOVA: 'electricity bills' and 'tenancy status'.

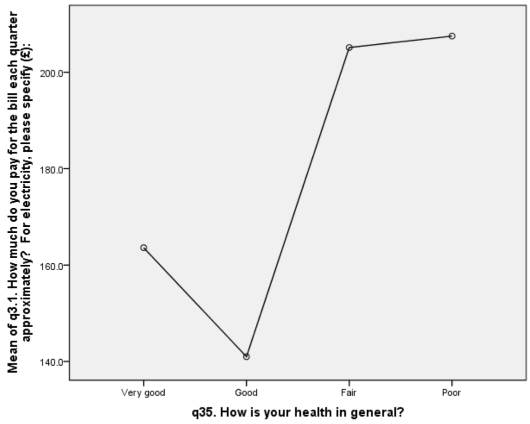


Figure 5. 50. ANOVA: 'electricity bills' and 'health conditions'.

According to Figure 5.49, 'owner occupied' households tend to spend highest amount of 'quarterly electricity bills' followed by 'social renters' and 'housing association renters'. Occupants in 'good' health condition tend to spend less on 'quarterly electricity bills' and it gradually increases along with 'fair' and 'poor' health conditions (see Figure 5.50).

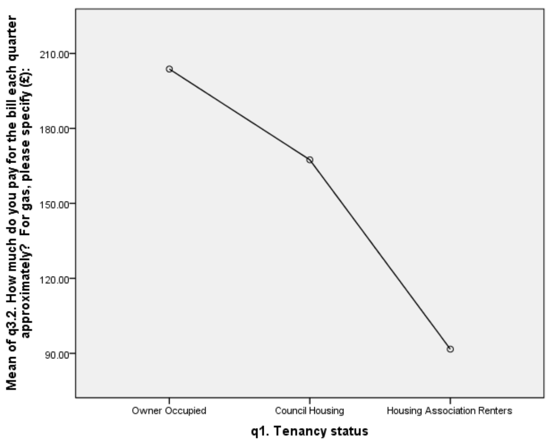


Figure 5. 51. ANOVA test: 'gas bills' and 'tenancy status'.

According to Figure 5.51, 'owner occupied' households tend to spend highest amount of 'quarterly gas bills' followed by 'social renters' and 'housing association renters'.

It is believed (Guerra-Santin, 2011; Nicholls and Strengers, 2017) that occupants with different household profiles tend to operate their homes differently. Therefore, it leads to different energy consumption patterns. So, the correlations between respondents' socio-demographic characteristics and their energy behaviour were also explored in the aspects of 'age groups', 'number of occupants', 'employment status' and 'health conditions'.

5.3.2.6 'Age groups' and 'energy consumption behaviour'

The research investigates whether the respondents in different age groups would operate their homes differently. As a result, significant and moderate correlations between 'children', 'teenagers', 'infants' and 'energy behaviour' were identified in Table 5.12. The analysis of 'try using less gas and electricity', 'living rooms hrs heaters on during weekdays' and 'weekends' were based on less variables (see Table 5.12) due to missing answers.

q29.2. Members of household children (3-12 yrs)	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q11. At what temperature do you set your wall thermostat? (in winter)	0.384**	0.006	49
q13.1. How often do you turn on the extractor fan when you take the shower?	-0.407**	0.004	49
q8.1.2. Living Room Hrs heaters on (weekdays)	0.281*	0.023	46
q16.1. Try using less gas and electricity	-0.294*	0.042	48
q16.4. Try heating as less room as possible.	-0.314*	0.033	49
q8.1.2. Living Room Hrs occupied (weekdays)	0.351**	0.005	45
q29.3. Members of household Teenagers (12-19yrs)	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q11. At what temperature do you set your wall thermostat? (in winter)	0.411**	0.003	49
q13.1. How often do you turn on the extractor fan when you take the shower?	-0.312*	0.029	49
q8.1.2'. Living Room Hrs heaters on (weekends)	0.406**	0.001	46
q16.8. Put on a jumper instead of heating.	-0.287*	0.049	49
q29.1. Members of household infants (0-3 yrs)	**Correlation**	**Sig. (2-tailed)**	**N**

	Coefficient		
q8.1.2. Living Room Hrs heaters on (weekdays)	0.301*	0.016	46
q8.1.2'. Living Room Hrs heaters on (weekends)	0.372**	0.002	46

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 12. Correlation between ‘children’, ‘teenagers’, ‘infants’ and ‘energy consumption behaviour’.

As a result, families with more ‘number of children’ (0.384**, $p<0.01$) and ‘teenagers’ (0.411**, $p<0.01$) tend to set up ‘temperature’ higher on their wall thermostats with more ‘heating hours in living room’ (0.281*, $p<0.05$ (number of children)) (0.406**, $p<0.01$ (number of teenagers)). More ‘number of children’ (-0.407**, $p<0.01$) and ‘teenagers’ (-0.312*, $p<0.05$) also negatively impact on the use of ‘extractor fans’. Besides, families with more ‘number of children’ tend to have longer ‘occupancy pattern in living room’ (0.351**, $p<0.01$), ‘try using less gas and electricity’ (-0.294*, $p<0.05$) and ‘try heating as less room as possible’ (-0.314*, $p<0.05$) less frequently. In addition, household with more ‘number of teenagers’ tend to ‘put on a jumper instead of heating’ (-0.287*, $p<0.05$) less frequently. Families with more ‘number of infants’ tend to have longer ‘heating hours in living room’ during ‘weekdays’ (0.301*, $p<0.05$) and ‘weekends’ (0.372**, $p<0.01$). The results imply that infant, children and teenagers will impact on the length of heating hours at home as respondents claimed that ‘we use more energy when kids come back from college’ and ‘because we have small children and need to keep it warm for them’. As a result, households with more children could not follow energy saving actions properly. This is supported by Brounen et al. (2012) that households with children generally consume more energy than the ones without children due to higher comfort levels required and greater use of entertainment appliances.

Apart from the exploring how young people operate their homes, other age groups and their associated energy consumption behaviour were also identified in Table 5.13.

q29.8. Members of household 55-64yrs	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q17. Rate your ability to read the utility bill	-0.275*	0.037	49
q10.2. How often do you use your heating controls? (in winter) Wall thermostat	-0.291*	0.043	49
q10.3. How often do you use your heating controls? (in winter) Boiler thermostat	-0.373*	0.028	49
q16.8. Put on a jumper instead of heating.	0.377*	0.022	49
q29.9. Members of household 65yrs or over	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**

q10.3. How often do you use your heating controls? (in winter) Boiler thermostat	-0.289*	0.041	49
q16.1. Try using less gas and electricity	0.391**	0.008	49
q16.4. Try heating as less rooms as possible.	0.336*	0.026	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 13. Correlation between 'elderlies' and 'energy consumption behaviour'.

As a result, significant and moderate correlations between 'higher age groups and 'energy behaviour' were identified. Families with more 'numbers between 55-64 yrs' tend to feel more difficult to understand utility bills (-0.275*, p<0.05). They also less frequently use 'wall thermostat' (-0.291*, p<0.05) and 'boiler thermostat' (-0.373*, p<0.05). On the other hand, families with more 'members between 55-64 yrs' tend to 'put on a jumper instead of heating' (0.377*, p<0.05) more frequently. Besides, the households with more 'members at 65 yrs or over' tend to use 'boiler thermostat' (-0.289*, p<0.05) less frequently but 'try using less gas and electricity' (0.391**, p<0.01) and 'try heating as less room as possible' (0.336*, p<0.05) more frequently. It implies that older-aged occupants may try to save energy through basic approaches in order to use as less energy as possible.

q29.4. Members of household 19-24 yrs	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q16.16. Avoid using energy at peak time.	-0.297*	0.039	49
q29.6. Members of household 35-44 yrs	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q13.1. How often do you turn on the extractor fan when you take the shower?	-0.349*	0.014	49
q11. At what temperature do you set your wall thermostat? (in winter)	0.308*	0.033	49
q16.11. Turn off TV when leave the living room.	-0.290*	0.043	49
q29.7. Members of household 45-54 yrs	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q16.2. Turn your heating up or down as required	-0.297*	0.038	49
q16.6. Use blankets instead of heating system	-0.283*	0.049	49

*Correlation is significant at the 0.05 level (2-tailed).

Table 5. 14. Correlation between 'adults' and 'energy consumption behaviour'.

According to Table 5.14, moderate correlations were also identified between 'adults' and a number of energy consumption behaviours. Families with more 'adults between 19-24 yrs' tend to 'avoid using energy at peak times' (-0.297*, p<0.05) less frequently. Families with more 'adults between 35-44 yrs' tend to set up 'temperature on wall thermostats' (0.308*, p<0.05) higher and use 'extractor fans' (-0.349*, p<0.05) and 'turn off the TV when leave the living room' (-0.290*, p<0.05) less frequently. Besides, households with more 'adults between 45-54 yrs' tend to 'turn heating up or down as required' (-0.297*, p<0.05) and 'use blankets instead of heating system' (-0.283*, p<0.05) less frequently. The results imply that those age groups did not follow energy saving actions very well and tend to sacrifice energy efficiency for personal comforts. The reasons of this were explored during the focus group interview.

5.3.2.7 'Number of occupants' and 'energy consumption behaviour'

The study previously found that large families tend to consume more energy than small families. The study also investigates whether different family sizes determine the way occupants operate their homes. The analysis of 'living rooms, hours heaters on during weekdays' and 'weekends' were based on less variables (see Table 5.15) due to missing answers.

qII. Number of Occupants	Correlation Coefficient	Sig. (2-tailed)	N
q11. At what temperature do you set your wall thermostat? (in winter)	0.325*	0.023	49
q13.1. How often do you turn on the extractor fan when you take the shower?	-0.368**	0.009	49
q10.2. How often do you use your heating controls? (in winter) Wall thermostat	-0.288*	0.044	49
q16.1. Try using less gas and electricity	-0.362*	0.011	49
q16.4. Try heating as less room as possible.	-0.314*	0.028	49
q16.11. Turn off TV when leave the living room.	-0.337*	0.026	49
q16.16. Avoid using energy at peak time.	-0.408**	0.002	49
q8.1.2. Living Room Hrs occupied (weekdays)	0.323**	0.005	45
q8.1.2'. Living Room Hrs occupied (weekends)	0.280*	0.016	45
q8.1.2. Living Room Hrs heaters on (weekdays)	0.285*	0.013	46

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 15. Correlation between 'number of occupants' and 'energy consumption behaviour'.

According to Table 5.15, significant and moderate correlations were identified between 'number of occupants' and occupants' 'energy consumption behaviour'. As a result, households with more ‘number of occupants’ tend to set up ‘temperature on wall thermostat’ (0.325*, p<0.05) higher with longer ‘occupancy’ (0.323**, p<0.01) and ‘heating’ (0.285*, p<0.05) patterns. Besides, larger families tend to use ‘extractor fans’ (-0.368**, p<0.01) and ‘wall thermostats’ (-0.288*, p<0.05) less frequently. They also tend to ‘try using less gas and electricity’ (-0.362*, p<0.05), try heating as less room as possible’ (-0.314*, p<0.05), ‘turn off TV when leave the living room’ (-0.337*, p<0.05), and ‘avoid using energy at peak times’ (-0.308**, p<0.01) less frequently. The results imply that larger families with more complex composition may not operate their homes effectively as each member’s thermal comfort needs to be met. The more number of occupants also increase the possibility of longer occupancy patterns and consequently increase the hours that heating systems are used during winter. Same findings were also identified by several scholars (Yun and Steemers, 2011; Abrahamse and Steg, 2009). Elsharkawy (2013) also stated that the number of occupants in the family also determines the difficulties of managing energy use.

5.3.2.8 ‘Employment status’ and ‘energy consumption behaviour’

Another socio-demographic characteristic that could potentially impact on occupants’ energy behaviour is the occupants’ ‘employment status’. The correlations between them were also explored. The analysis of ‘living room, hours heaters on in weekdays’ were based on 45 variables due to missing answers.

q31.1. Economic status of each family member Full-time employed	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q16.2. Turn your heating up or down as required	-0.285*	0.048	49
q16.9. Go out to avoid using heating.	-0.306*	0.033	49
q16.16. Avoid using energy at peak time.	-0.388**	0.006	49
q31.7. Economic status of each family member Unemployed	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q8.1.2. Living Room Hrs occupied (weekdays)	0.309*	0.015	45
q31.5. Economic status of each family member Retired.	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q16.10. Turn off lights when you leave the room.	0.350*	0.019	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 16. Correlation between ‘employment status’ and ‘energy consumption behaviour’.

According to Table 5.16, significant and moderate correlations between ‘employment status’ and ‘energy consumption behaviour’ were indicated. As a result, households with more ‘full-time employed member’ tend to ‘turn heating up or down as required’ (-0.285*, p<0.05), ‘go out to avoid using heating’ (-0.306*, p<0.05) and ‘avoid using energy at peak time’ (-0.388**, p<0.01) less frequently. Besides, households with more ‘unemployed member’ tend to have longer ‘occupancy patterns in living room’ (0.309*, p<0.05). Households with more ‘retired member’ tend to ‘turn off lights when leave the room’ (0.350*, p<0.05) more frequently. The results imply occupants with different employment status will determine their occupancy patterns at homes and consequently impact on their capability to manage their energy use.

5.3.2.9 ‘Health condition’ and ‘energy consumption behaviour’

The research also investigates if occupants with different ‘health conditions’ will operate their homes differently. The analysis of ‘main bedroom hours heaters on in weekdays’ was based on 46 variables due to missing answers.

q35. How is your health in general?	Correlation Coefficient	Sig. (2-tailed)	N
q11. At what temperature do you set your wall thermostat? (in winter)	0.275*	0.043	49
q12.1. How often do you open your windows in winter?	-0.288*	0.041	49
q8.2.2. Main bedroom Hrs heaters on (weekdays)	0.304*	0.025	46

*Correlation is significant at the 0.05 level (2-tailed).

Table 5. 17. Correlation between ‘health condition’ and ‘energy consumption behaviour’.

According to Table 5.17, moderate correlations were indicated between occupants’ ‘health conditions’ and their energy consumption behaviours. As a result, occupants’ with poorer ‘health condition’ tend to set ‘temperature on wall thermostat’ (0.275*, p<0.05) higher with more hours with ‘heaters on’ (0.304*, p<0.05), and ‘open the windows’ (-0.288*, p<0.05) less frequently. The results imply that occupants with poor health condition may require extra heating and consequently consume more energy than the ones in good health conditions (Guerra-Santin, 2011; Yun and Steemers, 2011; Abrahamse and Steg, 2009).

5.3.2.10 ‘Household income levels’ and ‘Energy consumption behaviour’

The research also explored what kind of behavioural variables may be affected by occupants’ income levels. The analysis was based on less variables (see Table 5.18) due to missing answers.

q33. Total household income level (annual):	Correlation Coefficient	Sig. (2-tailed)	N
q8.1.2. Living Room Hrs heaters on (weekdays)	0.379*	0.026	45
q8.2.2. Main bedroom Hrs heaters on (weekdays)	0.309*	0.048	45
q8.2.3. Hours thermostat on (weekdays)	0.336*	0.037	39
q16.4. Try heating as less room as possible.	-0.310*	0.032	48
q16.9. Go out to avoid using heating.	-0.353*	0.014	48
q16.13. Wash clothes in shorter washing cycle.	-0.349*	0.015	48
q16.15. Reduce time spend in the shower.	-0.451**	0.001	48

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 18. Correlation between 'total household income level' and the 'energy use patterns'

According to Table 5.18, the significant and moderate correlations were indicated between the 'household income level' and a number of energy consumption behaviours at both the 0.01 and 0.05 levels. As a result, households with higher 'income levels' tend to have longer 'heating patterns' in living room (0.379*, p<0.05) and main bedroom (0.309*, p<0.05) during weekdays. Therefore, they also tend to turn on 'thermostat' (0.336*, p<0.05) for longer hours during weekdays. Besides, households with higher 'income levels' also tend to follow energy saving actions less frequently, such as 'try heating as less room as possible' (-0.310*, p<0.05), 'go out to avoid using heating' (-0.353*, p<0.05), 'wash clothes in shorter washing cycle' (-0.349*, p<0.05) and 'reduce time spend in the shower' (-0.451**, p<0.01). It shows that higher income levels positively impact on the heating patterns and consequently increase home energy consumption. A few recent studies (Sugiura et al, 2013; Chen et al., 2013) also support this research finding. Sukarno et al. (2017) also stated that occupants with higher income levels tend to have larger electricity appliances and are less willing to compromise the personal comforts for less energy consumption.

5.3.2.11 'Housing issues', 'energy bills', 'energy consumption behaviours'

As stated in 'Section 5.2: General survey findings', the housing issues that occupants are experiencing in Estate A and Estate B showed huge variations. Thus the correlation analysis was carried out separately for the questions about 'housing issues'. The research tried to explore whether different degrees of problematic housing issues will affect energy bills and the way people operate their homes. The analysis of 'hours extractor fans opened' was based on 15 variables due to missing variables. The results are shown below:

q7.2. How often do you experience the issues below in your home? (1 is never; 5 is always)Damp	Correlation Coefficient	Sig. (2-tailed)	N
q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	0.562*	0.015	18
q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	0.626**	0.005	18
q7.3. How often do you experience the issues below in your home? (1 is never; 5 is always) Mould	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q13.2. Please specify the number of hours (hrs) opening extractor fan	-0.545*	0.036	15
q7.5. How often do you experience the issues below in your home? (1 is never; 5 is always)Condensation	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q13.2. Please specify the number of hours (hrs) opening extractor fan	-0.528*	0.043	15

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 19. Correlation between 'quarterly bills', 'energy consumption behaviour' and 'housing issues' at Estate A

According to Table 5.19, significant correlations were indicated between the 'housing issues' at the Estate A and a number of energy use variables at both the 0.01 and 0.05 levels. As a result, correlations were found between 'Damp' and 'quarterly electricity bills' (0.562*, p<0.05) and 'quarterly gas bills' (0.626**, p<0.01). The electricity and gas bills tend to increase while the 'Damp' issue at homes increases. Besides, correlations were also found between 'Mould' (-0.545*, p<0.05), 'Condensation' (-0.528*, p<0.05) and the 'hours of opening the extractor fans'. According to the result, the hours of opening the extractor fans increases while the 'Mould' and 'Condensation' issues at their homes decreases. 'Damp', 'mould' and 'condensation' increase the possibilities of low energy efficiency as they will directly impact on indoor air quality and potentially influence human health and wellbeing (World Health Organization, 2009). Shortt and Rugkasa (2007) also argued that the 'damp', 'mould' and 'condensation' could decrease the home energy efficiency and increase the chances of fuel poverty.

q7.1. How often do you experience the issues below in your home? (1 is never; 5 is always) Cold	Correlation Coefficient	Sig. (2-tailed)	N
q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	0.289*	0.038	32
q7.5. How often do you experience the issues below in your home? (1 is never; 5 is always)Condensation	**Correlation Coefficient**	**Sig. (2-tailed)**	**N**
q3.1. How much do you pay for the bill each quarter	0.295*	0.035	32

approximately? For electricity, please specify (£):			
q10.2. How often do you use your heating controls? (in winter) Wall thermostat	-0.441**	0.003	32

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 20. Correlation between ‘quarterly bills’, ‘energy consumption behaviour’ and ‘housing issues’ at Estate B.

According to Table 5.20, significant and moderate correlations was also found between the ‘housing issues’ at Estate B and a number of energy use variables at both the 0.01 and 0.05 levels. As a result, the ‘Cold’ (0.289*, $p<0.05$) and ‘Condensation’ (0.295*, $p<0.05$) issues increases while the ‘quarterly electricity bills’ increases. Besides, the ‘frequency of using wall thermostat in winter’ (-0.441**, $p<0.01$) increases while the ‘Condensation’ issue decreases.

5.3.2.12 ‘Flat orientation’ and other variables

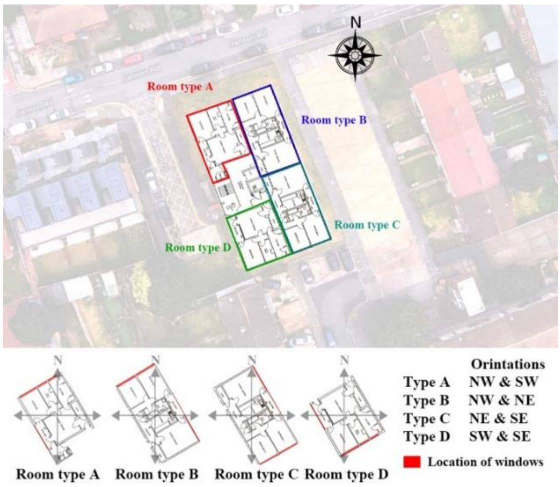


Figure 5. 52. Flat orientations at Estate A.

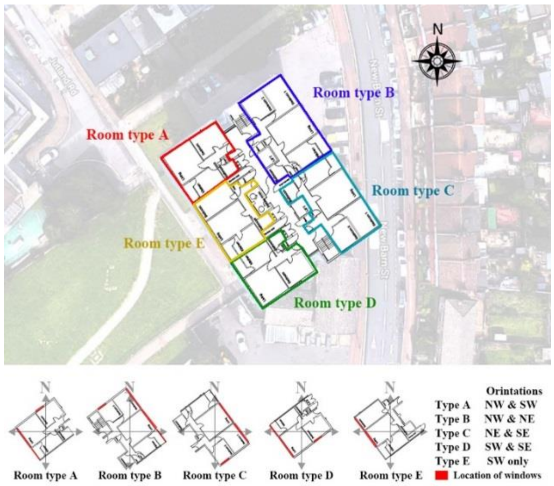


Figure 5. 53. Flat orientations at Estate B.

The orientations of flats are determined by the location of windows. According to Figure 5.52, there are 4 flats on each floor which are facing ‘southwest and northwest’, ‘northwest and northeast’, ‘northeast and southeast’, and ‘southeast and southwest’. According to Figure 5.53, there are 5 flats located on each floor which are facing ‘southwest and northwest’, ‘northwest and northeast’, ‘northeast and southeast’, ‘south east and southwest’ and ‘southwest only’.

It is believed that different orientations of flats will significantly impact on the heat gains and indoor thermal comfort (Li et al., 2002). Therefore, it affects the way that occupants operate their homes. In order to test if the energy consumption and occupants’ energy consumption behaviour in the case studies are affected by orientations, the correlations and ANOVA test were conducted.

Orientation of flats	Correlation Coefficient	Sig. (2-tailed)	N
q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	0.439**	0.002	49
q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	0.436**	0.002	49
q7.1. How often do you experience the issues below in your home? (1 is never; 5 is always) Cold	0.369**	0.009	49
q7.3. How often do you experience the issues below in your home? (1 is never; 5 is always) Mould	0.461**	0.001	49
q11. At what temperature do you set your wall thermostat? (in winter)	0.437**	0.002	49
q12.1. How often do you open your windows in winter?	-0.388**	0.006	49

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. 21. Correlations between housing conditions, energy related questions and 'orientations'.

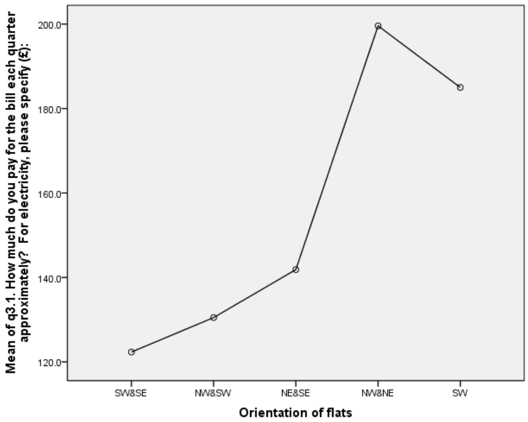
According to Table 5.21, significant correlations were identified between 'orientation of flats' and a number of variables at both 0.05 and 0.01 levels, such as the 'orientation of flats' and 'quarterly electricity bills' (0.305*, $p<0.05$), the frequency of experiencing 'cold' at home (0.436**, $p<0.01$), the frequency of experiencing 'mould' at home (0.241*, $p<0.41$), temperature set up on wall thermostat (0.337*, $p<0.05$) and the frequency of opening the windows (-0.388**, $p<0.01$). As the options of orientation are categorical data which are not in order, the relationships between different orientations and abovementioned variables need to be further explored by using ANOVA test.

Dependent Variable	F	Sig.
q3.1. How much do you pay for the bill each quarter approximately? For electricity, please specify (£):	3.746	0.010
q3.2. How much do you pay for the bill each quarter approximately? For gas, please specify (£):	2.976	0.029
q7.1. How often do you experience the issues below in your home? (1 is never; 5 is always) Cold	3.079	0.025
q7.3. How often do you experience the issues below in your home? (1 is never; 5 is always) Mould	3.190	0.022
q11. At what temperature do you set your wall thermostat? (in	4.287	0.005

winter)		
q12.1. How often do you open your windows in winter?	4.193	0.006

Table 5. 22. ANOVA test between housing conditions, energy related questions and ‘orientations’.

According to Table 5.22, significant differences of ‘quarterly electricity bills’, ‘cold’, ‘mould’, ‘temperature set on wall thermostat’ and ‘frequency of opening the windows’ were identified with different categories of ‘orientation of flats’.



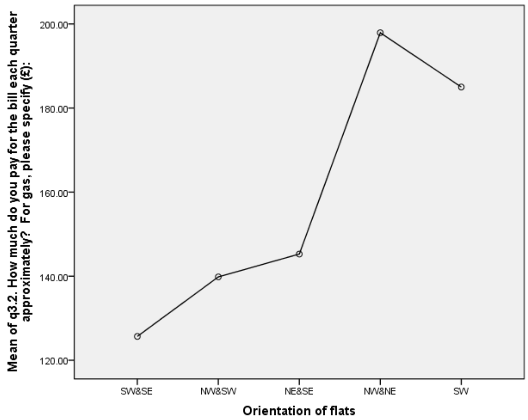


Figure 5. 54. ANOVA test: ‘Orientations’ and ‘quarterly electricity bills’. Figure 5. 55. ANOVA test: ‘Orientations’ and ‘quarterly gas bills’.

According to Figure 5.54, occupants who live in the flats with ‘southwest and southeast’ facing tended to spend the least on ‘quarterly electricity bills’. The ‘quarterly electricity bills’ gradually increase in sequence of ‘southwest and southeast’, ‘northeast and southeast’, ‘northwest and southwest’, ‘southwest only’ and ‘northwest and northeast’. On the other hand, similar results were obtained from ANOVA test between ‘orientation of flats’ and ‘quarterly gas bills’. According to Figure 5.55, occupants who live in the flats with ‘southwest and southeast’ facing tended to also spend the least on ‘quarterly gas bills’. The ‘quarterly gas bills’ gradually increase in sequence of ‘southwest and southeast’, ‘northwest and southwest, ‘northeast and southeast’, ‘northeast only’ and ‘northwest and northeast’. It indicated that occupants living in south facing flats experienced better thermal conditions and tended to spend less on electricity and gas bills. The ones living in east or west facing flats with certain levels of direct solar access spend more on their bills. However, occupants who lived in ‘northeast’ and ‘northwest’ facing flats would pay higher energy bills.

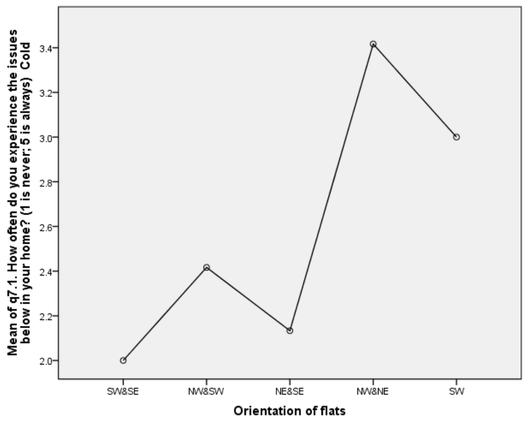


Figure 5. 56. ANOVA test: ‘Orientations’ and ‘cold’.

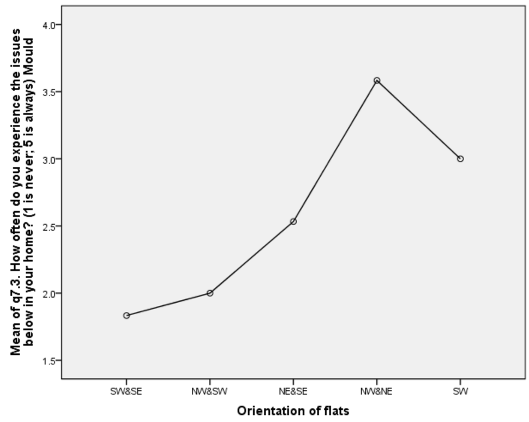


Figure 5. 57. ANOVA test: ‘orientations’ and ‘mould’.

According to Figure 5.56, occupants experienced the ‘cold’ issues at homes more frequently in sequence of the flat orientations facing towards ‘southwest and southeast’, ‘northeast and southeast’, ‘northwest and southwest’, ‘southwest only’ and ‘northwest and northeast’. According to Figure 5.57, occupants had experienced the ‘mould’ issues at homes more frequently in sequence of flat orientations facing towards ‘southwest and southeast’, ‘northwest and southwest’, ‘northeast and southeast’, ‘southwest only’ and ‘northwest and northeast’. Similarities were indicated between the 2 different housing issues and their relationships with the orientations of flats. However, the ‘cold’ issues were more obvious for the flats facing ‘northwest and southwest’ and the ones facing ‘northeast and southeast’. In contrast, the ‘mould’ issues were more obvious in the flats facing ‘northeast and southeast’ than the ones facing ‘northwest and southwest’.

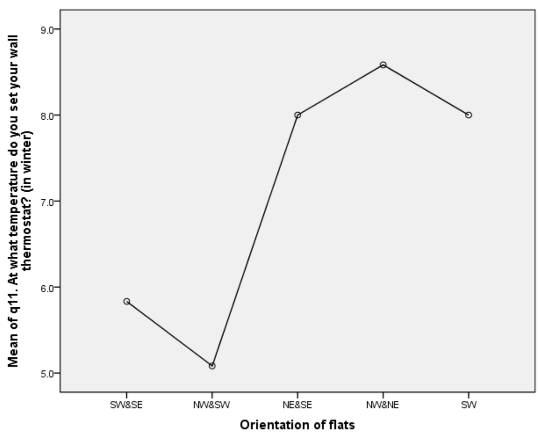


Figure 5. 58. ANOVA test: ‘orientations’ and ‘temperature’.

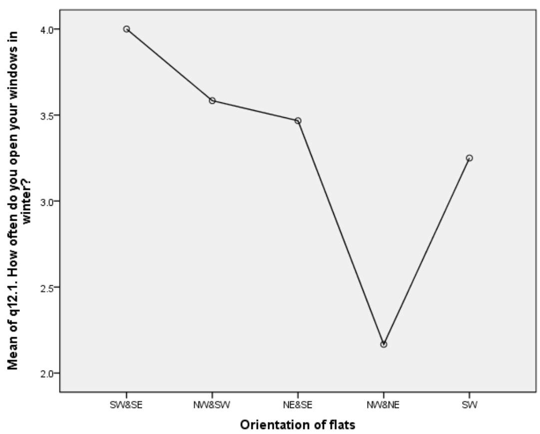


Figure 5. 59. ANOVA test: ‘orientations’ and ‘use of windows’.

According to Figure 5.58, the temperatures set on wall thermostats by the occupants increases in the sequence of the flat orientations facing ‘northwest and southwest’, ‘southwest and southeast’, ‘northeast and southeast’, ‘southwest only’ and ‘northwest and northeast’. It implies that flats with more south-facing windows normally tend to receive more solar radiation thus occupants’ heating requirements may be less than the ones living in the north-facing flats. According to Figure 5.59, the 'frequency of opening the windows' decreased in sequence with the flat orientations' towards 'southwest and southeast', 'northwest and southwest', 'northeast and southeast', 'southwest only' and 'northwest and northeast'. In general, it showed that occupants living in south-facing flats tend to open their windows more than the ones living in north-facing flats.

Significant differences between different flat orientations with a number of variables were identified in the ANOVA test. Due to the flat orientation factors, south-facing flats in the UK receive more heat gain and less heat loss with abundant sufficient solar radiation. As a result, occupants tend to open the windows and set lower temperature on wall thermostat more frequently, and consume less heating and electricity. Kontoleon and Zenginis (2017) also indicated that the south-oriented buildings were characterized with the most heat gains and north-oriented buildings were characterized with the most heat losses in the UK. Same point of view was also supported by Abanda and Byers (2016) through modelling the building performance of different orientations that building orientation significantly contributes to building energy performance. As a result, the flats with more south-facing windows tend to have less 'cold' and 'mould' issues than the ones with north-facing windows. Flats with different orientations demonstrate different levels of housing problems. It implies that the retrofit interventions may need to be specifically tailored towards different building facades rather than consistently applied to the whole building.

5.4 Conclusion

A significant of findings are identified to describe the current condition of home energy performance in the aspects of occupants' energy consumption behaviour, occupancy patterns and socio-demographic characteristics from the last section. The correlation analysis indicates that tenancy status significantly impact on home energy performance. Fuel poverty is also obvious in the research case study as 38.7 per cent of the households are in the risk of it when correlating their annual incomes and energy bills from the questionnaires.

It is also found that household profiles influence home energy performance in different aspects. Age groups as one of the dominating factors significantly impact on the use of heating systems, ventilation components and energy saving activities. Besides, employment status could potentially impact on the occupancy patterns at homes and consequently impact on occupants' flexibility on energy management. In addition, occupants in poor health condition could also require extra heating and ignore the importance of air ventilation. Moreover, the household profiles also influence both the occupancy and heating patterns at homes and consequently impact on home energy consumption. For instance, the occupants with higher income levels tend to have longer heating patterns and spend more energy than low income families at homes.

Besides, the temperature set up on the thermostat will directly impact on energy performance according to the research findings. The reason for this is that to remain higher indoor temperatures will require higher energy consumption. Although 21 °C is recommended as an appropriate indoor temperature, the majority of the occupants tend to set it higher. In the case study, 40 per cent of the respondents set their wall thermostats higher than 21 °C which is relatively high, 30 per cent of them set their wall thermostats less or equal to 21 °C and 30 per cent of them do not know what temperature they set it at. Besides, 24 per cent of them set their wall thermostats equal or more than 24 °C which may imply to overheating problems and implications to their own health. On the other hand, occupants' perception of comfortable temperature is also influenced by the type of activities at homes. Additionally, the research found that the use of windows, extractor fans and trickle vents also significantly impact on home energy performance. Moreover, occupants who have received energy advice tend to perform better on operating their homes in different aspects, such as 'using different types of heating controls' and 'energy conservation behaviour'.

Furthermore, the orientations of flats also have significant impact on home energy performance concerning occurrences of housing issues, use of windows and temperature set on wall thermostat. Due to varying levels of solar radiation, south facing flats tend to be warmer and consequently may open the windows more frequently and set the indoor temperature lower. According to the research findings at the first stage, occupants did not have sufficient energy knowledge as they were not familiar with the heating systems and ventilation systems at their homes. They also tend to consume more energy than they should due to a variety of reasons. The key findings of the questionnaire survey were summarised in bullet points as below:

- Majority of the respondents were social renters (84 per cent). More than half of them (56 per cent) have been living there for more than 10 years.
- Thirty-eight per cent of participating households pay more than national average level (£154.75) for their quarterly electricity bills and 36 per cent of them pay more than national average level (£157.5) for their quarterly gas bills (DBEIS, 2018).
- Thirty per cent of participating households do not have employed family members. Fifty-four per cent of them earn less than £12,000 per annual. The low income level and high energy bills lead to significant fuel poverty problems.
- Respondents do not have sufficient knowledge in using heating controls, extractor fans and trickle vents to maintain a good living environment. They failed to follow a

number of energy conservation approaches.

- The way that homes operated were found significantly impact on energy performance. They include the use of wall thermostats, boiler thermostats, radiator valves, windows, extractor fans, trickle vents and the indoor temperature.
- Occupants' energy consumption behaviour is correlated with a number of socio-demographic factors, such as family size, income levels, employment status and occupants' health conditions.
- The provision of energy advice was proven effective for promoting behavioural change.
- Housing problems, such as mould, condensation and cold, could cause more heating consumption. Flat orientations also significantly impact on occupants' energy consumption behaviour and energy performance.

A focus group interview was arranged to probe into details of the key issues. the barriers of energy conservation were explored. Besides, the implementation of smart meters and the likelihood of occupants using energy management applications are explored. The findings of the focus group interview are demonstrated in the next section.

Chapter 6. Data analysis: Focus group interview

6.1 Introduction

The focus group interview was arranged in order to probe more into details of the key findings of the questionnaire survey and inform potential behavioural interventions for energy efficiency. The structure of the interview was split into 3 themes. The current conditions of smart meter implementation and occupants' experiences of using energy management applications are firstly explored. Then, interviewees' energy consumption behaviour, occupancy patterns and energy performance are thoroughly discussed in order to help interpret the research findings of the questionnaire survey. Lastly, a number of proposed application features that are believed helpful are demonstrated for discussion. As a result, discussion and feedback helped explain the underlying reasons for the correlations such as those between: 'number of occupants', 'number of children', 'number of teenagers' and energy performance; 'change of energy tariffs' and energy performance; and between a number of energy consumption behaviour and energy performance. In addition, interviewees' attitudes to energy application features were also explored in a variety of aspects such as real-time behavioural suggestions, energy comparison, gamification design, ranking and rewarding systems. The findings from the focus group interview are illustrated below.

6.2 Interview findings

6.2.1 Background of interviewees

A total of 9 participants attended the focus group. Due to the relatively small sample size and the unavailability of accompanying staff from the local authority, only 1 focus group was arranged. In order to obtain more resourceful and valuable information to support the research outcome, more focus groups are recommended. Among the interviewees, there was 1 interviewee from the following age groups: '19-24', '25-34', '55-64' and '65 years or over'. Two interviewees were '35-44' years old and 3 interviewees were '45-54' years old. Six interviewees were female and 3 interviewees were male. Further, 4 of the interviewees were 'full-time employed' and 1 'part-time employed'. One of the interviewees was 'self-employed' and 3 'unemployed'. Five of the interviewees had 'secondary (GCSE) qualifications' as their highest education level, 1 had 'A. AS Level (Level 3 award)', 1 'Masters or PhD degree' and 2 of them 'do not have any degree'. In addition, the interviewees were made up of 1 'White', 1 'Asian or Asian British' and 7 'Black or Black British'.

The employment status of the interviewees was comprised of 4 full-time employed interviewees, 1 part-time employed interviewee, 1 self-employed interviewee and 3 unemployed interviewees. The composition of ‘full-time employed’ represents more than the participants in the first phase of the research. This is also the reason why interviewees preferred to conduct the interview at the weekend. Although 2 interviewees who were aged ’55-64’ and ’65 years or over’ joined the discussion, both of them were from a large family. None of the interviewees represented single elderly in the interview. The implications of these factors will be discussed by considering the feedback that interviewees provided in the following sections.

6.2.2 Implementation of smart meter

Based on the summary findings of the first phase of the research, the majority of occupants did not have much experience in using smart meters nor energy management applications. Hence, their knowledge and the current condition of their smart meters were firstly explored. Then, a video that explains the functions of energy management applications was demonstrated at the beginning of the interview in order to help occupants better understand the research topic and ensure more fruitful discussions.

Five interviewees knew what the smart meter is but 4 of them did not. Among the interviewees who knew smart meters, most of them tried to install it. However, only 1 of them has had a smart meter successfully installed at his home. On the other hand, the rest of the interviewees do not have smart meters at their homes. The reasons for the low installation rate of smart meters were explored with the interviewees. In order to install the smart meter, occupants who live in social housing estates need to obtain permissions from the council to open the central electrical cupboard in the communal area. Most of the interviewees expressed difficulties in getting that permission. For example, an interviewee expressed the difficulty of getting the permission, saying “we need to ask for the permission from council…but I’ve been asking them for a long time but they didn’t respond”. Another interviewee expressed the same feeling that “I was calling the council and ask them to open the cupboard on the day…and they refused to do it for health and safety reasons”. It showed that energy suppliers could not have access to install the smart meters for the occupants unless it is granted by the council. This implies that social housing management needs to be more cooperative to facilitate the installation of smart meters.

The barriers to implementing smart meters were explored during the interview. One interviewee expressed that it was difficult to book an appointment with energy companies even if the management of social housing estates grant access. She claimed that "I thought I was kicked in the teeth. I've tried constantly now for last 8 months to get it. And I'm getting the same response". This shows that energy suppliers need to make more efforts on installing smart meters in social housing estates in order to meet the target of the roll-out of smart meters by the end of 2020. Concerns about energy companies' obligations were also raised by interviewees during the discussion. The interviewee who had successfully installed a smart meter expressed that he managed to do so by pushing the energy supplier very hard. He told his energy supplier that it is the right of clients to ask for it and he may switch to another company if they refused to do this for him.

Another reason for the low implementation rate of smart meters is low awareness and knowledge of adopting smart technology for energy conservation among occupants. This is also reflected in a number of recent studies (Energy Saving Trust, 2011; Elsharkawy, 2013; Elsharkawy and Rutherford, 2018). It has been found that occupants failed to facilitate the process due to the lack of relevant knowledge. One of the interviewees turned down the offer of installing the smart meter that was provided by the energy supplier when she had switched to a new one. She said "The EDF offered me a smart meter. I said no, no, no, leave it". After realising the advantages of the smart meter, she expressed that she will contact her energy supplier again for the original offer. Another interviewee thought she is not allowed to change the energy meter at her home. She expressed that "Because of my contract. Whatever the meter was there, the council wants it out there". Then, she was told that her understanding is incorrect during the meeting. However, she has missed the best opportunity. It is noted that social renters are allowed to choose energy suppliers and upgrade their meters.

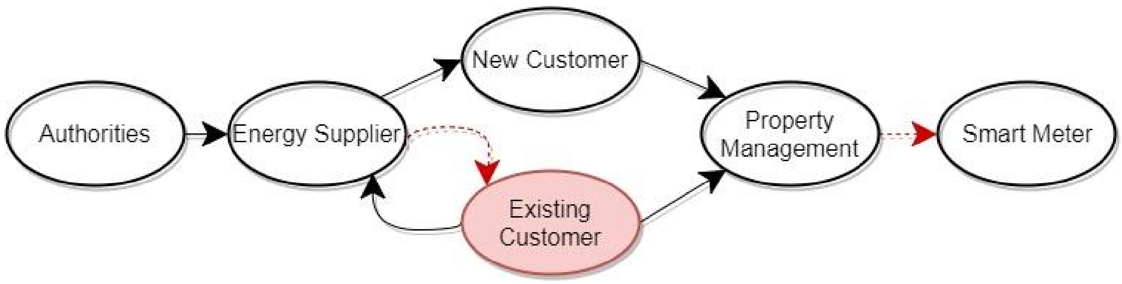


Figure 6. 1. Implementation of smart meters in the case study social housing estates (Source: Author).

Based on the discussions above, there are several problems identified which may show the implementation of smart meters in social housing estates. According to Figure 6.1, although energy suppliers are committed to complete the roll-out of smart meters by 2020, they are less focused on existing customers. Customers need to push their energy suppliers for installation, especially in social housing estates. The potential risk of implementing smart meters using energy companies was argued by Hannon et al. (2013).

Energy companies need to gain profile on selling energy and consequently are less focused on providing energy conservation measures to users. Secondly, occupants need to be further educated in terms of home energy efficiency technologies, as they will need to make the decisions on installing those measures (Energy Saving Trust, 2011; Elsharkawy, 2013; Elsharkawy and Rutherford, 2018). That would help to achieve more energy and financial savings, and the roll-out of smart meters. Lastly, the installation of smart meters in social housing takes longer than for normal properties due to the lengthy process. So, estate management needs to be fully supportive, otherwise, progress will be lost in the process of coordination.

6.2.3 Energy consumption behaviour

Interviewees' energy consumption behaviour and their awareness of energy saving were explored during the interview. The aim was to thoroughly understand their occupancy and energy use patterns and the implications for energy consumption. Thus, it helped to find the best solution to improve methods occupants have to operate their homes in social housing estates.

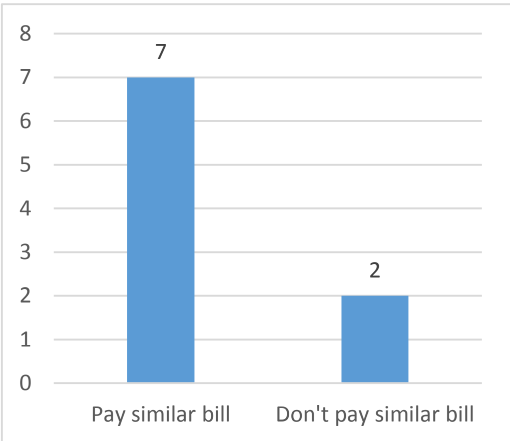


Figure 6. 2. Do you pay similar bill across the years?

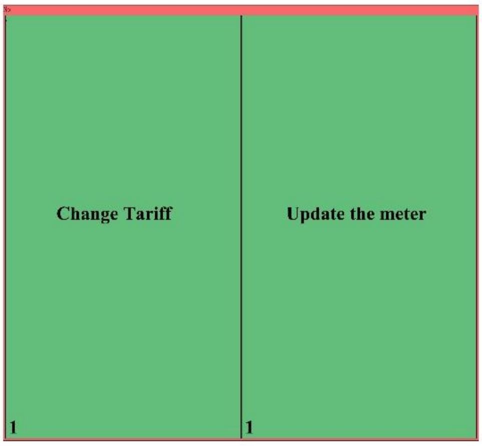


Figure 6. 3. If not, why?

According to Figure 6.2, 7 interviewees expressed that they pay more or less similar bills in the same seasons across recent years. This implies that interviewees tend to keep the same methods of operating their homes long-term. Therefore, those behaviours form part of human habits and are difficult to change. The difficulty of changing occupants' energy consumption behaviours is also highlighted by Elsharkawy and Rutherford (2018). Santangelo and Tondelli (2017) also argue that although energy feedback is recognised as the best way to change occupants' behaviour, it is unlikely to motivate changes. On the other hand, 2 interviewees expressed that they were aware of changes on their quarterly bills in recent years. According to Figure 6.3, 1 interviewee paid a lower bill than before as his energy consumption behaviour improved through interaction with smart meters.

Another interviewee was aware of a lower payment on her bill due to a change of energy tariff. The positive influence of smart meters on home energy efficiency is widely recognised (Wilson et al., 2017; Basit et al., 2017). Further, the above reflects that some occupants have a certain level of energy conservation awareness and tend to save energy through different approaches. The interviewees' answers also helped to further explain the reason for the established correlations between 'change of energy tariffs' and 'energy saving approaches' in the first phase of the research. They indicate that occupants who had previously changed energy tariffs or plans tended to follow energy saving approaches more frequently. To investigate if energy consumption is related to the way that interviewees operate their homes, a number of questions were asked below.

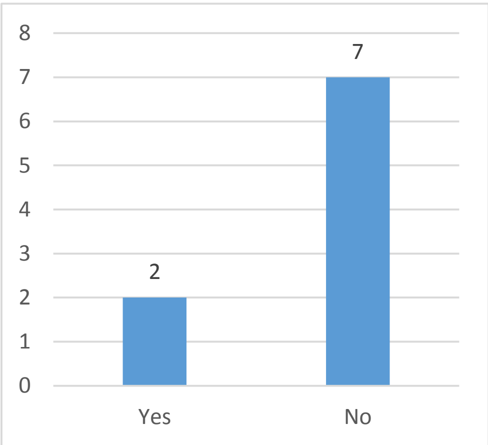


Figure 6. 4. Change the way of using housing components?

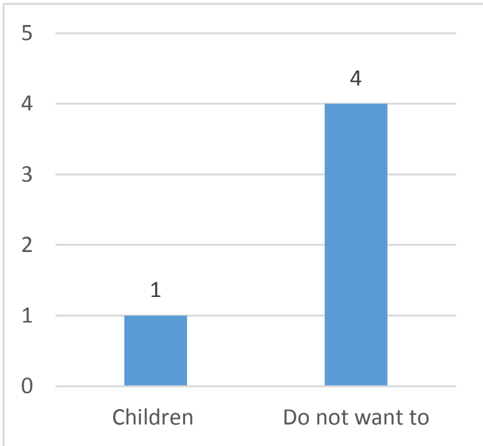


Figure 6. 5. If not, why?

According to Figure 6.4, 2 of the interviewees expressed that they have recently changed their method of using components in their homes. It is noted that they are the ones who had either upgraded to a smart meter or changed energy tariffs. This shows that meter upgrade and change of tariff will influence energy consumption behaviour, thus increasing energy efficiency (Wilson et al., 2017; Basit et al., 2017). Seven interviewees had not changed their method of using components in their homes. The reason for that was also explored with 1 interviewee stating she could not do so because of her children. She expressed that "It is difficult to change the way we use. Because I have several kids with different ages. That is consuming a lot of gas and electricity. And they are all using either play station or iPad". This indicated that the interviewee could not manage the use of housing components efficiently due to the children behaviour. The children's impact on energy consumption are also indicated by Middlemiss and Gillard (2015) in their households' housing and socio-economic conditions survey. Based on the interview among 15 interviewees from social housing households, parents were found to be difficult to stop children from using entertainment at home, especially when there is no money for entertainment outside the home. Further, children are always overlooked by parents in terms of thermal comfort. Another 4 interviewees had not changed their methods because they did not want to. This shows that the majority of interviewees tended to stick to the same method of operating their homes long-term, and do not seek to improve their energy consumption behaviour upon their own initiative.

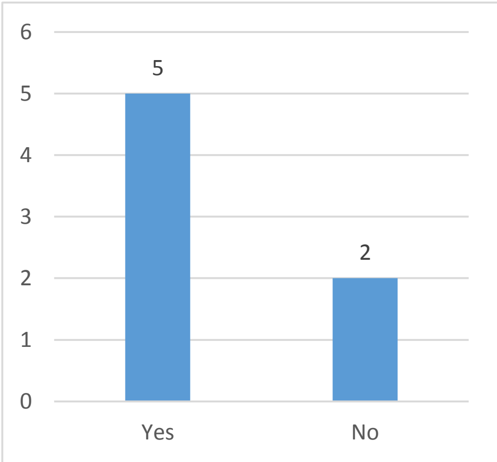


Figure 6. 6. Do you have potential to save energy?

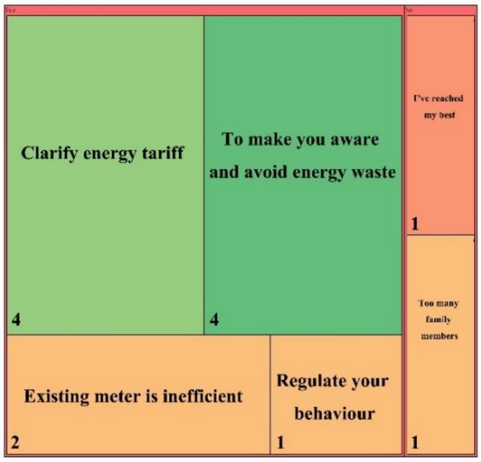


Figure 6. 7. Why?

In addition, interviewees were asked to evaluate their current energy use. There were 7 interviewees who answered this question. According to Figure 6.6, 5 interviewees admitted that they have potential to save energy in the future. There are a number of reasons expressed and reflected in the NVivo tree diagram. According to Figure 6.7, occupants do not thoroughly understand their bills and energy tariffs, which leads to unnecessary costs. They believe that they can save more energy if they have a clear understanding of their bills. Further, their existing meters are not efficient. They believe they can save more by upgrading their meters. One of the interviewees expressed that "I'm on direct debit. It is a lot. I'm up for the lowest direct debit, 70 pounds. What if I use top up? So I can wash my cloth by myself". Interviewees also believe it would help them regulate their energy consumption behaviour and make them aware of the importance of energy usage if they had smart meters installed. For example, an interviewee expressed that "If you see how much you are using, it still makes you aware. If you go to the bathroom, you make sure you turn the lights off". The results show that occupants want to save energy and also wish to be further educated on how to do so appropriately. On the other hand, 2 of the interviewees did not think they could further save energy as their family members are too many to manage or they have already reached optimum savings. One interviewee who lives with 3 kids and 2 elderlies said "I'm not easy to manage energy because I got children…they use electricity in different times". The negative impact of a large family and number of children is also indicated by Guerra-Santin (2011), Yun and Steemers (2011) and Abrahamse and Steg (2009). Another interviewee stated "Pay as you go, only because I did not get enough money to do direct debit. I can save money by myself". This shows that finance is one of the influential factors in energy consumption behaviour.

Two interviewees expressed that they had reached their optimum in terms of energy savings. One of these had a smart meter in his home, which helped to improve his energy consumption behaviour. As a result, the interviewee spent a lot less on his bills. His feedback supported the found correlations between 'energy performance' and 'energy consumption behaviour' identified at the first stage of the research. He commented on the change of his behaviour after adopting the smart meter. The significant correlations found between 'energy performance' and 'use of wall thermostat' were also supported by the interviewee, who stated "hmm…in winter, I get back home at 5:30 PM. So I get the heater on by about 4 o'clock. And that saves money. If I come from work, I do not feel cold". The interviewee also tried to save energy for free and expressed that "in the morning, I go out to the shops and come back. It is warm. In a way you put on your jumper or set on your thermostat to come on certain times, and it will save you money". This also helped to explain how 'energy saving approaches' helped to reduce energy consumption from the correlation analysis. Another interviewee who had upgraded her meter also commented on the change in her energy consumption behaviour, "I pay not even 20 pounds a month for electrical or gas…I always take off plugs when I leave. So I do see a difference".

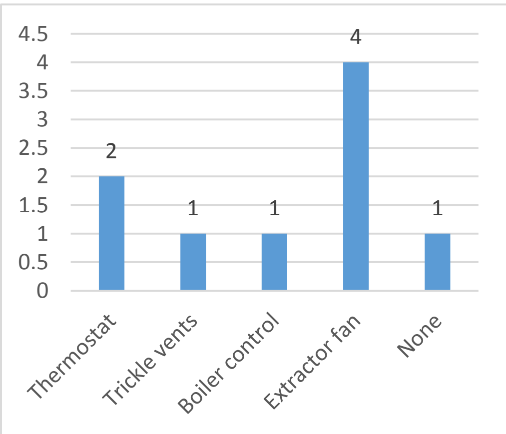


Figure 6. 8. Components never adjusted at home?

Word	Length	Count	Weighted Percentage
extractor	9	5	4.46
fans	4	4	3.57
boiler	6	3	2.68
know	4	3	2.68
thermostat	10	3	2.68
burn	4	2	1.79
heating	7	2	1.79
noisy	5	2	1.79
actually	8	1	0.89

Table 6. 1. Word frequency of the topic.

Interviewees' knowledge on how to use electrical appliances and other components was also explored. Interviewees were asked if there are any components that have never been adjusted at home. According to Figure 6.8, 4 interviewees had never used extractor fans at their homes due to their working condition, especially the noise produced. They expressed "but I don't use extractor fans. Not because of the money, because it makes kind of noise". One of the interviewees expressed that she does not have an extractor fan installed where other participants had had it done during the last refurbishment. This shows that refurbishment of the flats in social housing estates may not be very consistent.

According to Table 6.1, ‘extractor’ and ‘fans’ were the most mentioned words, taking 4.46 and 3.57 per cent of the conversation on this topic. This indicated that the use of extractor fans is the most problematic issue in the case study. ‘Noisy’ was also mentioned a few times as the most mentioned reason. Failing to use extractor fans will decrease air ventilation and increase the possibilities of mould and condensation (World Health Organization, 2009). Thus, home energy efficiency may reduce and more costs on heating generated (Shortt and Rugkasa, 2007). This indicated that occupants do not have sufficient knowledge about the function of extractor fans and tend to compromise energy savings for personal comfort. However, deep retrofit is also needed to upgrade the living environment of many social housing estates.

Two interviewees had never touched their thermostats as they were currently broken and had been left for long time; 1 interviewee could not use the switch on the boiler, so she had to use the boiler thermostat to boost hot water; another interviewee did not know what the trickle vent was so she unintentionally left it open all the time. She said “Seriously, I don’t even know what trickle vent is. I don’t even know if I got that one or not”. The same issue was identified in the questionnaire survey that some of the participants did not know the function of trickle vents. Only two interviewees expressed that they know all of the housing components very well.

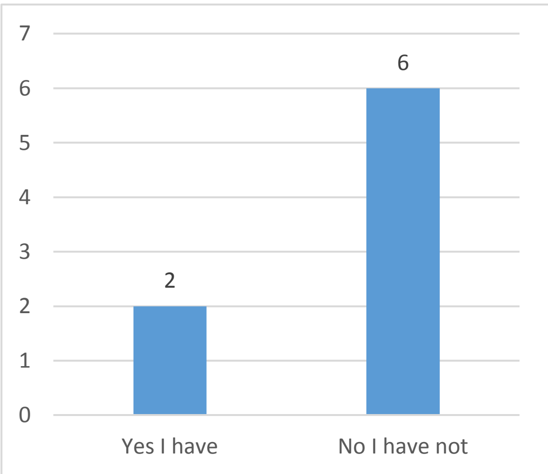


Figure 6. 9. Did you try to avoid peak time?

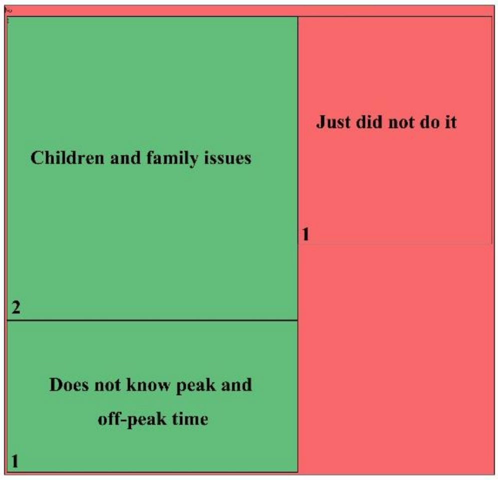


Figure 6. 10. If not, why?

To explore occupants’ knowledge and awareness of energy conservation, they were asked if they have ever tried to avoid energy peak times. According to Figure 6.9, only 2 interviewees intentionally avoid using electricity and gas at peak times. Six of them did not manage to do so. A number of reasons for this were provided (See Figure 6.10). Children and family issues were raised again as one of the major barriers to doing so. Interviewees also had a lack of knowledge on peak and off-peak times. Thus, they could not avoid peak times. One of the interviewees was aware of the difference in the bill charged. However, she still did not change her consumption pattern.

Word	Length	Count	Weighted Percentage
energy	6	14	2.63
use	3	8	1.5
different	9	7	1.31
difficult	9	7	1.31
gas	3	7	1.31
kids	4	7	1.31
one	3	7	1.31
think	5	7	1.31
smart	5	6	1.13

Table 6. 2. Frequency of words mentioned.

In the focus group, one of the interviewees had a big family with 3 children and 2 parents. When looking at her word cloud of conversation in this particular part of the interview, ‘different’, ‘difficult’ and ‘kids’ were the most mentioned words, taking 1.31 per cent of the overall conversation (see Table 6.2). This shows that a family with a more complicated demographical composition is more difficult for managing energy use effectively.

The same findings were indicated in the established correlations between ‘number of children’, ‘number of students’ and the ‘quarterly bills’ (Guerra-Santin, 2011; Yun and Steemers, 2011; Abrahamse and Steg, 2009). The interviewee with children issues commented on children consuming more energy that “It is difficult to manage that, because they do not eat twice. You need to cook if they want to eat. We always cook in different hours”. Another interviewee also expressed that “Especially you have teenager. You cannot force them to do something, like go out or put on a jumper to save energy”. Further, one interviewee expressed her worry about her child’s comfort, “He does not like to put the jumper on. We have to turn on the heating all the time. And he feels cold if we did not do it. That’s why I got more energy to pay”. Apart from the children issue, the interviewees also explained why they consume more energy as adults. For example, 1 interviewee expressed “there’s no time. I wake up at 4 o’clock and leave at 5 o’clock. Then I come back at 8 o’clock. Only today I have my time to rest. The other days, I have no time”. This helped to further explore why the correlations between ‘quarterly energy bills’ and ‘number of adults’ were found during the first stage of the study. Workload may stop adults improving energy consumption behaviour as their occupancy pattern is very limited and fixed.

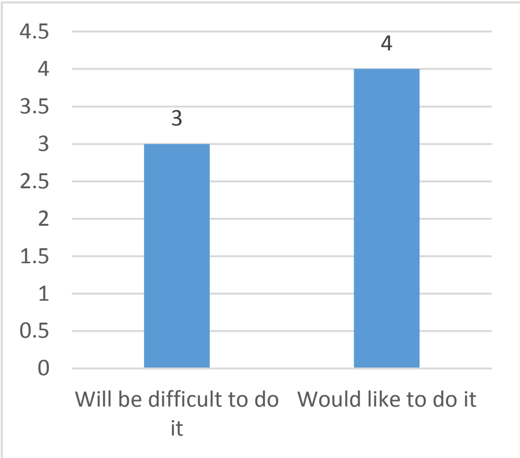


Figure 6. 11. Save energy for free?

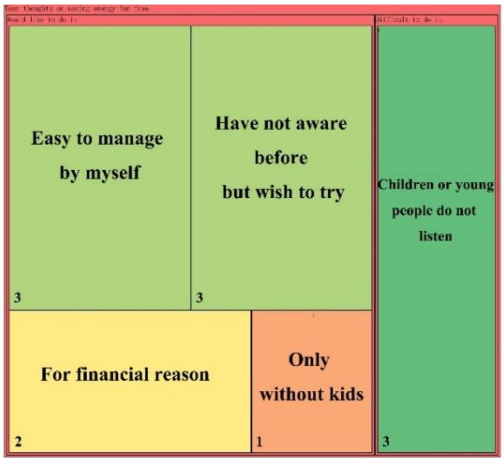


Figure 6. 12. Your thoughts on saving energy for free.

There are a number of sustainable actions which help occupants to save energy for free such as ‘go out to avoid using heating’, ‘turn off light when leaving a room’ and ‘put on a jumper instead of heating’. Interviewees’ attitudes towards those energy conservation approaches were investigated. As shown in Figure 6.11, 3 interviewees felt that it is difficult to follow these activities due to the issue of children or young people. If children did not want to put on a jumper, heaters have to be turned on to keep warm. Additionally, it is difficult to persuade children or teenagers to do something if they do not want to such as doing outdoor activities to avoid using heating. On the other hand, 4 interviewees would like to try these actions because they are easy to manage by themselves without children or for financial reasons, and they have not been aware of them before. It is also implied that the number of occupants in a family will significantly impact on energy performance as interviewees who live alone could more effectively manage their energy use. By contrast, complicated family composition leads to complicated occupancy and energy use patterns. Thus, more occupants per household increases the challenges of energy management.

6.2.4 Energy management application

Energy management application as a form of Human-Computer Interactions (HCI) could be used to address environmental sustainability and energy efficiency (DiSalvo et al., 2010). The importance of adopting energy management applications to regulate occupants’ energy consumption behaviour has been discussed in several studies (Zhao et al., 2017; D’Oca et al., 2014). Apart from exploring interviewees’ energy conservation awareness and their energy consumption behaviour, the focus group aimed to help inform the design of an energy management application. Highlights from the review of existing energy applications and proposed features were broadly discussed with the interviewees.

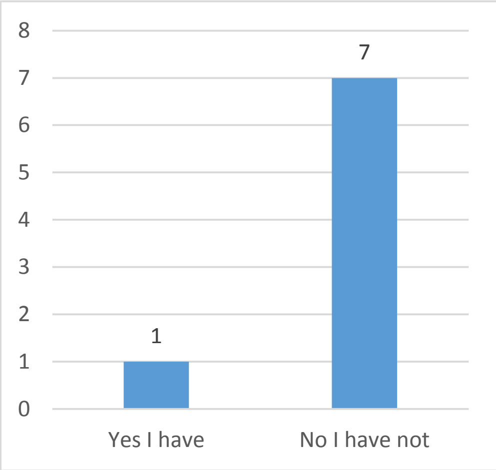


Figure 6. 13. Have you used energy app before?

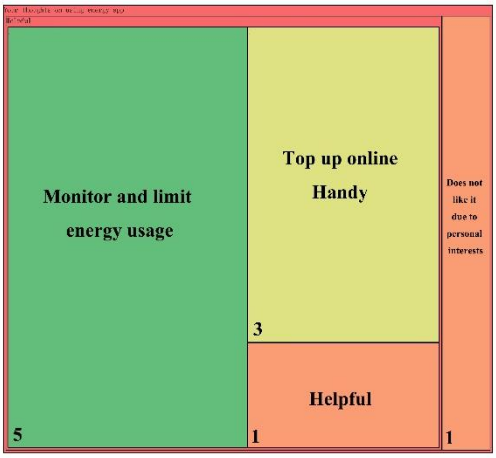


Figure 6. 14. What are your thoughts on energy app?

Before the discussion, a video was shown to demonstrate to interviewees how energy management applications interact with occupants and help them improve their energy saving actions. According to Figure 6.13, only 1 interviewee had experience in using energy applications, and another 7 of them had never used energy applications before. Occupants can use the applications that are developed by energy suppliers on their smart phones with their log-in credentials to access real-time bills, energy analysis and manage their accounts (British Gas, 2018; EDF Energy, 2018; E.ON UK, 2018). However, the majority of the energy management applications developed by independent application developers need to be based on smart control systems where smart meters and sensors are installed (Han and Lim, 2010). Although the majority of the interviewees did not have smart meters nor used energy applications, their thoughts were still investigated based on the video shown. According to Figure 6.14, only 1 interviewee expressed that she does not use applications on her smart phone. The other interviewees believed energy applications would be helpful on monitoring and limiting energy usage and making it more convenient to manage energy use. One interviewee commented on the energy management application, “it will tell you up to one penny. You know how much you spending”. Another interviewee expressed that “yeah, it would be helpful. You can top up your meter on line”.

Figure 6. 15. Comparison of app feature 1, 2 and 3 (Source: Author).

As previously discussed, the behavioural suggestions have not yet been widely adopted on energy management applications. The importance of real-time behavioural suggestions for energy end users was highlighted by Chou et al. (2017) and Chou and Telaga (2014). Some of the existing applications do provide real-time behavioural suggestions to users by asking them to set up a baseline manually or the applications automatically alert users based on their historical energy patterns (see Figure 6.15, feature 1 and 2). Apart from that, a proposed way of providing real-time behavioural suggestions was raised for tailored benchmark settings: by using the found correlations from the questionnaire survey, users could be helped to identify a proper energy consumption benchmark taking into consideration their socio-demographic information (see Figure 6.15, feature 3). In detail, different energy saving targets will be set up towards social housing households in different family sizes, existence of children, income levels and employment status. Then occupants are alerted based on their real-time energy consumption behaviour. The 3 different methods of real-time behaviour suggestions were demonstrated with easy-to-understand illustrations and explained to the interviewees.

Six interviewees preferred the third application feature as they believed it would more effectively help them reduce energy usage. One of the interviewees indicated the reason why he preferred the third rather than second option was that “it is about the patterns. You know, you may not know the functions and miss something”. This showed that interviewees were aware that they may not have sufficient knowledge on improving home energy performance and wish to be informed. Thus, they believed that behavioural suggestions based on historic patterns could not fundamentally help them. This also reflects that the majority of interviewees tend to keep the same method of operating their homes without any changes to their bills. Therefore, real-time behavioural alerts based on historic patterns may not be effective enough. One interviewee preferred both the second and third application features. One interviewee preferred the second application feature only as it would be easier to use in comparison with the third one. She stated “It is just because it’s all new at the beginning. Obviously I’m still looking to get used to it”. Another interviewee expressed that he would prefer to use the first application feature as he has a very good understanding of his energy use. He expressed that “I prefer to do it manually. Because I’m very aware of my energy usage. So, I have habits. So I don’t need the application as much to remind me”. However, he stated that he chose the first application because he lives alone. He would choose the third application feature if he had a more complicated family composition and energy use patterns. However, he also raised that “it can also bring problems if you got more occupants in your flat. Because one person likes more heating than the other person. So you know where will be argument”. The interviewee’s point of view implies that it would be difficult to satisfy all family members with different perceptions of thermal comfort levels (Jones et al., 2016).

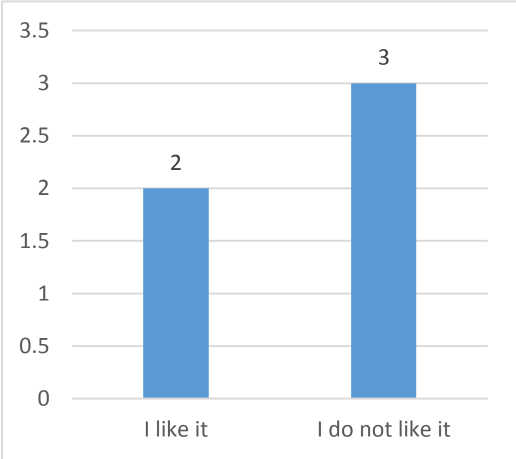


Figure 6. 16. App feature – socialising platform.

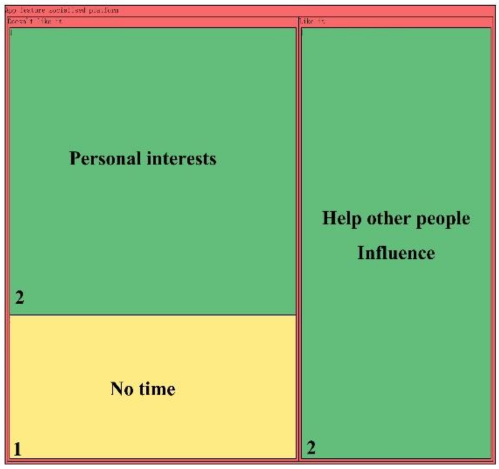


Figure 6. 17. Your thoughts on socialising platform.

Interviewees were also asked about their feelings about posting their energy saving activities on a socialising platform, making comments and ‘liking’ each other’s posts. There were 5 interviewees who answered this question. According to Figure 6.16, 2 of the interviewees liked the idea as it helps and influences other people. One interviewee made a comment that “it encourages me to try what you are trying to do. And it saves energy”. On the other hand, 3 interviewees did not like the idea due to personal interests and lack of spare time. The positive influence of popularising energy saving as social norm is highlighted by Petkov et al. (2011).

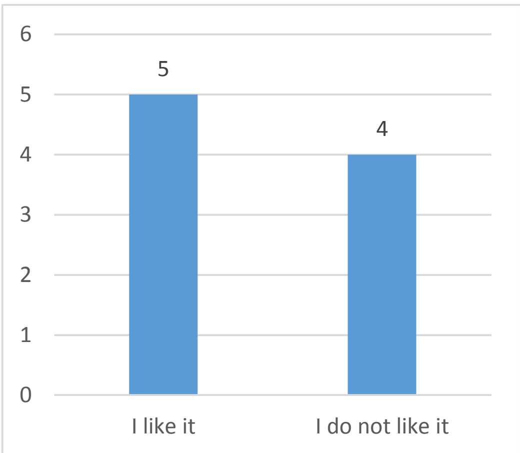


Figure 6. 18. App feature – gamification design.

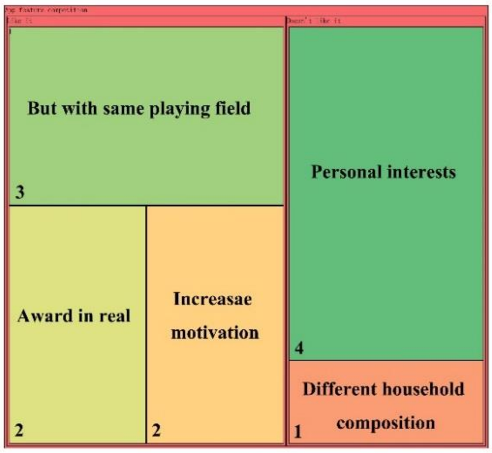


Figure 6. 19. Your thoughts on gamification design.

Furthermore, it is believed that gamification design would potentially increase users’ incentives to engage with energy conservation. Petkov et al. (2011) recognise the positive influence of gamification design on occupants’ motivation for the EnergyWiz application through their use of semi-structured interview. So, the interviewees were asked if they are interested in competing with each other on energy savings. As shown in Figure 6.18, 5 interviewees liked this idea as it would increase their motivation. On the other hand, 4 interviewees did not like it due to personal interests and family issues. These included the 2 interviewees who are 'older-aged' and 2 'middle-aged' interviewees with children. Household profiles significantly impact on the adoption of energy management applications (Petkov et al., 2011). According to Figure 6.19, the interviewees who liked gamification design expressed that they would only compete with people on the same playing field in terms of household demographics and housing conditions. An interviewee said that "they can be, but you have to be on the same field. I live on my own. I cannot compete with somebody with 3 kids and husband". Petkov et al. (2011) also state that energy self-comparison and comparison with neighbours living in the same conditions, and providing challenging tasks, will increase occupants' incentives for energy saving. This viewpoint is supported by Weiss et al. (2012). Further, McKechnie (2015) incorporates energy comparison features into the EnergyCloud application to engage more energy users. Two of the interviewees mentioned that it would be more attractive if the winner of the competition got a real reward such as a discount, promotions or free products. The interviewee asked "anything for being on the top of the rank? Or is it just being on the top?" Another interviewee also put forward the idea that "if you are on the top, you don't get like 5 per cent off on your bill or something? See if it is like that, OK, we will do it without doubt". Moreover, 1 interviewee expressed that he does not like to compete with others. It is also stated by Petkov et al. (2011) that some occupants prefer to only compete with their friends rather than anonymous people.

Moreover, half of the interviewees felt that they want to find out the reasons why they pay a higher bill than their neighbours who have the same household and housing conditions. The other half of the interviewees felt it would be normal if somebody pays less than they do if they are living in the same conditions but may have different occupancy patterns and attitudes. One interviewee expressed that she was taught to always leave her heaters on at a moderate temperature rather than turn them up full only when coming back home for energy saving. However, her husband believes that this is not safe. This shows that occupants have different judgements on home operation. Therefore, they will not have the same patterns as others. Additionally, all of the interviewees thought it would decrease their motivation if they found that they were always at the bottom of the rank no matter how much effort they made. It might make them not trust the ranking system or doubt the design of the application. Hence, the validity of energy saving achievements needs to be monitored and validated in order to keep occupants motivated.

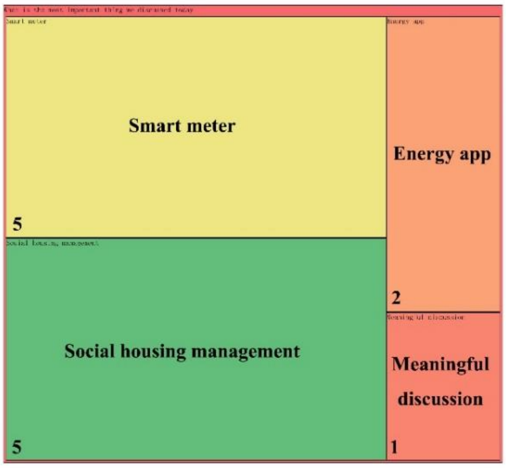


Figure 6. 20. What would you say is the most important issue?

Word	Length	Number	Percentage (%)
meter	5	12	2.43
smart	5	9	1.83
council	7	8	1.62
come	4	7	1.42
right	5	6	1.22
call	4	5	1.01
cupboard	8	5	1.01
gas	3	5	1.01
want	4	5	1.01
permission	10	4	0.81
concierge	9	4	0.81
edf	3	4	0.81

Table 6. 3. Word frequency of the topic.

At the end of the interview, the interviewees were asked to highlight the most important issues from the discussion, which helps to classify the importance of different barriers. According to Figure 6.20, they thought the meeting was meaningful and definitely helped raise their awareness of energy conservation. This shows that popularising knowledge of energy consumption behaviour and the function of smart meters and energy management applications may be welcomed by wider audience. The majority of them expressed that they would follow the suggestions to save energy. All of them wished to install the smart meters as soon as possible as 1 interviewee stated he already had successfully installed one and this helps manage his energy use very well. Some of the interviewees also wished to try using energy management applications on their smart phones, while a few of them did not prefer to use it on their phones. Besides, the interviewees also highlighted their concerns again about management of the estate and energy suppliers. Further approaches or measures need to be made by the local authority and energy suppliers to facilitate the pace of smart meter implementation, especially in social housing estates. Permission would be better asked through the social landlords (council) instead of the individual tenant with one-off installation in all flats with the same energy supplier. In this case, energy suppliers would not need to approach flats individually and persuade the tenants.

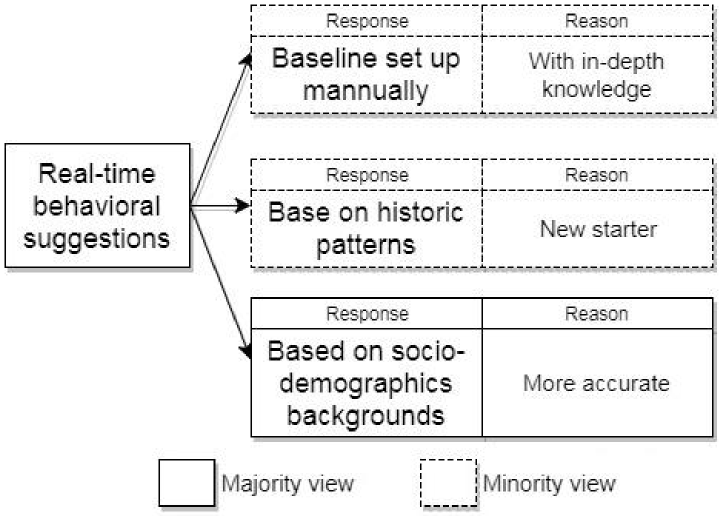


Figure 6. 21. Attitudes of application features: real-time behavioural suggestions (Source: Author).

To sum up, interviewees' attitudes towards different application features were developed in the form of diagrams. The majority views are presented in boxes with solid lines and minority views in boxes with dashed lines. According to Figure 6.21, the majority of the interviewees preferred to receive real-time behavioural suggestions based on their socio-demographic characteristics as this could help them to set up appropriate benchmarks instead of this being based on historic patterns. This would fundamentally change their long-term habitual actions. Taking household profiles into consideration for energy benchmarks is also reflected in the study of Laskari et al. (2016) on developing energy and water advice programmes for social housing occupants. However, 1 interviewee with in-depth knowledge on energy saving preferred both to set up the baseline manually and receive automatic advice based on socio-demographic characteristic. Another interviewee preferred to receive behavioural suggestions based on historic patterns only because it feels easier for new starters.

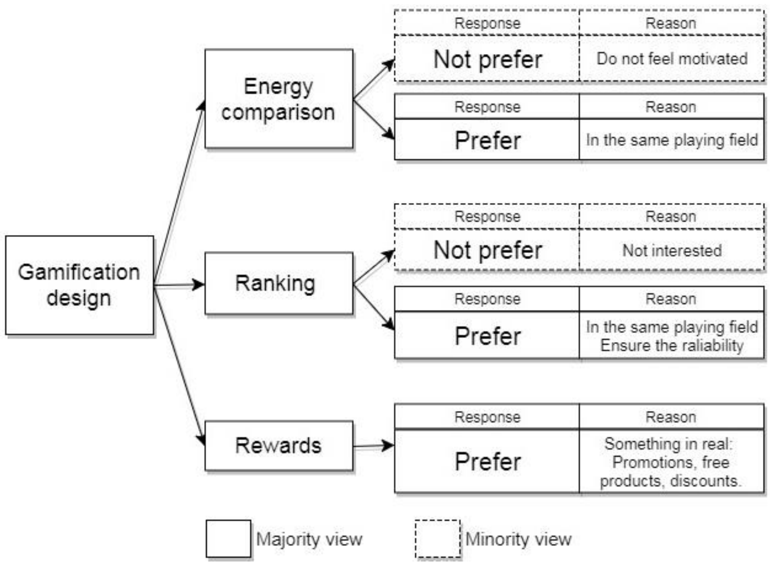


Figure 6. 22. Attitudes of application features: gamification design (Source: Author).

As shown in Figure 6.22, gamification design was asked in terms of 3 different application features. The majority of the interviewees preferred the energy comparison features as this would increase their motivations. However, candidates need to be living in the same conditions to be comparable. The majority of the interviewees also preferred the ranking system but reliability of the system needs to be ensured. Otherwise, interviewees may lose interest. Rewarding the winners with something real would definitely increase interviewees' motivation to save energy. This could include promotions, free products and discounts. The minority views on this topic were expressed by the older-aged interviewees who are not in the habit of using smart phones.

In addition, the majority of the interviewees preferred to have a social platform on their energy management application as they would like to influence each other with regards to energy savings. The interviewees were also asked if they would like to be advised of actions that save energy for free. The majority of the interviewees expressed that they were willing to save energy for financial reasons. They were also quite flexible about managing their time. On the other hand, some interviewees expressed that they could not do so as they have to cater for children's needs and consequently could not flexibly manage their time nor energy use.

6.3 Conclusion

Interviewees' current situations, in terms of smart meter installation, energy consumption behaviour and their attitudes towards energy application features, were thoroughly investigated during the focus group interview. There are a number of influential factors that limit the potential of energy savings in social housing estates. It is noted that the influential factors differ according to different age groups. Further, a number of identified themes helped further explain the data acquired from the questionnaire survey.

Although the majority of the interviewees (5) knew what a smart meter is, most of them (4) could not have it installed successfully. It was found that the social housing management did not provide sufficient support coupled with energy suppliers not being keen to upgrade meters for existing customers. Three interviewees did not know what a smart meter is and 1 of them had turned down an offer of a smart meter when she switched energy company. This implies that awareness of occupants needs to be raised in an effective communication method. Occupants need to be aware of the importance of smart meters and the process of installing them. In addition, energy companies are progressing relatively well in the private rent sector but not in social housing estates. Therefore, specific regulations need to be planned to address this issue.

There are a number of issues that limit the promotion of energy consumption behaviour. The influence of different barriers, according to different age groups with relevant profiles, has been concluded. The types of barriers preventing energy saving have been categorised according to the themes concluded from the interview transcription. The interviewees were also categorised by different age groups to explore corresponding barriers. The age groups were defined as 'young' (19-24 yrs), 'middle-aged' (25-54 yrs) and 'older-aged' (55 yrs or over). The 'family size' and 'whether children at home' of different age groups were also presented and discussed with respect to different barriers. The impact of each barrier on different age groups was presented with 'weak', 'moderate or 'strong' used according to particular issues mentioned by the interviewees.

According to the completed demographical form, there were 3 interviewees who live on their own. They were either '19-24' years old or '35-44' years old, 4 interviewees who were living with their children were all '25-54' years old. Another 2 interviewees who were living in large families (with children, parents and grandparents) were older-aged.

Age of ref. person	Family size	With children	Barriers to energy consumption behaviour						
			Lack of energy knowledge	Personal capability	Personal interest	Value for money	Work load	Occupancy pattern	Personal comfort
Young	Small	No	Weak	Weak	Weak	Strong	Moderate	Weak	Strong
Middle-aged	Small middle	Both	Moderate	Moderate	Moderate	Moderate	Strong	Strong	Weak
Older-aged	Large	Yes	Strong	Strong	Strong	Strong	Weak	Strong	Weak

Table 6. 4. Impact of energy barriers in different demographical groups (Source: Author).

As illustrated in Table 6.4, the impact of 'lack of energy knowledge', 'personal capability' and 'personal interest' on energy savings increases along with the increase in ages. Both of the interviewees who were '55 yrs or over' expressed that they did not understand their energy bills well. One of them also expressed that she does not know what a smart meter is. Further, part of the 'middle-aged' interviewees also did not know what a smart meter is. One 'middle-aged' interviewee turned down the offer of a smart meter provided by her energy supplier. But 'young' interviewees tend to have more energy knowledge on smart meters and energy saving actions. Furthermore, the 2 'older-aged' interviewees expressed that it is difficult to manage energy use and adopt certain energy saving actions, as both of them are from large families with complex occupancy and energy patterns. On the other hand, 1 of the ‘middle-aged’ interviewees had successfully installed smart meters by negotiating with social housing management and pushing the energy company. A ‘young’ interviewee was also able to change her energy supplier, upgrade the meter and effectively manage energy use. ‘Young’ and ‘middle-aged’ interviewees were also easier to learn new things. ‘Older-aged’ interviewees failed to change suppliers and install smart meters due to lack of communication. Another reason preventing ‘older-aged’ and ‘middle-aged’ members from saving energy was to ‘cater for children’s needs’. On the other hand, ‘young’ interviewees were good at dealing with complex issues. Moreover, ‘personal interest’ significantly impacts on ‘older-aged’ members and moderately impacts on ‘middle-aged’ occupants in energy saving, as interviewees from both age groups expressed that they did not adopt energy saving measures for that reason.

‘Value for money’ strongly influences ‘young’ and ‘older-aged’ interviewees but only moderately influences ‘middle-aged’ participants. The reason for this is that ‘middle-aged’ interviewees have relatively high annual incomes and wish to save time by paying more. On the other hand, ‘young’ and ‘older-aged’ interviewees with lower incomes are more willing to take energy saving actions. ‘Workload’ strongly impacts on ‘middle-aged’ interviewees and moderately impacts on ‘young’ interviewees but rarely impacts on ‘older-aged’ interviewees due to employment status. Some ‘middle-aged’ interviewees expressed that they even worked during the weekend and there was therefore not too much choice for them to manage energy use. Work patterns limit occupants’ abilities to effectively manage energy use. In addition, ‘occupancy patterns’ did not influence ‘young’ interviewees too much but strongly influenced the ‘middle-aged’ and ‘older-aged’ interviewees. The reason is that large families with children and grandparents always have different patterns. For example, the kitchen is used 3 times for a small family but 5 or 6 times for large families with different dietary habits. Therefore, their energy use pattern is longer than that of small families. Moreover, ‘personal comfort’ only strongly influences ‘young’ interviewees but not ‘middle-aged’ and ‘older-aged’ interviewees according to the feedback.

A large variation of energy usage determined by demographic characteristics was identified during the discussion. Most of the interviewees preferred to receive real-time behavioural suggestions by taking into consideration socio-demographic characteristics. Interviewees also preferred to communicate with each other regarding their achievements of energy savings on a social platform because it positively influences one other. Furthermore, interviewees liked the gamification design of the energy application which provides ranking and rewarding systems to them. However, concerns were raised that candidates would need to be on the same playing field to compete with each other. Financial rewards would also more effectively increase incentives to compete and save energy. Additionally, the use of energy management applications strongly depends on personal interests. It is not expected that those who may not be comfortable to use smart phones would be convinced to use energy management applications, unless they may access them through other smart technologies or gadgets.

Chapter 7. Discussion

7.1 Introduction

The research explores the reasons why retrofit programmes may not meet set targets by examining a number of factors that could potentially impact on home energy performance, which was conducted through a questionnaire survey and a focus group interview. It aims to develop viable interventions for reduced operational energy in the UK social housing sector and consequentially improve retrofit outcomes by focusing on both policy-making and occupants' engagement through smart technology. The factors examined in the research include occupants' energy consumption behaviour, socio-demographic characteristics, occupancy profiles and energy use patterns. A number of interesting findings are identified based on the data collected during both phases of the research. The data indicates that the way occupants operate their homes, their occupancy patterns and socio-demographic characteristics strongly influences home energy performance. Additionally, valuable feedback from the focus group interview helps to inform the proposal of energy management applications. This chapter will extend the discussion following the analysed quantitative and qualitative research findings to provide integrated research discussion.

Based on the findings of the questionnaire survey, correlations analysis was conducted to identify the potential relationship between home energy performance and a series of behavioural and socio-demographic characteristics. The household profiles of the data sample are compared with national statistics to evaluate the representativeness of the research findings. Then, the impact of occupants' socio-demographic characteristics on different aspects is thoroughly discussed. A discussion of occupants' energy consumption behaviours and occupancy patterns in terms of home energy performance follows. In addition, the participant's feedback from a focus group interview helped to further interpret the identified correlations from the questionnaire survey. The occupants' preferences for proposed application features are outlined. Moreover, behavioural intervention strategies, which are based on the research findings, are broadly discussed in 2 aspects: a number of suggestions for behavioural intervention are developed from the research findings to improve occupants' energy consumption behaviours through policy-making; the design guidelines for on energy management application, which aims to improve occupants' energy consumption behaviour through increased Computer-Human Interactions (CHI), are also demonstrated to improve the delivery of retrofit programmes through bottom-up approach.

7.2 Representativeness of the research

The case study is compared with the most recent annual social renter reports (DCLG, 2017) in the aspects of demographic and economic characteristics in order to cross-validate the data acquired from the case study. As the report only considers social renters, the 'owner occupied' respondents are omitted from the comparisons. There are currently 1,658,000 affordable houses owned by the local authority and housing association (DCLG, 2018). The research results may not only apply to the particular case study estates, but generate profound influences towards the UK's social housing sector.

Housing surveys comprising all types of homes are carried out annually by the DCLG covering a number of aspects, such as demographic and economic characteristics of renters, accommodation characteristics, rents and housing benefit, and types of lettings. The research first looks at the composition of the economic status of social housing renters. The most recent report (DCLG, 2017) indicated that during 2015-16, 42 per cent of social renters in the UK were working; 7 per cent of them were unemployed; 28 per cent of them were retired; and 22 per cent of them were in other conditions, such as student and/or unable to work. On the other hand, according to the research data sample, the total responded households comprise 48 per cent of social renters who are currently working; 14 per cent of them are unemployed; 11 per cent of them are retired; and 27 per cent come under other conditions. As a result, the percentage of 'working' occupants is higher than the national statistics and percentage of 'retired' occupants is lower than the national statistics. The reason for this is that the 'single elderly' was difficult to reach at Estate B either because they were either carer-needed or unable to complete the survey. This lead to a smaller proportion of 'retired' social renters compared to the proportion of other economic status groups.

Besides, the report (DCLG, 2018) indicates that during 2015-16, 42.3 per cent of the social housings were occupied by one occupant; 24.4 per cent of them were occupied by 2 occupants; 13.3 per cent of them were occupied by 3 occupants; 11.0 per cent of them were occupied by 4 occupants; 5.6 per cent of them were occupied by 5 occupants; and 3.4 per cent of them were occupied by 6 or more occupants. On the other hand, the case study indicates that 35.7 per cent of participating households were formed by one people; 16.7 per cent of them were occupied by 2 people; 3 people and 4 people; 9.5 per cent of them were occupied by 5 people; and 4.7 per cent of them were occupied by 6 or more people. According to the study, the proportion of households occupied by 1 or 2 persons in the case studies are less than the national social housing average but the proportion of households with more than 2 persons is higher than the national average. The difficulties of reaching single elderlies lead to less percentage of single occupied households. Notably, there are slightly more households occupied by 3 or 4 persons in the case study than the national average. In general, the distribution of family members in social housing in the case studies reflects the statistics indicated in the report (DCLG, 2017).

Another recent report (DCLG, 2017) indicated that 8.3 per cent of the social renters in the UK had been living in their properties for less than 1 year during 2015 to 2016, while 6 per cent of the participants had been living in their flats for less than 1 year in the case studies; 27.8 per cent of UK social renters had been living in their properties for 1 to 5 years in national statistics, while 20 per cent of the participants have the same length of residence in the case study; 20.1 per cent of overall UK social renters had been living in their properties for 5 to 10 years, while 18 per cent of participating households had been living in their flats for same length of residences in case study; 24.0 per cent of UK social renters had been living in their homes for 10 to 20 years, while 34 per cent of respondents had been living in their flats for the same length of residences in the case study; 19.9 per cent of UK social renters had been living in their homes for more than 20 years, while 22 per cent of respondents had been living in their flats for the same length of residence in case study. According to the results, both the national annual report and the case studies indicated that the number of social housing households increases in relation to the increase in the length of residency. Apart from this, the largest proportion comes from 'living years between 10 to 20'.

The national mean gross weekly income of social household reference person (and partner) is £349 from 2015 to 2016 (DCLG, 2017). However, the case study showed that the average mean gross weekly income was £293,64, which is lower than the national average. This indicates the poor financial conditions of social renters in society. On the other hand, the questionnaire indicates that the private renters earn £602 per week which is much higher than the former. The reason why weekly household income in the case studies is lower than the national average may be that participants were not keen to disclose their detailed financial circumstances during the survey and may tend to provide lower figures. The results of the data sample have been analysed against national demographical and economic figures for social renters in the UK. As a result, the case studies generally represent the conditions of social renters across the UK.

7.3 Energy performance of the case studies

The current condition of energy performance in both social housing estates was examined according to the information provided by respondents to the survey questionnaire. According to the reports on annual household energy bills (DBEIS, 2018), average annual bills in the UK domestic sector are £558 for electricity and £630 for gas regardless of the type of dwelling, which comprises £1,188 of average annual bill for both electricity and gas. According to the questionnaire survey, the households in both case studies spend less on their energy bills than the national average level, comprising 38 per cent of the data sample. The other 62 per cent of households in the case studies spend more on their energy bills than the national average level. Furthermore, 22 per cent of the data sample spent more than £2,000 on their annual bills. With a relatively low employment rate (50 per cent of full-time employed compared with 75.6 per cent of full-time employed in the national statistics (Gov.uk, 2018)) and income levels (54 per cent of the households earned less than £12,000 per annual compared with £27,200 for median household disposable income in 2017 (Office for National Statistics, 2018)), households in both social housing estates may be at risk of fuel poverty.

As previously stated, 54 per cent of respondents indicated that their annual incomes were 'below £12,000' and 26 per cent receive annual incomes of 'between £12,000 and £20,000'. By comparing this with their annual bills, 38 per cent of the households are identified as fuel poor. According to DBEIS (2018), the percentage of fuel poor properties in England's social housing sector is 16 per cent, which is lower than the case study. According to the correlation analysis, single elderly tends to consume less energy as they are more careful with energy use. As a number of single elderly could not be reached in the research, the annual energy bills and percentage of fuel poor properties could be slightly higher than in reality. Nevertheless, the energy condition of the case study estates with respect to occupants' socio-demographic characteristics is not optimistic. The energy efficiency needs to be fundamentally increased through retrofit measures and improved energy consumption behaviours.

As heating comprises the majority of home energy consumption in the UK (DBEIS, 2016), its current condition was primarily explored in the research. The significant energy contribution from heating is also confirmed by the research that household 'energy bills' are significantly correlated with a number of factors such as 'use of wall thermostat' (-0.372**, $p<0.01$) and 'temperature set up on the thermostat' (0.224*, $p<0.05$). The impact of 'number of occupants' and 'number of children' was found on both 'occupancy patterns in living room' (0.323**, $p<0.01$), (0.351**, $p<0.01$) and 'heating patterns in living room' (0.285*, $p<0.01$), (0.281*, $p<0.05$). Further, occupants' 'heating patterns in living room' were also found to be correlated with their 'occupancy patterns' (0.401**, $p<0.01$). Therefore, the household occupancy profile plays an important role in determining, and consequently influencing the heating consumption. The influence of socio-demographic characterises on 'occupancy patterns' and 'heating patterns' can also be indicated in the research as more occupants tend to spend fewer hours at home during weekdays but more during weekends, hence requiring more heating demand. This shows that employment status also influences occupants' 'occupancy patterns' and 'heating patterns'. In addition, the research indicated that 'income levels' also determine the use of a centralised wall thermostat' (0.336*, $p<0.05$).

In the case studies, occupants were found to be unfamiliar with the function of heating controls. Only 28 per cent of respondents claimed they have all types of heating controls in their homes including radiator valves, boiler and wall thermostats. It has been confirmed by the local authority that almost all of the flats are equipped with all heating controls. This indicates that occupants could not manage their heating use effectively by adjusting heating controls. Besides, the frequency that occupants use those heating controls is also very low. Only 36 per cent of respondents tend to use their boiler and wall thermostats at least once a day and 38 per cent of them tend to use their radiator valves at least once a day. Therefore, energy performance at the case study estates was found inefficient. It was also found that 22 per cent of respondents tend to set their wall thermostats to more than 22°C and 30 per cent of them did not know what temperature they set them to. Moreover, significant heating demands were also identified in the case studies as 26.1 per cent of households tend to spend '10-12 hrs' and 4.3 per cent of them 'more than 12 hrs' on heating in the living room during weekdays. Due to change of 'occupancy patterns', 21.7 per cent of the households tend to spend '10-12 hrs' and 13.1 per cent of them 'more than 12 hrs' on heating during weekends. Therefore, knowledge on how to properly operate heating systems needs to be communicated among occupants of similar housing conditions.

Smart meters are currently being widely adopted to help reduce home energy consumption through regulating occupants' energy consumption behaviour (Wilson et al., 2017; Basit et al., 2017). The roll-out of smart meters by energy companies across the UK's domestic sector by 2020 was set by the government (DBEIS, 2013). However, by the time of the case study, only 20 per cent of the respondents had had smart meters installed at their homes. The reason for the low implementation rate was explored in the focus group interview. It was found that collaboration between estate management and energy company is not efficient, which lead to a time-consuming process. Occupants' energy awareness and knowledge also need to be improved as some occupants were not aware that they have the right to upgrade their meters. One interviewee also turned down the offer of a smart meter from the energy company as she did not know what it was. Several researchers (Elsharkawy and Rutherford, 2018; Guerra-Santin, 2011; Yun and Steemers, 2011) also assert that occupants' energy awareness needs to be improved through education. Conversely, Hannon et al. (2013) such that energy companies have a conflict between making profits and facilitating smart meters. Therefore, new approaches need to be adopted to work together for deploying smart meters with more efficient energy management at the users' level.

A possible suggestion is that the government may work together with energy companies to implement smart meters for all households with the same energy supplier by using a 'blanket approach'. This would potentially facilitate the pace of smart meter installation and increase the efficiency of the process in terms of time and finance. It is also noted that the relatively poor energy consumption behaviour identified in the case studies is due to lack of understanding of the energy bills and lack of advice communicated, so occupants do not know what they need to do to reduce their bills. Occupants also expressed that they spend too much money on energy but felt difficult to understand their electricity and gas bills. Therefore, local authorities and communities need to work on improving occupants' energy knowledge and awareness through different approaches.

The factors that impact on home energy performance are discussed based on the findings of questionnaire survey and focus group interview in the following section. The impact of housing conditions is first discussed and followed by discussing the impact of occupants' socio-demographic characteristics.

7.4 Factors affecting home energy performance

7.4.1 Impact of housing conditions on energy performance

According to the correlation analysis, housing issues are significantly correlated with occupants' energy behaviour and consequently impact on home energy performance. Households with more 'damp' issues in homes tend to pay more on their 'quarterly electricity bills' (0.562*, $p<0.05$) and 'quarterly gas bills' (0.626**, $p<0.01$). Households with more 'condensation' (0.295*, $p<0.05$) and 'cold' (0.289*, $p<0.05$) also tend to pay more on 'quarterly electricity bills'. Occupants who have more 'hours extractor fans on' tend to have fewer problems of 'mould' (-0.545*, $p<0.05$) and 'condensation' (-0.528*, $p<0.05$) at their homes. Further, occupants who use a 'wall thermostat' less frequently tend to have more 'condensation' (-0.441**, $p<0.01$) problems at their homes. The reason is that the lack of using heating controls may result in higher indoor air temperature and energy over-consumption. Higher indoor air temperature may also increase the possibility of condensation in homes (You et al., 2017). This shows that housing issues will negatively impact on indoor climate and more heating is assumed to be required to achieve thermal comfort. This potentially increases energy consumption and simultaneously develops potential risks to human health (World Health Organization, 2009). In addition, as can be expected, higher energy bills increase the risk of fuel poverty (Shortt and Rugkasa, 2007).

The orientation of flats is also significantly correlated with home energy performance. Occupants who live in 'south-facing' flats tend to consume less energy than the ones who live in 'north-facing' flats because they receive more solar radiation. It is suggested that future retrofit measures need to be tailored according to different orientations of façades. The increasing temperature during the summer could lead to serious overheating problems as the case study tower blocks were designed according to older building regulations and standards. South-facing flats with improved insulation installed will absorb and retain more solar radiation than other orientations. According to the correlation analysis, north-facing flats with less solar radiation tend to have more indoor issues; 'cold' (0.436**, p<0.01) and 'mould' (0.241*, p<0.41). Therefore, in-depth retrofit measures need to be considered for orientations with less solar radiation access to ensure acceptable indoor thermal environments.

7.4.2 Impact of occupants' socio-demographic characteristics on energy performance

A number of findings were identified through the questionnaire survey and focus group interview. The findings show that occupants' socio-demographic characteristics and housing conditions significantly impact on home energy performance. According to the correlation analysis, occupant's 'quarterly electricity bills' are significantly or moderately correlated with 'tenancy status' (-0.356**, p<0.01), 'number of children (3-12 yrs)' (0.302**, p<0.01), 'number of adults (25-34)' (0.291*, p<0.05), 'number of retired person' (-0.247*, p<0.05), 'number of students' (0.255*, p<0.05), 'health condition' (0.239*, p<0.05) and 'total number of occupants' (0.306**, p<0.01). Their 'quarterly gas bills' are also significantly or moderately correlated with 'tenancy status' (-0.275*, p<0.05), 'member of teenagers (12-19 yrs)' (0.396**, p<0.01) and 'number of students' (0.244*, p<0.01). Additionally, it is found that the length of using thermostats is correlated with household 'income levels'.

With higher income levels, 'owner occupied' households tend to consume more energy than 'social renters' regarding the length of using a thermostat. Similar findings were also indicated by Guerra-Santin (2011) and Poortinga et al. (2003). Households with higher income levels tend to use large appliances more frequently and consequently consume more energy. This suggests that 'owner occupied' properties in social housing estates may have greater potential for energy saving.

The correlations between numbers of children, infants, teenagers, students, retired persons, the total number of occupants and energy consumption are also identified by several other researchers (Guerra-Santin, 2011; Nicholls and Strengers, 2017; Poortinga et al., 2003). The reason for this was investigated during the focus group interview in exploring the idea that different household profiles determine varying methods of operating homes. Therefore, a tailored approach needs to be adopted when delivering retrofit programmes by addressing different socio-demographic characteristics of households. For example, types of thermostat could be selectively adopted according to occupants' age groups and family sizes. The difference between programmable and manual thermostats is that programmable ones are used to predict heating demand whereas manual thermostats are used only when heating is actually needed (Guerra-Santin, 2011). According to the research findings, 'elderly' with relatively long occupancy patterns and poorer health conditions may require more heating consumption in their homes. It would be easier for them to use the manual thermostats instead of programmable ones so they can only heat rooms within the rooms and hours needed. It may also be difficult for 'elderly' to set up programmable thermostats properly. By contrast, programmable thermostats may be more suitable for 'younger' generations because they are capable of learning new knowledge but perhaps sometimes not keen to follow energy conservation actions. Therefore, it is easier for them to programme a thermostat in advance to avoid energy waste. For 'large families' and 'families with children', manual thermostats in each room may be more suitable to effectively reduce energy waste. However, only one thermostat in the living room of each flat is connected to the central heating system. So, the use of radiator valves becomes more important as these can switch on/off unused radiators.

In this section, the research findings indicate clear influences of housing and occupants' socio-demographic characteristics on energy consumption behaviour and consequently on home energy performance. The issues raised and possible suggestions for behavioural intervention strategies are discussed in the following sections.

7.5 Recommendations to engage occupants for improved retrofit outcome

7.5.1 Improving occupants' energy consumption behaviour through policy-making

Home energy performance is found to be influenced by household profiles and housing conditions. The reason for this is that occupants' energy consumption behaviours are determined by a number of social and technical issues. Investigations of how home energy performance is influenced by occupants' energy consumption behaviours in the case study were conducted. Possible suggestions and discussions of behavioural interventions through policy-making are presented.

7.5.1.1 Behavioural intervention through energy advice

Lack of energy awareness is identified as one of the predominant barriers for home energy efficiency in the case studies. Occupants were found to be unfamiliar with the use of heating controls, which could lead to inefficient energy consumption and waste. According to the questionnaire survey, although wall thermostat, boiler thermostat and radiator valves were all provided in each flat, only 28 per cent of the respondents knew they have them at their homes. The majority of the occupants were not aware of their important influence on energy reduction so they tended not to use the heating controls. Only a small proportion of respondents tended to use their boiler thermostats (36 per cent), wall thermostats (36 per cent) and radiator valves (38 per cent) at least once a day to adjust their heating systems during the winter. Thirty per cent of the respondents did not know what temperature was set up on their wall thermostat, which also indicates poor awareness on the home operation and energy efficiency. In addition, saving energy by adopting heating controls was also found the least preferred approach among occupants due to lack of relevant knowledge. With the information and advice provided, a number of interviewees expressed that they would like to follow those energy conservation actions during the focus group interview. Interviewees expressed that they were not aware of those approaches but wished to do so for financial savings.

A number of occupants (42 per cent) did not know the function of the trickle vent and consequently did not know if it is open or closed. They also tended to use extractor fans a lot less due to the noise produced. A remarkable 48 per cent of the respondents never used their extractor fans. These habits could potentially reduce indoor air quality and generate a series of housing problems including damp, mould, and condensation. To tackle this issue, occupants' energy awareness and effective methods of operating their homes need to be promoted through the effective provision of energy advice. Another aspect that also reflects occupants' poor energy knowledge is the understanding of utility bills. Only 48 per cent of the respondents felt it was very easy to understand their bills. The rest of respondents indicated certain levels of difficulties in knowing exactly the amount of energy used for the money spent. It is also indicated in the focus group interview that only one interviewee with a good understanding of his bills tried to change the energy tariff to reduce the cost. However, the majority of the interviewees were not able to decide whether the current energy suppliers or tariffs are the most suitable one for them. Four interviewees believed that they still have the potential to save energy but need the energy tariffs to be clarified.

Occupants' energy consumption behaviour could be potentially promoted by the provision of energy information and advice according to the correlation analysis. 'Energy advice' is significantly correlated with 'quarterly electricity bills' (0.340**, $p<0.01$) and 'quarterly gas bills' (0.352**, $p<0.01$). The reason for this is that occupants who received 'energy advice' tended to more effectively operate their homes in the following aspects: 'use of wall thermostat' (-0.257*, $p<0.05$), 'use of boiler thermostat' (-0.334*, $p<0.05$), 'try using less gas and electricity' (-0.339**, $p<0.01$), 'set hot water thermostat lower' (-0.326*, $p<0.05$), 'unplug unused equipment' (-0.401**, $p<0.01$), etc. Therefore, improving occupants' energy consumption behaviour through energy advice is vital for improving home energy performance. Gupta and Gregg (2016) state that communicating energy information and advice to occupants is significant for improving home energy performance. The importance of energy advice is also highlighted by several other researchers (Simpson et al., 2016; Guerra-Santin, 2011; Elsharkawy and Rutherford, 2018; Laskari et al., 2016). However, only 47 per cent of respondents had previously received energy advice, where 85 per cent of these received advice from energy suppliers. It is noted that the first phase of the retrofit has been completed at Estate A. According to 'Approved Document L1B: Conservation of fuel and power in existing dwellings', sufficient information regarding building service, operation and maintenance need to be provided to owners to ensure home energy efficiency (Gov.UK, 2016). Therefore, advice on how to properly use retrofitted measures should have been provided by installers. This indicates that statutory guidance has not been carried out properly (Elsharkawy and Rutherford, 2018). The method of delivering energy information and advice to the occupants of retrofitted dwellings should be improved.

7.5.1.2 Design of energy advice

Methods of providing effective energy advice have also been investigated. Instructions and advice need to be given following the handover of the project by 'face-to-face' interactions. Reports (GLA, 2010; GLA, 2016) indicate that lack of communication between retrofit installer and occupant leads to inefficient delivery of a project because occupants may not understand how to properly operate their retrofitted homes. It is also argued that installation conducted during occupancy may effectively get occupants engaged and consequently improve their energy consumption behaviour. The future design of retrofit programmes could encourage interaction between installer and occupants and make instructions for home operation a mandatory requirement after handover with several follow-ups. Apart from 'face-to-face' advice, there are many other ways to provide energy information to occupants such as interactive workshops, emails, posting informative brochures, TV campaigns, among other types of media. According to the focus group interview, a number of interviewees felt it was difficult to understand their bills or did not understand the functions of housing components. This shows the conventional instruction manuals need to be replaced with another format of advice. Elsharkawy and Rutherford (2018) also argue that user instruction manuals for newly retrofitted measures are limited and difficult to understand. The design of user manuals needs to be comprehensive but simple for people without prior knowledge. In addition, to address the generally poor understanding of energy bills, energy information and advice need to guide occupants on how to understand their bills with different tariffs. Policy makers could also work on simplifying and visualizing energy bills together with energy companies. Zhao et al. (2017) also state the provision of energy advice needs to be clear and intuitive.

The information included in energy advice also needs to be strategically designed. In the research, occupants were asked what are their most and least occurring energy saving actions. The most occurring energy saving actions of occupants include ‘turn off lights when leaving the room’, ‘close curtains at night to keep heat’, ‘turn off TV when leaving the living room’ and ‘try heating as few rooms as possible’. The least followed energy saving actions include ‘adjust wall and hot water thermostat’, ‘set hot water thermostat lower’, ‘go out avoid using heating’ and ‘use blankets instead of heating system’. This shows that occupants with a certain level of energy saving awareness tend to save energy by following conventional approaches. The approaches that require more energy conservation knowledge have not been implemented. Further, energy saving actions which may sacrifice personal comfort were not followed well by occupants. However, both personal comfort and energy efficiency could be achieved by the effective home operation. Therefore, use of heating systems, thermostats and ventilation systems need to be specifically addressed by policy makers to make occupants familiar with advanced energy saving approaches. Moreover, occupant’s perception of comfort could be wrong and consequently lead to more energy consumption and health risks. Hence, the information and advice could also focus on educating people about what is the healthiest indoor temperature and air quality.

However, it was also found that some occupants felt it was difficult to follow particular energy advice even when suggestions were provided during the interview. Barriers are considered significantly related to occupants’ socio-demographic characteristics such as the size of family, number of children and age group. Therefore, energy advice needs to be tailored for varying socio-demographic backgrounds (Abrahamse and Steg, 2009). Gupta (2010) also argues that information for occupants should focus on ‘need-to-know’ rather than ‘nice-to-have’. Based on this research, tailored energy advice could be targeted to different social-demographic groups in terms of age and family size.

According to the interview feedback, variances of behavioural barriers were demonstrated among ‘young’, ‘middle-aged’ and ‘older-aged’ members in terms of age group and ‘small’, ‘medium’ and ‘large’ in terms of family size. It is noted that families with children always bring more challenge to home energy performance due to the concerns of children’s thermal comfort and the use of entertainment appliances. Therefore, the energy advice needs to focus on effective use of heating systems, especially thermostats, and a set of tailored energy conservation suggestions for parents and children to ‘have fun together’ instead of ‘playing play station’ at homes. This issue is generally found in middle or large-sized families. Besides, ‘young’ occupants are more concerned about their personal comforts and may spend more money on that. However, ‘young’ occupants are more willing to follow energy saving actions for even small savings. So the design of energy advice for ‘young’ people needs to concentrate on highlighting financial returns and the balance between personal comfort and energy conservation. The definition of a good living environment needs to be clarified as the majority of the occupants’ may choose living conditions which may have a negative impact on their health such as overheating, or cause excessive mould, damp and condensation. ‘Middle-aged’ occupants expressed that their behavioural improvement is more impacted by high daily workload because it limits their occupancy patterns at home and consequently restricts the duration when energy is used. Therefore, it would be more effective to provide energy advice to ‘middle-aged’ occupants in learning how to effectively manage energy use in limited occupancy periods due to the heavy workload. It would also be necessary to educate ‘middle-aged’ occupants in how to choose the most suitable energy tariff so that they can pay ‘off-peak’ utility bills for their off-work time.

The requirement of ‘personal comfort’ was expressed by both ‘young’ and ‘middle-aged’ interviewees. The government’s motivation for retrofit is to reduce CO_2 emissions and increase energy efficiency. However, this may be different from the energy users’ side, who also expect improved comfort and living conditions within their homes (Neuhoff et al., 2011; Mlecnik et al., 2010). Beillan et al. (2011) state that energy efficiency is not an exclusive motivator for occupants. Therefore, other issues need to be addressed and reflected during the provision of energy advice to attract more attention.

‘Older-aged’ members are influenced by many barriers, especially those with ‘large families and children’. Their behavioural barriers include ‘lack of energy knowledge’, ‘personal capability’, ‘value for money’, ‘occupancy patterns’ and ‘lack of interest in using smart technology’. It is found that better results in promoting energy consumption behaviour to ‘older-aged’ members could be achieved by physical support rather than energy advice and information. It is highly likely that 'older-aged' occupants may tend to ignore mailed leaflets or brochures. Further, it seems difficult to educate 'older-aged' occupants with energy knowledge to increase their ability to handle complex instructions. It is also unrealistic to explain to 'older-aged' occupants how to effectively manage energy use when taking care of a large family for cooking and cleaning. Although the importance of smart technology has been recognised, a considerable proportion of 'older-aged' occupants are not interested in or not capable of using it. This may be another barrier stopping the implementation of smart meters and associated energy management applications. As a result, advanced metering and monitoring devices will be more suitable for those flats, especially the ones occupied by single elderly, because they do not require a high level of interactions but will feed data back to management level for additional assistance and support. Additionally, 'small families' tend to have fewer barriers than 'large families' or 'families with children' as they have more options when consuming energy. Thus, they tend to manage their energy use effectively.

In addition, another reason for energy over-consumption is occupants' habitual behaviour such as 'keep unused equipment plugged-in' and 'keep the lights on when leave the room'. The results show that 40 per cent of respondents have previously received energy advice from an energy company or local authority, however, some of them expressed that they still 'use more energy than they should'. The reasons expressed were that occupants were either 'too lazy' or 'my comfort is more important to me'. To promote changes in ingrained energy behaviours, consistent and long-term interactions through the provision of energy advice and information are required (Barthelmes et al., 2018).

This section provides recommendations towards the provision of energy advice according to the research findings. The delivery approach and design of energy advice are discussed. First, it is important to facilitate induction meetings and hands-on opportunities for occupants during the handover of a retrofit project under the instructions of installers with sufficient knowledge. It has been found that delivering energy information through conventional leaflets before the retrofit was not effective with the occupants in the case studies. The manual guide needs to be 'easy-to-understand' and straightforward. On the other hand, the energy advice through leaflets, brochures or other media also needs to be tailored according to occupants' socio-demographic characteristics. Second, occupants prefer adopting conventional energy saving approaches than the ones involving advanced techniques, such as the use of heating controls and ventilation systems. Those issues also need to be specifically addressed. Apart from the approaches discussed in this section, other possible strategies that could potentially promote occupants' improved energy consumption behaviour are discussed in the following section.

7.5.1.3 Other possible strategies for behavioural intervention

Community-based systematic approaches are also suggested in order to effectively promote occupants' energy behaviour and motivation (Owens and Driffill, 2008; Moloney et al., 2010). Occupants would expect to obtain clear information relating to the direct benefits from campaigns or workshops held by a local community or council than information provided in leaflets or brochures. The research findings indicate high energy demand, that is caused by inefficient energy consumption behaviours, in both case studies. Besides, the concerns for children were also raised a number of times in the interview. Occupants need to understand that improved insulation and energy consumption behaviour will improve the indoor environment and consequently reduce the children's illnesses and school absences (Howden-Chapman, 2011). Improved indoor environments also reduce the number of adults experiencing illness and number of hospital admissions (Howden-Chapman, 2011). A number of occupants also expressed their concerns about the safety of the community due to the invasion of strangers during the home visit at a preliminary stage of the research. The retrofit work could also improve safety for a community due to the improved building envelop and safer accesses. In terms of economics, the retrofit adds value to a property (Heffner and Campbell, 2011). Therefore, apart from direct financial benefits, community-based approaches could promote occupants' energy consumption behaviours and motivations in wider aspects such as social welfare, personal health and economic benefits.

Students' and 'teenagers' were found to be difficult to get to follow efficient energy behaviour as they need to consume more energy on entertainment or heating. Energy advice and information may not work effectively for them. However, their incentive for energy saving may be increased through different approaches. It is argued by Fell and Chiu (2014) that children could be motivated on energy saving by being given responsibilities. Parents could be incentivised to lead by role model as an effective approach for educating their children.

It was reflected in the focus group interview that by knowing one interviewee has successfully installed a smart meter, the rest of interviewees expressed their willingness to follow and inquired about the detailed process. The same interviewee who shared his method of effectively managing heating use also attracted great interest from others. It showed that occupants are also easy to be influenced by others. Therefore, demonstrations of neighbour's performance which belongs to 'Antecedent Strategy' could be one of the effective approaches (Abrahamse, 2007). Apart from highlighting the social, environmental and financial benefits to promote behavioural change, pro-environmental behavioural interventions are also considered an effective way to regulate occupants' energy consumption behaviour (Keizer and Schultz, 2012 and Guo et al., 2018), such as social norms. Different strategies of social norms could be employed to promote occupants' energy consumption behaviour. The commitment of energy saving and rewards by achieving the goals could be employed to increase occupants' incentives. Although similar aspects are found in the energy management applications for the same purpose through energy comparison and gamification design, occupants who are not familiar with interacting with smart technologies also need to be reached through different approaches.

Apart from demonstrations, commitment as another form of 'Antecedent Strategy' could also be adopted (Abrahamse, 2007). The percentage of energy reduction could be agreed at the beginning with household and energy consultant, who is invited to the workshop, as a goal to try and achieve. Workshops need to be held regularly to monitor the progress of energy saving and reward the achievers in economic and social rewards. It is believed that to reward occupants through public propaganda has a more positive influence on energy efficiency (Handgraaf et al, 2013). Then, energy use feedback or advice could be provided by the consultant in order to help households with fewer savings. Occupants could be encouraged to share their experiences on how to operate their homes and influence each other. However, the solution is based on long-term consistent community-based workshops and follow-ups. Following discussion of providing energy advice through the abovementioned approaches, energy management applications, which aims to optimise home operation and improve the retrofit delivery and outcomes, are discussed in the next section.

7.5.2 Improving occupants' energy consumption behaviour through smart technologies

Besides influencing occupants' energy consumption behaviours through policy-making, the possibility of utilizing smart technology to motivate occupants for energy saving was also explored in the focus group interview. Possible suggestions for new energy management applications are presented as another form of behavioural intervention to engage more occupants. The application is expected to help occupants achieve optimal home operation through the manual operation that is supported by real-time behavioural suggestions and automatic operation that helps particular socio-demographic background overcome unavoidable barriers. The behavioural policy may not be thoroughly implemented through the dissemination of energy knowledge and information. Therefore, an integrated approach with the adoption of proposed energy management application could potentially help to facilitate the delivery of the policy (Walker et al., 2014; Ahmadi-

Karvigh et al., 2017). The importance of the proposed application and how it is developed based on the research findings are presented in the following sections.

7.5.2.1 Energy management applications for optimizing home energy performance

The importance of IHDs and energy management applications for energy efficiency were thoroughly discussed in the previous chapters (Gellings, 2009; Rosenow and Galvin, 2013; Zhao et al., 2017; D'Oca et al., 2014). It is recognised that HCI could effectively improve occupants' energy consumption behaviour (DiSalvo et al., 2010). A number of selected application features were demonstrated during the focus group interview. The feasibilities of those features of motivating energy saving actions were examined and concluded through suggestions for future energy management applications.

By evaluating the method of providing real-time behavioural suggestions from several existing energy management applications (OVO Energy, 2017; efergy engage, 2017; Homeselfe, 2017), the concern is raised that providing behavioural suggestions based on historic energy patterns may not be effective as occupants tend to keep the same method of operating their homes in long-term. Therefore, interviewees were asked if they have noticed any changes on their bills in recent years. The majority of the interviewees claimed that they did not notice any change on their bills. This shows that occupants may follow the same methods of operating their homes and consequently paying similar bills. This is supported by Verplanken et al. (1997) and Verplanken and Wood (2006). Occupants' energy consumption behaviour is difficult to change. Elsharkawy and Rutherford (2018) also highlight that the inefficiency of retrofit delivery is caused by occupants' ingrained energy behaviour. The research finding also indicates that energy performance is significantly affected by household profiles. Hence, the real-time behavioural suggestions could be tailored by considering household profiles to suit different users. During the interview, interviewees were presented with different scenarios of real-time behavioural suggestions which include 'suggestions based on manual set-up', 'suggestions based on historic patterns' and 'suggestions based on socio-demographic characteristics'. Six interviewees preferred the third scenario as they all realised their energy use patterns are significantly influenced by a number of issues relating to their household profiles. Consideration of socio-demographic characteristics is also stated in many studies (Guerra-Santin, 2011; Kavousian et al., 2013; Conan, 1981). It is also found that provision of real-time suggestions only, may not achieve optimal home operation as occupants have a variety of unavoidable challenges. The rational steps of how the proposed energy management application responds to different users are discussed in the following section.

Petkov et al. (2011) state that setting energy users on a socialised platform will effectively increase their incentives as people tend to be influenced by social norms (European Environmental Agency, 2013). The feasibility of this was examined during the focus group interview. Most of the interviewees liked the idea as it helps to influence each other. Besides this, interviewees expressed that they are interested in energy comparison as it will increase their motivation. These findings are supported by Weiss et al. (2012) and McKechnie (2015). Moreover, the rewards will incentivise the users to save energy (Sintov et al, 2015; JouleBug, 2018), but the badges normally used were less attractive. People wished to have something real, such as free products, promotions or discounts. What also has not been addressed in previous studies is that the energy saving achievements need to be monitored and validated, otherwise this method may decrease occupants' motivation.

Most of the older-aged interviewees and several of the middle-aged interviewees expressed that they did not prefer to use smart technologies and/or smart phones. This is recognised to be one of the prevalent barriers to energy efficiency. For this reason, the energy management application employs building automation that is without user interactions, and consequently reduces the difficulties in reaching optimal energy performance. The other application features also need to be simplified with a user-friendly interface. In addition, the application also acts as a monitoring device to communicate poor energy behaviour back to the energy supplier or local authority to identify any issues and implement follow up interventions.

7.5.2.2 The significance of the energy management application

According to the research findings, energy consumption behaviour was also influenced by occupants' socio-demographic characteristics, both positively and negatively. Therefore, factors that may potentially lead to poor environmental management are summarised in order to form the framework of the energy management application. Related behaviour identified in the research case studies includes the use of heating systems, windows, ventilation systems and electrical appliances. Consequently, the different strategies of communication will be designed according to the opportunities and barriers identified in the focus group interview. It also helped to examine the feasibilities of certain innovative application features in the market from the users' points of view in an attempt to make them more effective. The application features examined include a socialised online platform, energy comparisons and gamification options to be used with neighbours sharing comparable living circumstances (concerning household make up, household type, size, etc.).

The proposed energy management application is expected to improve home energy performance by meeting a number of goals: it offers an approach to regulate occupants' energy consumption behaviour through consideration of household profiles rather than simply relying on historic energy patterns; it effectively engages energy users for energy saving interactions and increases their energy awareness through a number of features such as socialised platforms, energy comparison and gamification features; it strengthens the connections between energy users' level and energy management level by feeding back household energy consumption data to the energy companies to identify potential energy saving opportunities and avoid energy waste. The feedback mechanism also helps to identify improper energy use patterns and report to energy management level and local authorities to take further actions for health and safety purposes towards vulnerable people including older-aged occupants and people with disabilities.

Socio-demographic characteristics		Influencing variables		Groups	Statistics
No. of occupants		Occupancy	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.323**, p<0.01
			Weekends	0, 1, 2, 3,4 … 24 hrs	0.280*, p<0.05
		Heating system	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.285*, p<0.05
			Try heat less rooms	Never … Always	-0.314*, p<0.05
		Wall thermostat	Frequency	Never … Always	-0.288*, p<0.05
			Temperature	<18, 18, 19 … >24 ° C	0.325*, p<0.05
		Extractor fan	Frequency	Never … Always	-0.368**, p<0.01
		Turn off TV	Frequency	Never … Always	-0.337*, p<0.05
		Avoid peak time	Frequency	Never … Always	-0.308**, p<0.01
Age groups	Infants, Children, Teenagers (0-18yrs)	Occupancy	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.351**, p<0.01
		Heating system	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.301*, p<0.05
			Weekends	0, 1, 2, 3,4 … 24 hrs	0.372**, p<0.01
			Try heat less rooms	Never … Always	-0.314*, p<0.05
		Wall thermostat	Temperature	<18, 18, 19 … >24 ° C	0.364**, p<0.01
		Extractor fan	Frequency	Never … Always	-0.312*, p<0.05
	Middle-aged (19-54yrs)	Heating system	Adjust as required	Never … Always	-0.297*, p<0.05
		Wall thermostat	Temperature	<18, 18, 19 … >24 ° C	0.308*, p<0.05
		Extractor fan	Frequency	Never … Always	-0.349*, p<0.05
		Turn off TV	Frequency	Never … Always	-0.290*, p<0.05
		Avoid peak time	Frequency	Never … Always	-0.297*, p<0.05
	Older-aged (55yrs or over)	Wall thermostat	Frequency	Never … Always	-0.291*, p<0.05
		Boiler thermostat	Frequency	Never … Always	-0.373*, p<0.05
Employment status	Full-time employed	Heating system	Adjust as required	Never … Always	-0.285*, p<0.05
		Avoid peak time	Frequency	Never … Always	-0.388**, p<0.01
	Unemployed	Heating system	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.309*, p<0.05
		Heating system	Living room	0, 1, 2, 3,4 … 24 hrs	0.379*, p<0.05
			Main bedroom	0, 1, 2, 3,4 … 24 hrs	0.309*, p<0.05

Income levels		Try heat less rooms	Never … Always	-0.310*, p<0.05
	Thermostat	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.336*, p<0.05
	Washing machine	Frequency	Never … Always	-0.349*, p<0.05
Health condition	Heating system	Weekdays	0, 1, 2, 3,4 … 24 hrs	0.275*, p<0.05
	Wall thermostat	Temperature	<18, 18, 19 … >24 ° C	0.304*, p<0.05
	Windows	Frequency	Never … Always	-0.288*, p<0.05

Table 7. 1. Impact of socio-demographic characteristics on energy consumption behaviour (Source: Author)

As illustrated in Table 7.1, family size is one of the most important factors that determines how occupants operate their homes. Larger families tend to have longer occupancy and heating patterns at home. With complex compositions, larger families also could not manage energy use effectively in the aspects of 'try heat less rooms', 'avoid using energy at peak time' and 'turn off TV when leave the room'. Larger families also tend to use extractor fans less frequently and set wall thermostats at relatively higher temperature. Further, age groups are found to be one of the most significant socio-demographic variables for energy consumption. Families with more infants, children and teenagers tend to have longer occupancy patterns, more heating requirements, higher heating temperature and lower use of extractor fans. Families with more adults tend to have higher heating temperature and lower use of extractor fans. Adults are also found to not follow energy saving actions well such as 'adjust heaters as required', 'turn off TV when leaving the room' and 'avoid using energy at peak time'. Families with more older-aged occupants tend to use wall and boiler thermostats less frequently. Older-aged occupants feel it may be more difficult to understand utility bills but tend to follow traditional energy saving actions such as 'try use less electricity' and 'try heat less rooms'. Additionally, employment status determines occupants' occupancy pattern and consequently influences a number of behavioural variables. Full-time employed family members tend to 'adjust heating as required' and 'avoid using energy at peak time' less frequently. Unemployed family members tend to have longer occupancy patterns. Retired family members tend to 'turn off lights when room is not occupied' more frequently. Furthermore, households with higher income levels tend to have longer heating patterns and tend to follow energy saving actions less frequently, such as 'try heat less rooms' and 'wash cloth with shorter cycle'. Occupants with poorer health conditions tend to open windows less frequently and have longer heating patterns with higher temperature.

The factors that generate poor home environmental management in the aspects of household profiles were refined based on the comprehensive research findings and concluded in this section. The aim is to develop a framework for gathering socio-demographic datasets from occupants and identify how that correlates with the current and recommended operation of their homes. The information could be translated into a parametric processor for building environmental control via an energy management application. This may help improve home operation through either real-time behavioural suggestions or automatic controls according to the barriers identified by different socio-demographics. A strategy of interactions based on the literature review and interview findings is suggested in the following section.

7.5.2.3 Strategy of interaction

According to the focus group interview, behavioural suggestions may not be fully adopted due to a variety of barriers for different socio-demographic backgrounds. The unavoidable barriers include 'personal abilities' for 'older-aged' occupants and occupants in 'poor health condition', 'complicated occupancy patterns' for 'larger families', 'more heating requirement' for the 'families with children' and 'limited occupancy patterns' for full-time employed occupants. The functions of proposed energy management application are split into two parts to meet the requirements of different user profiles. The building automation is the automatic and centralised control of building systems, such as heating, ventilation, electrical appliances and other systems. To enable automatic operation, the identified systems and appliances are controlled through a building management system by a terminal unit controller used to control electrical appliances, ventilation, windows and heating systems. Further, programmable thermostats are equipped to automatically programme, store and repeat multiple daily settings and improve heating efficiency for users who are not able to frequently use their thermostats. On the other hand, manual operation is driven by real-time behavioural suggestions to remind users about efficient energy behaviours. Users will be able to switch between the automatic and manual operation to meet specific requirements. Evidence-based suggestions are provided for policy makers in order to design effective behavioural intervention strategies. As a result, the proposal of the energy management application is used to facilitate the implementation of policy by influencing energy users.

Automatic mode

According to the focus group interview, occupants, who are older-age, do not have sufficient energy knowledge, hence they face difficulties to appreciate their utility bills and advanced energy saving approaches by using thermostats or avoiding using energy at peak times. In addition, all of the older interviewees were not interested in engaging with energy management applications. Similar findings are also indicated from the correlation analysis. Energy advice may also not be effective as older occupants could easily ignore it. Therefore, automatic building control could be better for them, especially older occupants in a small size family without younger family members to provide support. Disabled members and members in poor health condition, with higher heat demand and fewer use of ventilation systems, are also found not to operate their homes effectively in the research (Yun and Steemers, 2011; Abrahamse and Steg, 2009). Mendes et al (2015) argue that smart control and communication technology need to be adopted, especially for elderly and disabled occupants, to optimize energy performance and monitor their health conditions. Ghazal and Al-Khatib (2015) also state that a comprehensive building automation, comprising appliances, lighting systems, HVAC systems, humidity and temperature sensors and security systems, is necessary for elderly and disabled occupants with locomotion difficulties. Similar points of review are also held by Bhoyar (2015), and Asadullah and Ullah (2017).

In the case studies, the use of wall thermostat and boiler thermostat, that are identified as key behaviour for older-aged occupants, disabled occupants, and people in poor health condition, generates poor management. Therefore, programmable thermostats could be equipped in their flats to automatically switch on a heating system and adjust the temperature according to a user's occupancy pattern. Occupants with higher requirement of thermal comfort and longer heating patterns could benefit from the effective use of heating controls (Guerra-Santin, 2011). Besides, high heating consumption is indicated among unemployed family members due to high occupancy patterns. Yohanis et al (2008) indicate that unemployed and old occupants who stay at home during the day time could generate extra but small energy consumption due to off-peak hours. Automatic operation of heating systems with programmable thermostats could be also applied to old, unemployed family members. Additionally, flats occupied by older and disabled occupants may not have sufficient air infiltration with long occupancy patterns. In order to address those issues, air quality meters and sensors need to be equipped inside and outside the flats to detect internal air quality, such as CO_2 level and moisture, and external temperature, wind speed and directions for proper equipment response. Therefore, the advanced energy management system could automatically open trickle vents or extractor fans to have fresh air and adjust indoor temperature through the control of heating systems in the flats.

The research also finds that the full-time employed adult family members could not effectively manage the use of heating systems and tend to set higher temperatures on thermostats due to high workload. The obvious differences regarding occupancy patterns of full-time employed occupants are also indicated in several studies (Aerts et al, 2013; Lopes et al., 2012). With limited time at home, interviewees tend to set a higher temperature to get warm quickly during the winter, which could lead to energy over-consumption. To address this issue, automatic mode could be adopted for heating control through programmable thermostats, which allow homes to be heated prior to arrival with lower and consistent temperatures. The thermostat is programmed based on the correlations identified in the case study with consideration of different socio-demographic characteristic. Therefore, it avoids energy waste from a higher temperature which is set by occupants without in-depth knowledge.

Interviewees from large families also felt it difficult to manage their energy use effectively due to different requirements of heating, cooking and appliances use. A mass of energy waste may be generated during the process. For example, one family member may leave the TV on when leaving a room, anticipating somebody else will use it. It also does not make sense to turn off the heater when leaving a room because somebody else will enter the room soon. Guerra-Santin (2011) also states that large families require intensive use of appliances and space, thus consuming more energy. Similar findings are also indicated in several studies (Yun and Steemers, 2011; Abrahamse and Steg, 2009; Elsharkawy and Rutherford, 2018). Due to the difficulties of addressing behavioural issue to each family member with different ages, employment status and health conditions, heating systems could be controlled automatically by identifying occupancy of each room from a sensor to avoid waste. Programmable thermostats could also be equipped to adjust the heating temperature automatically. Interviewees with children also expressed difficulties in managing their energy use in the aspects of heating and ventilation. It is shown in the correlation analysis that families with more children tend to have longer heating patterns with less use of thermostats and ventilation systems. To address those issues, thermostats need to be automatically turned on for heating efficiency with reasonable temperatures as parents always tend to set higher temperatures for children. Extractor fans and trickle vents also need to be automatically controlled to allow reasonable air infiltration.

Moreover, a variety of household profiles fail to effectively manage their energy use within off-peak times, such as middle-aged and older-aged occupants, large families, and full-time employed members. Therefore, monitoring energy supply prices and time of day related to peak charging should also be a factor to properly automate with as many parameters as possible. The section has explained how far building automation goes for different household profiles according to the research findings. On the other hand, the manual operation will be adopted for the users who are able to follow the behavioural suggestions. The details of manual operations are discussed in the following section.

Manual operation

Manual operation is supported by real-time behavioural suggestions from the energy management application. It applies to part of the building appliances and systems for the users who do not have unavoidable barriers. Tailored suggestions are provided according to the poor energy consumption behaviour identified with different socio-demographic characteristics. Besides, the decision made in the application is also based on the indoor and outdoor monitoring regarding air quality, wind speed and directions. The real-time behavioural suggestions not only help optimize home operation but also increase occupants' energy awareness and potentially increase the uptake of the future retrofit programme.

Apart from automatic operation of heating systems for adults, poor behaviour on ventilation systems, windows and electrical appliances could be addressed with real-time behavioural suggestions and achieved by manual operation. Adults tend to use extractor fans less frequently and consume excessive energy on electrical appliances such as TVs. By capturing indoor air quality and use of ventilation systems, adult users could be alerted to turn on extractor fans or trickle vents for the better indoor climate. They could also be alerted to turn off TVs or other electrical appliances for entertainment when they have left a room. Besides, families with more children or unwell persons tend to use ventilation systems less frequently. However, it is not possible to force them to open windows through automatic mode as it may lead to negative impact on their health. Therefore, real-time suggestions could be given instead of automatic controls for users' decisions. Moreover, the research identified that households with more unemployed members tended to consume more heating due to longer occupancy patterns. If the unemployed members are young or adult, real-time behavioural suggestions could be adopted to help them effectively manage energy usage and simultaneously improve their energy awareness.

In addition, the older-aged members proved to be difficult to follow advanced energy saving technologies but were comfortable with conventional approaches. The findings indicate that single families with older occupants tend to spend less on electricity and gas bills. Waste of electricity is not indicated among older occupants as they tend to only use electrical appliances when it is necessary. The positive impact of energy conservation by the elderly is also indicated by Kavousian et al. (2013) and Guerra-Santin (2011). Therefore, automatic control is not necessary for those components due to high awareness of energy saving. Alternatively, real-time suggestions on electrical appliances could be adopted for 'older-aged' occupants according to their energy consumption and occupancy.

A number of energy saving actions could also be suggested by energy management applications according to different household profiles. Adults and large families could not effectively manage their energy use due to limited or complex occupancy patterns. Similarly, older occupants wish to save energy but have limited knowledge of bills. Therefore, it is important to make them aware of peak time and off-peak time. Alerts could be adopted to remind of upcoming peak hours and encourage users to consume energy during off-peak times. Further, by capturing users' occupancy and heating patterns while considering their health conditions, a number of suggestions could be adopted by energy management applications to save energy for free such as 'go out to avoid heating' and 'put on a jumper instead of heating'.

Household profile	**Energy management application modes**	
	Automatic operation	Manual operation
Single older-aged	Heating system, extractor fans and trickle vents	Entertainment appliances and windows
Old unemployed	Heating system, extractor fans and trickle vents	Entertainment appliances and windows
Young/adult		Heating system, ventilation system, windows and entertainment appliances
Adult full-time employed	Heating system	Ventilation system, windows and electrical appliances
Small family with children	Heating system, extractor fans and trickle vents	Windows and entertainment appliances
Poor health/ carer-needed	Heating system, extractor fans and trickle vents	Windows and entertainment appliances
Large family	Heating system, entertainment appliances	Ventilation system and windows

Table 7. 2. Recommended application options in different household profiles (Source: Author)

The importance of home energy management and automatic controls are identified by several researchers (Walker et al., 2014; Ahmadi-Karvigh et al., 2017; Herrero et al., 2018). A full building automation strategy is always recommended (Ghazal and Al-Khatib, 2015; Bhoyar, 2015; Asadullah and Ullah, 2017). In addition, Wimsatt (2006) developed an application framework to tailor the scope of building automation according to the abilities of different socio-demographic groups. Adult users can access all building automation elements, while child users can only access entertainment appliances. However, all of the strategies do not focus on educating users and promote their energy behaviour through interventions, which is the essential of this research. The manual operation with real-time behavioural suggestions in the proposed application applies to the home appliances and systems that are manageable for different household profiles. Recommended options for both modes, through energy management applications, are concluded in Table 7.2. The choices of heating system, ventilation system and entertainment appliances are based on the barriers identified during the focus group interview.

As a result, a certain level of automatic operation is needed for all types of household profiles, except families with young or unemployed adult members only as they would be expected to follow real-time behavioural suggestions easily without any unavoidable barriers. Conversely, single elderly families, families with old unemployed members, children, poor health or carer-needed members could adopt an automatic operation strategy for their heating system, extractor fans and trickle vents for effective heating use while retaining a good level of indoor climate. However, the use of windows, which could generate a negative impact, and use of electrical appliances could be promoted through real-time suggestions. Further, large families with complex energy use patterns could adopt an automatic operation strategy for the heating system and using entertainment appliances for effective energy use. Use of ventilation systems could be promoted by real-time suggestions, adopted according to personal preferences. Additionally, families with full-time employed adults may fail to use heating systems effectively due to limited occupancy patterns. Therefore, an automatic strategy may be applicable to the use of heating systems. A manual operation strategy may be applicable to ventilation systems and electrical appliances.

7.5.2.4 Rationale of the application

To clearly explain how the proposed energy management application works through interactions with its users, a flow chart of logical operation steps is demonstrated in the Figure 7.1.

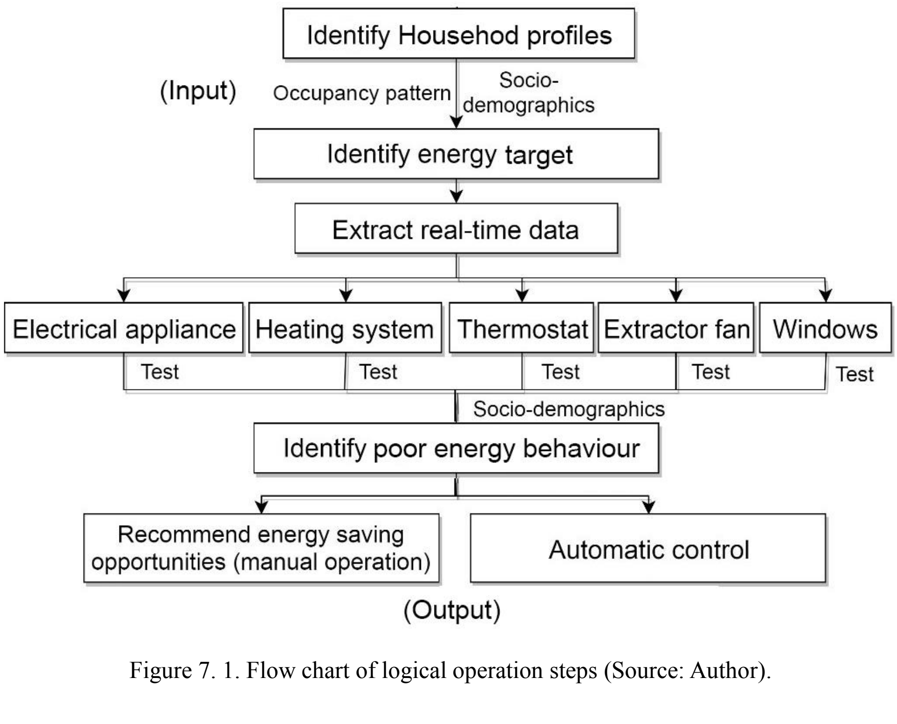


Figure 7. 1. Flow chart of logical operation steps (Source: Author).

The proposed application starts with the collection of contextual information, including users' socio-demographic characteristics and occupancy patterns, in order to set household energy targets and identify the systems and appliances involved in manual and automatic operation. To form a comprehensive energy management system, the application is connected with a number of data loggers, sensors, air quality monitors and wind meters to gather the current environmental conditions and usage patterns of the systems and appliances according to the contextual information entered. Consequently, those current usage patterns are examined by the found correlations in order to identify poor energy consumption behaviour. In order to address the identified poor actions, behavioural advice and alerts or automatic control are employed to optimise home operation.

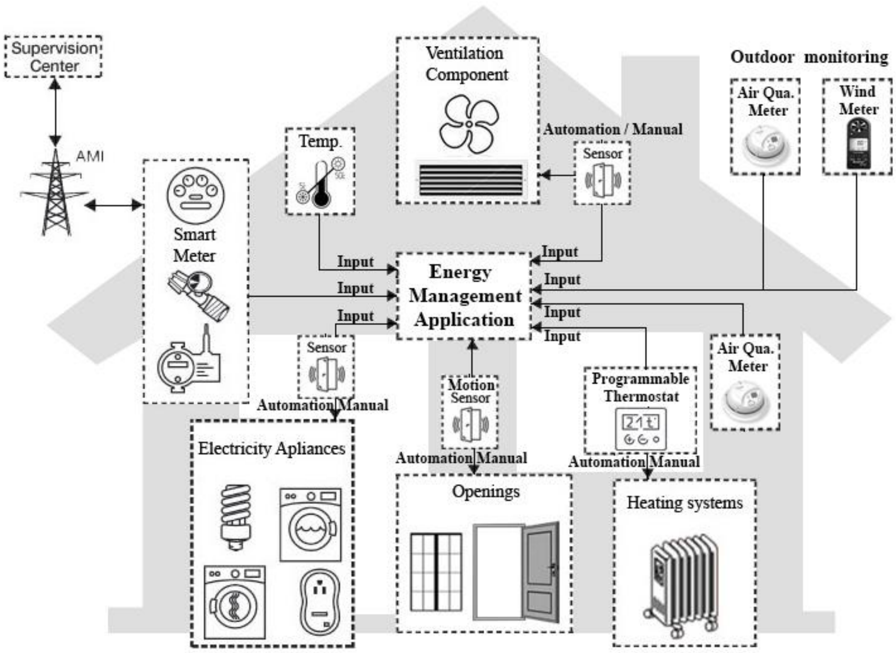


Figure 7. 2. Role of application in the home energy management system (Adapted from Bertrand, 2012).

Figure 7.2 demonstrates the role of the proposed energy management application in the home energy management system. The proposed energy management application needs to connect to the smart meters to obtain the real-time energy usage and details of the energy tariffs. In order to detect a variety of energy consumption behaviour relating to the use of electricity appliances, heating systems, openings and ventilation systems, sensors and thermostats were connected to the appliances and building systems to acquire real-time data. Additionally, air quality and wind meters are equipped to performance indoor and outdoor monitoring where the energy efficiency options are based on. Next, occupants are alerted to improve their home operation manually or informed to change the setting to the automatic operational mode from the application on their smart phones or other types of smart gadgets.

7.5.2.5 Suggested application features

Real-time behavioural suggestions

A number of studies (European Environmental Agency, 2013; Owens and Driffill, 2008) indicated that failure of behavioural intervention is due to lack of follow-up, clear and continual feedback. By receiving real-time behavioural alerts from the energy management application, occupants are able to improve the way they operate the homes. Although a number of applications have incorporated real-time alerts, they focus on reducing energy consumption without proper consideration of contextual background. Based on the correlation analysis, the proposed application is expected to identify the proper usage of heating systems, ventilation systems, and electrical appliances according to the users' socio-demographic characteristics. Tailored suggestions will 'pop-up' through the users' smart phones or other kinds of smart gadgets if use patterns are detected to be above the set benchmark. As the research focuses on social housing estates, the building characteristics will be pre-set according to the construction details to simplify the process. A number of application features are proposed in the following sections according to occupants' feedback during the interview.

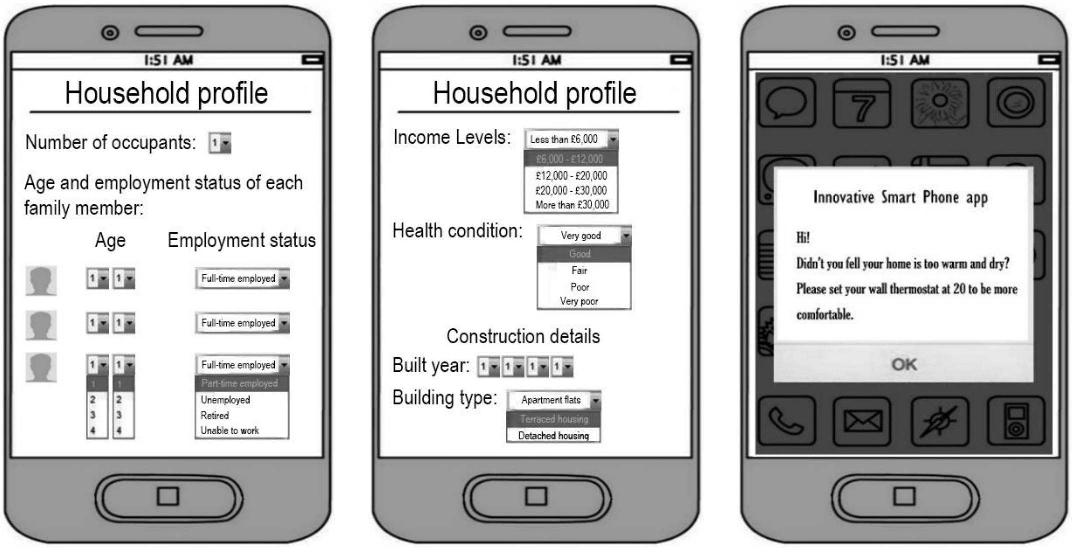


Figure 7. 3. Provisional features of 'real-time' behavioural suggestions (Source: Author).

Community energy forum

It has been asserted that social norms have significant impact on influencing occupants' energy consumption behaviour (European Environmental Agency, 2013; Bamberg and Moser, 2007; Keizer and Schultz, 2012). This also explains that 'comparing energy benchmarks' plays an important role in changing occupants' behaviour. The proposed energy forum will provide a 'public platform' for application users to publish their energy saving achievement and share their energy saving experiences. In considering privacy issues, the percentage of energy savings, which is valued as energy saving achievement, is used instead of actual energy usage. Therefore, occupants are expected to learn from the best practices with stimulated incentives and achieve more energy savings. Besides, gamification elements will be implemented for the same purposes, such as the badges and real rewards to the users with the biggest achievement. Energy saving achievements of similar housing characteristics and household profiles are ranked and announced within the community. Moreover, older-aged members are found to not engage well with smart technology at this moment. Offering a gaming version may appeal to some residents, especially younger members of the community, who will grow up to become tech-literate occupants. Therefore, appealing to those younger occupants would help break the tech-avoidance issues in long-term consideration.

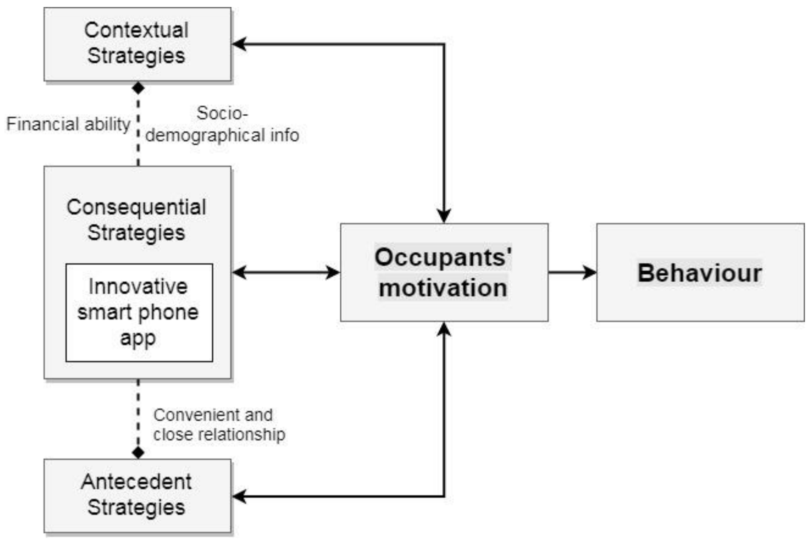


Figure 7. 4. Role of proposed application in facilitating behavioural interventions (Adapted from Han et al., 2013).

Figure 7.4 demonstrates how the proposed application may influence and facilitate behavioural intervention strategies. The adoption of energy management application belongs to 'Consequential Strategies' as it provides energy feedback after evaluation and awards the best practice (see Table 3.1). Besides, the access of 'community forum' in the application is one of the most important mechanisms of 'Antecedent Strategies' to provide energy saving information and organise workshops and campaigns (Abrahamse, 2007; Han et al., 2013). Staff or volunteers from the local community who are responsible for liaising with occupants will also be invited to the forum for broadcasting information about future events and campaigns. Besides, users can report technical problems and ask questions on the platform for a prompt response. The instant communication and feedback not only promote occupants' energy consumption behaviour, but also help policy makers clearly understand particular conditions of energy users for more effective policy design, which also plays an important role in facilitating the ‘Structural Strategies’.

Figure 7. 5. Provisional features of the energy forum (Source: Author).

According to Figure 7.5, application users within the same community are able to discuss problems and share their experiences. The reason for this is that the provision of an environment where people explore those changes alongside 'connected' others is important. (European Environmental Agency, 2013; Moloney et al., 2010; Owens and Driffill, 2008). Application users will be able to ask questions and seek help from the forum. Neighbours who are under the same conditions may provide the most effective solutions. Additionally, representatives of the community will be included in the forum to update news and facilitate energy conservation. The community as the closest public body are required by the government to organise workshops and showcases to increase occupants’ awareness. Furthermore, occupants can contact relevant parties for any specific queries. This process is also important as it reflects specific problems which need to be taken into consideration of the design of future retrofit projects.

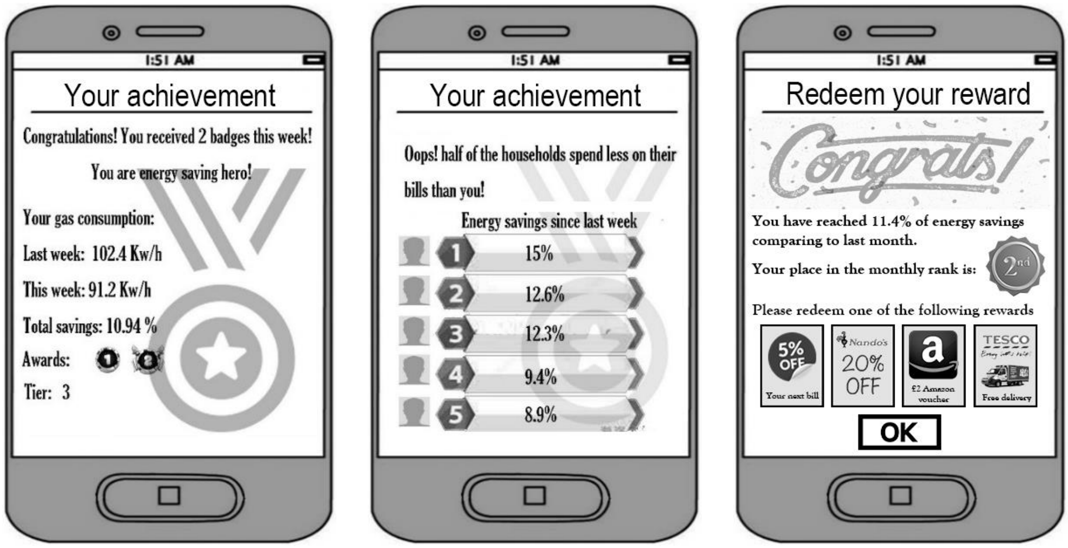


Figure 7. 6. Provisional features of the energy forum (Source: Author).

Gamification design is found to be one of the most popular elements and suggested to be incorporated into the proposed energy management application. Occupants will be able to compete with other users and rank energy saving achievements in the forum. Energy saving comparisons are proven effective in a number of case studies (Keizer and Schultz, 2012 and Guo et al., 2018). Badges, discounts, free products or other types of rewards will be awarded to occupants according to the feedback of focus group interview (see Figure 7.6).

7.6 Conclusion

This chapter broadly discusses the key issues identified during the research with a set of possible recommendations provided to policy makers. Energy conditions for the case study were first discussed with respect to income levels and energy bills of households. This indicated that the energy conditions of both social housing estates are not optimistic and a large proportion of the flats are at risk of fuel poverty. With relatively low income levels, more than half of the households pay energy bills above the national average. Further, the implementation of smart meters needs to speed up in the case study due to the low implementation rate. Practical issues preventing roll-out of smart meters were discussed during the focus group interview. It is suggested that the government could make a mandatory requirement of smart meter installation in the social housing sector instead of seeking permission from each household. A 'blanket approach' could be made to implement smart meters to all social housing flats with the same energy supplier in a community. Following this, the impact of housing condition and household profile on home energy performance was discussed. The impact of poor housing conditions and flat orientations on home energy performance and energy consumption behaviour have been presented. The poor living conditions negatively impact on indoor climate and consequently increase the possibilities of health risks. The poorer indoor climate also causes more heating demand. Moreover, flat orientations significantly impact on indoor climate due to different levels of solar radiation received: ‘north-facing’ flats with less solar radiation may also increase the risks of ‘cold’ and ‘mould’ problems and discourage home ventilation.

At the next stage, the impact of occupants’ energy consumption behaviour on home energy performance with respect to their socio-demographic characteristics was broadly discussed. This shows that household profiles determine occupants’ occupancy and energy use patterns, and consequently impact on energy consumption. Then, the importance of energy advice was raised with a set of tailored recommendations, targeting different household profiles. Recommendations are provided for policy makers and designers to increase efficiency of retrofit programmes through promoting occupants’ energy consumption behaviour. Financial returns provided from energy advice and information will be more effective for ‘young people’ and ‘older-aged’ occupants but less effective for ‘middle-aged’ occupants as they have to preferentially focus on their work and children. Similar to ‘middle-aged’ employed occupants, parents or grandparents in a ‘large family’ with ‘children’ also felt it difficult to promote their energy consumption behaviour due to limited energy use patterns. Energy advice needs to concentrate on the understanding of different energy tariffs and how to effectively balance energy saving and complicated energy patterns. Instead of energy advice in the format of leaflet or brochures, physical support is more suitable for ‘older-aged’ occupants due to ‘lack of energy knowledge’ and ‘personal capability’. Other advice also includes interactions with occupants during installation of retrofit measures and community-based education with systematic approaches.

The research not only focuses on behavioural intervention at policy makers’ level but also on directly engaging more energy end users through smart technology. This chapter contained discussion of different application features on engaging occupants and improving home energy performance based on findings of the focus group interview. A proposal of energy management application is provided to achieve optimal home operation and increase occupants’ incentives for energy saving. As big variances in home energy performance and energy consumption behaviour were identified among different household profiles in the case study, ‘real-time’ behavioural suggestions should be provided according to the particular socio-demographic characteristics of application users. Building automatic operation is also implemented in particular conditions instead of manual home operation when users have unavoidable barriers to achieve energy efficiency. Application users should also be able to communicate and compete with each other on energy saving achievements on a socialised platform. A rewards system is also suggested to motivate occupants.

This chapter presented the development of a set of recommendations to reduce home operational energy post retrofit which strengthen the government's top-down retrofit approach by promoting occupants' energy consumption behaviours. The suggested approaches of behavioural intervention vary from tailored energy advice, education and physical support to the informative proposal of an energy management application. The next chapter presents a review of the research in the sequence of research aims, methodology, data collection, data analysis and how this research contributes to the current knowledge. Research limitations and recommendations for future students are also discussed.

Chapter 8. Conclusion and recommendations

8.1 Introduction

The research focuses on improving home energy efficiency in the context of the 2 social housing estates in London. Comprehensive literature and report reviews were undertaken in order to gain a better understanding of the current situation in the UK's retrofit and identify potential gaps. Key issues concerning occupants' behaviour and lifestyle and its impact on home energy performance are identified through various studies. It is recognised that occupants' energy consumption behaviour, occupancy patterns and socio-demographic characteristics need to be taken into consideration to increase the efficiency of home operational energy post retrofit through behavioural intervention, that could benefit to the improved outcome of the retrofit programme (Firth et al., 2008; Urge-Vorsatz et al., 2007; Lee et al., 2013). However, the impact of those issues has not been thoroughly studied yet. Additionally, energy management applications are introduced in this study, as an effective method for behavioural intervention towards social housing energy consumption. It is found that applications generally lack novel and effective aspects for behavioural intervention and thus do not fully succeed in regulating occupants' energy consumption behaviour.

Based on the identified implications, the research aims to develop viable intervention strategies to reduce home operational energy in the UK social housing sector. A sequential explanatory mixed research design was adopted in order to investigate the relationships between occupants' energy consumption behaviour, occupancy patterns, socio-demographic characteristics and energy performance. As a result, a set of evidence-based suggestions were provided targeting both policy makers and energy end users in order to improve occupants' energy consumption behaviour. The provision of energy information and advice needs to strategically target occupants with different socio-demographic characteristics via varying approaches as an integral aspect of any retrofit programme. The proposal of an energy management application may also directly promote occupants' energy consumption behaviour through HCI. Following the data analysis and discussion, the research questions are hereby addressed concerning the impact of energy consumption behaviour on home energy performance and viable approaches for encouraging and achieving improved energy consumption behaviour for promising retrofit delivery and outcome. Finally, the research limitations and recommendations for future studies are also presented.

8.2 Energy consumption behaviour and home energy performance

The research first examined whether home energy performance is influenced by the ways occupants operate their homes. Based on the questionnaire survey and focus group interview, the research identifies a number of factors that correlate to home energy performance in the aspects of energy consumption behaviour and occupancy patterns.

It is found that the household electricity and gas bills are influenced by the use of windows, ventilation system, heating systems and controls in the case studies. For instance, the households that paid higher electricity and gas bills tend to use wall thermostat less frequently and set them at a relatively higher temperature than average. Besides, occupants who paid higher electricity and gas bills also tend to open their windows and use extractor fans less frequently, which could increase the levels of mould, damp and condensation inside the flats. The excessive use of kitchen appliances and bathing with fewer ventilations could lead to those housing issues and consequently impact on human health.

Additionally, respondents who paid higher electricity bills and gas bills also tended to 'go out to avoid using heating', 'unplug unused equipment' and 'use low energy light bulbs' less frequently. It indicates that occupants do not have sufficient energy saving awareness and may sacrifice energy use for personal comforts. Moreover, the majority of the interviewees from the focus group interview thought they spent too much on their bills. Their energy consumption behaviour was also explored during the event. Notably, only one interviewee would utilise all heating controls and ventilation systems at his home. The other interviewees expressed that they have never used either their wall thermostats, boiler thermostats, trickle vents or extractor fans at their homes. The majority of interviewees also expressed that they have sustained the way they operate their homes for a while without seeing any changes on their energy bills.

This may indicate that the occupants' energy consumption behaviour may be difficult to change. It is important to explore the drivers of those behaviours and make an effective strategy to promote efficient home operation, and consequently improve the delivery and outcome of retrofit projects.

8.3 Occupants' socio-demographic characteristics, housing characteristics and home energy performance

Apart from the relationship between occupants' energy consumption behaviour and home energy performance, occupants' socio-demographic characteristics and housing issues are also found to be relevant to home energy performance. It is also found that different household profiles and certain housing issues determine the way that occupants operate their homes.

A variety of aspects of household profiles are found to have direct impact on home energy performance, such as 'tenancy status', 'number of occupants', 'children', 'retired persons' and 'health conditions'. Some of those factors are also significantly correlated with occupants' 'occupancy patterns' and 'heating patterns'. Apart from household profiles, 'occupancy patterns' are also found to be correlated with 'heating patterns'. Further, 'income levels' also significantly affects 'hours thermostat on' in many flats. In summary, household profiles play an important role in home energy performance as they determine the way that homes are operated. Due to the established correlations between 'energy advice' and a number of behavioural factors, addressing the impact of household profiles is recognised as one of the effective means of behavioural intervention. Additionally, older-aged occupants are found to have the most barriers among other groups for behavioural promotion. Instead of energy advice and education, physical support or automatic home operation driven by policy makers could be better alternatives, especially for the ones living alone.

The main findings from the correlation analysis were further explored in the focus group interview to investigate the barriers of behavioural promotion in different household profiles. Based on the interview, several barriers were demonstrated among interviewees: 'young' interviewees were more capable of switching energy suppliers or upgrading energy meters, learning energy knowledge and managing their energy use effectively. Although they were more interested in saving on bills, they tended to sacrifice energy consumption for personal comforts; 'middle-aged' interviewees' energy behaviour was limited by energy knowledge, heavy workload or family commitments, where they did not have many options on when to use energy; the 'older-aged' also felt it difficult to follow energy advice and upgrade energy meters due to personal capability; 'large families' with 'children' may increase the complexity of occupancy and energy use patterns, hence holding back occupants from improving their energy consumption behaviour. Therefore, policy makers need to provide tailored energy advice and information for different types of household.

The research findings from the questionnaire survey and focus group interview informed the development of intervention strategies that are expected to promote occupants' energy behaviour and improve the delivery and outcomes of retrofit projects. The research aims to fundamentally improve the home operation in order to offset energy performance deficits and increase users' incentives for retrofit programme uptake.

8.4 Behavioural intervention through policy making

Based on the identified findings, the research aims to develop a set of evidence-based recommendations for policy makers to improve the efficiency of home operation by regulating occupants' energy consumption behaviour. It is noticed that some of the findings in this research are also agreed by other researcher, such as the negative impact of high household incomes, the existence of children, family sizes and poor health conditions towards energy consumption (Guerra-Santin, 2011; Nicholls and Strengers, 2017; Poortinga et al., 2003). Apart from that, a great number of findings are unique and not indicated in other projects. For instance, this research found that the limited occupancy pattern is one of the key barriers for full time employed occupants to optimise their energy use. Although parents realise that keeping children in the house may consume more energy, they still prefer to do that to avoid unpredictable expenses from outside. It demonstrates social factors need to be involved in energy conservation when making the policy. In the case study, the progress of smart meter replacements was found not efficient due to users' energy knowledge, lack of focus from the utility company and ineffective corporation with the local authority. Those issues need to be also addressed by the policy makers in order to meet the deadline of smart meter deployment in 2020. The research particularly focuses on the implications of energy operation in the UK social housing tower blocks and recommend solutions on both policy makers and energy end-users' level. Therefore, the research has unique contributions to policy makers, practitioners, energy users and researchers.

The problematic energy conditions in both social housing estates are caused by a number of reasons. Not only is it due to the poor building envelope, but this is also coupled with inefficient ways that occupants operate their homes due to lack of energy knowledge and specific socio-demographic characteristics. Therefore, the energy information and advice provided need to be strategically considered along with the technical aspects of delivering a retrofit project. The poor home operation proved that the conventional operation manual guide does not work well. Therefore, the provision of a simple, clear and straightforward manual guide for occupants without professional knowledge is suggested. The on-site induction and hands-on information workshops need to be introduced as a mandatory element within the process of retrofit delivery and facilitated by well-trained experts in order to ensure positive impact on occupants' home energy behaviour. Besides, occupants are found to be familiar with conventional energy saving approaches but less so towards actions that require more in-depth knowledge and understanding. Occupants also tend to use heating controls and ventilation systems less frequently in the case study. The energy advice and information need to specifically address the use of heating controls, ventilation systems and how to understand energy tariffs. Moreover, policy makers may also focus on educating occupants to understand the healthiest indoor environmental quality as occupants tended to undertake improper habits that may reduce their indoor environmental quality and have negative impact on their health and comfort.

A number of barriers could potentially prevent the implementation of energy advice and information according to specific socio-demographic characteristics. Therefore, policy makers need to tailor the energy advice and information according to different household profiles. According to the research findings in the questionnaire and the focus group, the existence of children generate more energy consumption in heating and entertainment. Hence, energy advice needs to focus on effective use of heating system, thermostats and energy conservation activities involving parents and their children; young and older-aged occupants' incentives could be stimulated by highlighting financial returns with the clear judgement of a good living environment to avoid potential health risks; full-time employed occupants need to increase their awareness of effective energy management in limited occupancy patterns and be popularized with energy knowledge in order to choose the most appropriate energy tariffs; older-aged occupants also needs to be physically supported due to the limited learning abilities.

Moreover, the orientations of flats determine the levels of solar radiation received, thus influence the household's heating demand and the uses of ventilation systems. This showed that the traditional way of retrofitting tower block buildings may need to be reconsidered, as flats in different orientations receive varying levels of solar radiation and winds. The consistent insulation applied to different building surfaces needs to be replaced by tailored approaches for each surface and reflected in the policy making.

A number of respondents and interviewees expressed that they have to consume more energy to avoid cold and potential health risks. The concerns of children's health also lead to more heating requirements. Besides, 27 per cent of respondents also concerns more about their personal comforts and entertainments. In addition, interviewees have also expressed their concerns about community security. Appearances of strangers were highly concerned and reported to the local authority. Therefore, apart from highlighting environmental and financial benefits, policy makers could also focus on other co-benefits in order to increase occupants' incentives, such as improved health and wellbeing. The community-based campaigns are advisable to encourage occupants' efficient energy consumption behaviour through social norms. Positive influences on behavioural change by other people were indicated in the interview that interviewees tended to save more energy if their neighbours consumed less than them. Further, older-aged respondents were hard to reach and felt difficult to follow the user manual. The community-based approach also provides another way to educate older-aged occupants through face to face interactions rather than computer-based interactions.

Apart from promoting occupants' energy behaviour, policy makers need to focus on the improvements in several aspects. Efforts need to be made by the government to facilitate the implementation of smart meters in social housing estates as this involves more parties than the private sector. It may also be more effective to make smart meter implementation a mandatory requirement in social housing estates. Local councils could work with energy suppliers to carry this out by using a community approach, which increases efficiency in terms of time and cost.

8.5 Behavioural intervention through energy management application

It is believed that the conventional 'top-down' approach may not work effectively on engaging occupants. Therefore, a strategy that targets both top and bottom levels are provided in order to strengthen the retrofit. The research raises a proposal of energy management application to directly impact on energy users with behaviour intervention. The proposed energy management application will directly focus on the energy users to improve their energy consumption behaviour through behavioural recommendations. Besides, it may offer automatic operation for particular households that are not able to effectively manage their energy use by themselves due to age, employment or health issues. The proposed energy management application is expected to help facilitate the delivery of policies for improved energy consumption behaviour and optimal home energy operation.

The proposed energy management application will be connected with heating systems, ventilation systems and electrical appliances to form a comprehensive home energy management system. Contextual information would be entered into the application, such as the socio-demographical background of households, occupancy patterns, etc. Consequently, the application would be able to set household energy targets and generate advice and alerts based on the found correlation in this research.

A number of proposed application features were concluded by the review of literature and applications, and were brought into discussion during the focus group interview. Behavioural suggestions based on historic patterns are found to be ineffective due to occupants' ingrained behaviours. The majority of the interviewees preferred to receive real-time behavioural suggestions based on their socio-demographic characteristics. The established correlations could potentially help to convert those variables to parameters and incorporate them into the energy management application. Interviewees also preferred a number of features such as energy comparisons, gamification elements and socialised platforms.

It is found that occupants with different socio-demographic background have unavoidable barriers in adopting energy advice. In contrast to addressing the importance of fully automated operation in the current market, the proposed application is expected to extend its automatic operation to part of the building appliances and systems to help occupants overcome those barriers. The manual operation which is supported by real-time behavioural suggestions remains as another significant strategy to promote occupants' energy behaviour and improve their energy knowledge through interactions. As a result, households occupied by 'young' or 'unemployed adult members' only are expected to follow real-time behavioural suggestions through the manual operation as they do not have unavoidable barriers. Families occupied by 'older members', 'unemployed members', 'children' or 'poor health' could adopt an automation strategy for the heating system, extractor fans and trickle vents for effective heating use while retaining a pleasant indoor climate. However, the use of windows, which could generate a negative impact, and use of electrical appliances could be promoted through real-time suggestions. The automatic operation of electrical appliances and windows could be extended for 'carer-needed' or 'disabled members' according to particular situations. Large families with complex energy use patterns could adopt an automation strategy for the heating system and electrical appliances for effective energy use. Use of ventilation systems could be promoted by real-time suggestions, adopted according to personal preferences. Families with full-time employed adults may fail to use heating systems effectively due to limited occupancy patterns. Therefore, an automation strategy could apply to the use of heating systems. A manual operation strategy could apply to ventilation systems and electrical appliances.

In addition, families occupied by 'older-aged members' or 'carers-needed' will benefit from the monitoring feature of the application, where improper energy uses could be fed back to the management level or local authority to take future actions. The lessons learned that could provide valuable guidance for future research are also presented in the following section.

8.6 Limitations of the research

A number of potential suggestions were raised and concluded to inform the future studies. It is notable that the questionnaire survey and focus group interview formed the major part of the data collection, ethical issues need to be carefully considered in order to protect participants' privacy and ensure the activity serves the interests of all parties. The details of the issues and relevant suggestions are presented below.

8.6.1 Questionnaire survey

During the first stage of the research, 18 out of 44 households responded at Estate A and 32 out of 109 households responded at Estate B. As a result, 50 questionnaires were collected where 32.7 per cent of households participated in the survey. Although the size of data sample in the research are sufficient to predict potential correlations among different variables (Weaver and Koopman, 2014; Bonett and Wright, 2000; Pajula and Tohka, 2016), it is relatively small compared with other similar studies (Mills and Schleich, 2012; Elsharkawy and Rutherford, 2015, 2018; Guerra-Santin, 2011). Future studies could work on improving the response rate of the questionnaire and increasing data sample by getting more social renters involved. The reason for the promising response rate of 40.9 per cent at Estate A is that the on-site constructor helped to facilitate the response by arranging coffee mornings, collecting questionnaires and disseminating project leaflets. On the other hand, the researcher distributed the questionnaire using a 'door-to-door' approach at Estate B, where only 29.3 per cent of occupants responded in the end. The questionnaire survey was incorporated into the coffee morning, which might make occupants feel it is relevant to the retrofit interventions. Therefore, they tended to be more cooperative and supportive. The local authority was contacted to accompany the questionnaire distribution to facilitate the process. However, this did not work on account of their availabilities. As a result, the engagement of staff from the local authority would also be helpful to increase the response rate and enlarge the data sample of the research.

During the research, single elderlies were more difficult to reach than other families. Thus, the feedback acquired from them was not as thorough as from others. Most of the single elderly met difficulties in understanding and completing the questionnaire by themselves. Therefore, advice and support were requested during the survey in order to complete the questionnaire. It indicates that specific approaches need to be adopted by local authorities or policy makers to reach this demographic group for retrofit consultations and further education.

Additionally, in order to ensure the interests of stakeholders, the draft questionnaire was sent to the local authority for review. Although much useful information was provided in order to engage occupants more effectively, a number of questions that may have negative impact were suggested to be removed. Apart from questions relating to ‘cold’, ‘mould’, ‘condensation’, ‘draught’ and ‘damp’, a previous version of the questionnaire also included issues of ‘leaking’, ‘physical damage’ and ‘service system’ where occupants could indicate where problems are actually occurring. Therefore, data of housing problems could be more detailed to ensure in-depth investigation between housing problems, occupants’ energy consumption behaviour and home energy performance. Another suggestion from the local authority was to minimise the number of questions and simplify the answer options. This would ensure smooth distribution and completion of the questionnaire survey as occupants would not lose patience. However, the reduced and simplified questions may decrease the content and accuracy of the data.

Although the questionnaire was reduced from 6 to 4 pages, a number of occupants lost their patience in the middle of completing the questionnaire. So, the design of the questions needs to be explicit and efficient with minimum time required to answer. Moreover, some occupants failed to thoroughly complete the ‘question 8’, which asked them to map their occupancy patterns including heating and thermostat patterns during weekdays and weekends in different rooms. To record occupancy patterns is difficult and time-consuming as occupants could not completely and accurately remember them. The use of heating or a thermostat could be very fragmented and thus difficult to record. A new approach needs to be adopted in order to capture this information in the future. According to the initial research plan, questionnaire completion took longer than the expected duration.

In order to reflect reality as much as possible, it is better to have actual data of household energy bills or energy consumption. However, the local authority was unable to provide this for the research. Alternatively, quarterly energy bills were asked in the questionnaire and utilised for research analysis. However, some of the respondents could not find their bills and therefore answered this question from memory. To increase the accuracy of the data, access to energy bills or energy consumption from the energy company or local authority needs to be granted. Further, information bias in the questionnaire survey and focus group interview may lead to inaccuracy of data. In order to raise the authorities’ awareness, occupants may describe their housing problems as more serious than they actually are to gain additional support. The upcoming retrofit work also implied to occupants that they were living in problematic homes. Moreover, occupants may consider the relationship between researcher and local authority when answering a number of sensitive questions such as household income levels, employment status and number of occupants. In order to obtain accurate data, confidentiality of the research needs to be particularly emphasised.

8.6.2 Focus group interview

Prior to the start of the interview, leaflets were distributed to each flat in both case studies of social housing estates in order to raise occupants' awareness. The researcher also had a number of opportunities to speak to the occupants and introduce the focus group interview. Therefore, it is important to inform occupants that it will be an informal interview with a very relaxed atmosphere to encourage participation. The aim of the interview needs to include emphasising the benefits occupants would gain from the research study. Additionally, as participants easily lost interest during the process, it is crucial to start with more candidates than needed in order to ensure successful delivery of the event. The researcher had 20 candidates who expressed their interest in taking part in the interview with only 8 to 10 interviewees expected to attend. Actually, 9 candidates showed up on the day. The reasons for absence include loss of connections and occupants' availability. As occupants have different work patterns and lifestyles, their availability needs to be checked and confirmed in advance. To ensure that the interview runs smoothly, presentations that outline all interview questions and necessary illustrations were prepared for interviewees to follow the process easily.

It is suggested (Krueger and Casey, 2015) that more focus groups arranged covering comprehensive socio-demographic backgrounds could help to obtain more meaningful answers. However, the number of focus group interviews in the research was restricted by the sample size. More focus groups are recommended in order to obtain richer and more grounded results. Two interviewees who were aged '55 years old or more' were invited to the interview. However, they were both from large families as opposed to living alone. Neither of them had a good understanding of their bills, smart meters or energy saving awareness. A few elderlies expressed their interest in taking part in the interview but dropped out later without providing reasons. It could be the case that the elderlies who live alone did not feel comfortable with the research approach. It is believed the same issue may occur in other events such as consultations on refurbishment held by the local council or energy supplier. Hence, the government needs to focus on this particular group of people and design appropriate approaches to maximise the chances of involving them.

On the interview day, extra time needs to be accounted for as some interviewees did not arrive on time. During the interview, although rules were introduced at the beginning, more than one interviewee might speak simultaneously during the discussion. The researcher politely stopped them and emphasised the rules again to the interviewees. Further, interviewees might not follow the topic and skip to other topics. The researcher needs to steer the discussion back to the interview topics or proceed to the next topic if sufficient information has been received. In addition, a few interviewees were not willing to speak too much. The researcher had to talk to them and encourage them to share their ideas. Lastly, the interview needs to be strategically planned in terms of the importance of the questions as the most important ones need to be thoroughly discussed, thus requiring more time allocated in the interview.

8.7 Recommendations for future research

The research aims to explore the impact of occupants' energy consumption behaviours, occupancy patterns and their socio-demographic characteristics on home energy performance through different approaches. Although valuable findings were identified in the research, more efforts could be made on a few aspects to refine the results for future studies.

One of the issues reflected during both phases of the research was that elderlies are difficult to reach. The relatively small proportion of elderlies among respondents had some impact on the representativeness of the sample. Based on a large number of correlations identified between household profiles, occupants' energy behaviours and home energy performance, distinct variances are indicated among different age groups. Therefore, engaging more elderlies in relevant research is recommended for future research.

The research indicated that 'flat orientations' significantly impact on 'energy bills' and 'housing issues' through occupants 'energy consumption behaviours'. However, the aspects found to describe this relationship were limited. The identified factors only include 'cold', 'mould', 'use of windows' and 'temperature on wall thermostat'. More in-depth exploration on how different 'orientations' of flats and other 'housing characteristics' may impact on 'energy consumption behaviour' are recommended. Apart from the variance of solar radiation on different façades of the building, the 'floor levels' could also potentially impact on the degree of 'housing issues' and consequently on occupants' 'energy behaviour' due to the different conditions of insulation and solar accessibility. It is reported by the council that top floor flats may have more serious 'damp' and 'mould' issues than lower floor flats due to poor insulation and cold bridges. Although it was not indicated in the research, this could be a new direction to work with in order to give more suggestions on the tailored design of retrofit measures.

The research identified how occupants with varying household profiles operate their homes differently in the aspects of the heating system, ventilation system, windows and electrical appliances. Future research may focus on gathering more comprehensive data of use patterns of each electrical appliance in order to thoroughly understand the impact of socio-demographic characteristics on energy consumption behaviour.

8.8 Contribution to current knowledge

Through 2 exemplary case study of social housing estates in London, the research examined the implications of occupants' energy related behaviours, lifestyles and their socio-demographic characteristics on home energy performance. The research found that the occupants' energy consumption behaviours significantly impact on energy consumption. Besides, household profiles determine the way that homes are operated. Therefore, the research aims to reduce the operational energy post retrofit in the UK's social housing sector by promoting occupants' behavioural change.

The research argued that effective behavioural intervention needs to focus on both policy makers and energy end-users' levels. Both aspects need to be strengthened and integrated to deliver effective home operation. To address that, evidence-based suggestions for policy makers were proposed based on the evidence obtained from the questionnaire survey and focus group interview. It is found that energy advice needs to be tailored to suit different socio-demographic groups. Approaches to deliver energy information also need to be varied to approach occupants with different backgrounds and stimulate their energy saving incentives. Additionally, a specification of the energy management application was also proposed in order to directly interact with energy end users to ensure the soft-landing of the policies. The design of the application was also based on the particular situation of energy users that were discussed in the focus group. Different approaches were adopted in order to optimised home operation, such as automatically controls and manually operation with real-time behavioural suggestions. It is believed that the UK's social housing sector could be benefited from the research findings as the operational energy will be essentially reduced. The research could also indirectly help to close the BPG and contribute to more effective retrofit projects.

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Appendix

Appendix I: Questionnaire template

Time : Date: Flat:

Section 1

1 *Tenancy status:* ☐ Owner Occupied ☐ Newham Council housing ☐ Housing Association renters

2 *How long have you been living in this property?*

☐ less than 12 months ☐ 1 up to 2 years ☐ 2 to 5 years ☐ 5 to 10 years ☐ 10 to 20 years ☐ 20+ years

3 *How much do you pay for the bill each quarter approximately?*

For electricity, please specify (£): ______________________

For gas, please specify (£): ______________________

4 *Have you received advice on how to reduce your energy bills?* ☐ Yes ☐ No

If yes, where did you receive the advice from?

☐ Newham Council ☐ The energy supplier ☐ Other, please specify: ______________

5 *Have you changed your energy supplier/energy plan?* ☐ Yes ☐ No

If yes, why?

6 *Secondary heating system:*

☐ Gas wall heater ☐ Electric portable ☐ Other ☐ No secondary heating

7 *How often do you experience the issues below in your home? (1 is never; 5 is always)*

	1	2	3	4	5
Cold	☐	☐	☐	☐	☐
Damp	☐	☐	☐	☐	☐
Mould	☐	☐	☐	☐	☐
Draught	☐	☐	☐	☐	☐
Condensation	☐	☐	☐	☐	☐

Section 2

8 *How many hours do you occupy and heat each of your room during weekdays and weekends?* (in winter)

Room Type		No. of Occupants	Weekdays	Weekends
			For example: 18:00 till 07:00 & 10:00 till 13:00	For example: 08:00 till 10:00 & 17:00 till 20:00
1.Living Room	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
2.Main Bedroom	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
3.Secondary Bedroom	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
4.Kitchen	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
5.Dining Room	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
6.Bathroom	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
7.Separate WC	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			
8.Corridor	*hrs occupied*			
	hrs heaters on			
	hrs thermostat on			

9 ***What heating controls do you have in the home?***

☐ Radiator valves ☐ Wall thermostat ☐ Boiler thermostat ☐ None

10 ***How often do you use your heating controls?*** **(in winter)**

	more than once a day	once a day	once a week	every two weeks	once every month	never
Radiator valves	☐	☐	☐	☐	☐	☐
Wall thermostat	☐	☐	☐	☐	☐	☐
Boiler thermostat	☐	☐	☐	☐	☐	☐

If you do not have a wall thermostat, please go to question 12.

11 ***At what temperature do you set your wall thermostat?*** **(in winter)**

☐ <18 ☐ 18 ☐ 19 ☐ 20 ☐ 21 ☐ 22 ☐ 23 ☐ 24 ☐ > 24

12 ***How often do you open your windows in winter?***

☐ Always ☐ Usually ☐ Sometimes ☐ Quite a few ☐ Never

Please specify the number of hours: ______________________________

13 ***How often do you turn on the extractor fan when you take the shower?***

☐ Always ☐ Usually ☐ Sometimes ☐ Quite a few ☐ Never

Please specify the number of hours: ______________________________

If you do not turn it on, can you explain the reason:

14 ***Are you familiar with the purpose of the trickle vent?*** ☐ Yes ☐ No

(A trickle vent is a small slot in the window to allow air to filter in even when the window is closed.)
If No, please go to question 16.

15 ***How often do you keep the trickle vents open when it is cold?***

☐ Always ☐ Usually ☐ Sometimes ☐ Quite a few ☐ Never

Please specify the number of hours: ______________________________

16 ***How frequently do you do the following activities? (1 is never; 5 is always)***

	1	2	3	4	5
Try using less gas and electricity	☐	☐	☐	☐	☐
Turn your heating up or down as required	☐	☐	☐	☐	☐
Use the thermostats to adjust temperature	☐	☐	☐	☐	☐
Try heating as less room as possible	☐	☐	☐	☐	☐
Set hot water thermostat lower	☐	☐	☐	☐	☐
Use blankets instead of heating system	☐	☐	☐	☐	☐
Close curtains at night to keep heat in	☐	☐	☐	☐	☐
Put on a jumper instead of heating	☐	☐	☐	☐	☐
Go out to avoid using heating	☐	☐	☐	☐	☐
Turn off lights when you leave the room	☐	☐	☐	☐	☐
Turn off TV when leave the living room	☐	☐	☐	☐	☐
Unplug unused equipment	☐	☐	☐	☐	☐
Wash clothes in shorter washing cycle	☐	☐	☐	☐	☐
Use low energy light bulbs	☐	☐	☐	☐	☐
Reduce time spend in the shower	☐	☐	☐	☐	☐
Avoid using energy at peak time	☐	☐	☐	☐	☐

17 *Rate your ability to read the utility bill (1 is very easy to understand; 5 is very difficult to understand)*

Very easy 1	2	3	4	Very difficult 5
☐	☐	☐	☐	☐

18 *In general, do you think you use more energy than you should to have a more comfortable home?* ☐ Yes ☐ No

If yes, why?

Section 3

19 *Does anyone of your household have a smart phone?* ☐ Yes ☐ No

20 *How comfortable do you like to use applications on your smart phone? (1 is very uncomfortable, 5 is very comfortable)*

Very uncomfortable 1	2	3	4	Very comfortable 5
☐	☐	☐	☐	☐

21 *Do you have smart meter installed at home?* ☐ Yes ☐ No

If no, please go to question 23.

22 *How often do you read smart meter and adjust energy use accordingly?*

☐ Always ☐ Usually ☐ Sometimes ☐ Quite a few ☐ Never

23 *Do you have energy monitoring application on your smart phone?* ☐ Yes ☐ No

If no, please go to question 25.

24 *How often do you use the energy monitoring application and adjust energy use accordingly?*

☐ Always ☐ Usually ☐ Sometimes ☐ Quite a few ☐ Never

25 *Which aspects would you find useful if you have an energy app on your smart phone?*

	less interesting 1	2	3	4	Very interesting 5
Real-time energy bill	☐	☐	☐	☐	☐
Real-time energy consumption	☐	☐	☐	☐	☐
Real-time energy consumption alerts / notification alarm	☐	☐	☐	☐	☐
Real-time behavioural suggestions	☐	☐	☐	☐	☐
Energy use pattern analysis	☐	☐	☐	☐	☐
Energy saving advice	☐	☐	☐	☐	☐
Your savings compared to your neighbours	☐	☐	☐	☐	☐
Comparison of energy prices	☐	☐	☐	☐	☐
Forecasting energy costs and savings	☐	☐	☐	☐	☐

If there is any other aspect that would help you, please make suggestions below:

26 *Would you like to be involved into focus group for additional information on the project?* ☐ Yes ☐ No

The researcher will arrange the delivery of the information alongside with the research team.

If yes, what type of information would you prefer?

☐ Information manuals / leaflets ☐ More technical info ☐ More physical help and support

☐ More hands-on info ☐ Other, please specify:

Section 4

27 ***Respondent's Gender:*** ☐ Male ☐ Female ☐ Prefer not to say

28 ***Age of household reference person:***

☐ 16-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65 or over

29 ***Members of household (please specify numbers of each age category):***

infants (0-3yrs) ________ children (3-12yrs) ________ Teenagers (12-19yrs) ________

19-24yrs ________ 25-34yrs ________ 35-44yrs ________

45-54yrs ________ 55-64yrs ________ 65yrs or over ________

30 ***Is English your first language?***

☐ Yes ☐ No ***If no, please specify your first language:*** ________

31 ***Economic status of each family member (please specify numbers of each employment category):***

Full-time employed ________ Part-time employed ________ Self-employed ________

Unable to work ________ Retired ________ Student ________ Unemployed ________

32 ***Ethnicity:***

☐ White ☐ Mixed ☐ Asian or Asian British ☐ Black or Black British ☐ Chinese

☐ Indian ☐ Pakistani or Bangladeshi ☐ Other, please specify: ________ ☐ No comment

33 ***Total household income level (Annual):***

☐ less than 6,000 ☐ 6,000-12,000 ☐ 12,000-20,000 ☐ 20,000-30,000

☐ more than 30,000

34 ***Your level of education:***

☐ Secondary (GCSE) Level 1 &2 ☐ A, AS Level (Level 3award) ☐ Diploma, teaching, nursing (Level 4award)

☐ Level 5 certificate ☐ Degree with honours (Level 6 award) ☐ Masters or PhD degree Level 7, 8 qualifications

☐ No degree

35 ***How is your health in general?***

☐ Very good ☐ Good ☐ Fair ☐ Poor ☐ Very poor

36 ***Any other comments:***

Appendix II: Questionnaire information page

Questionnaire Information Page

Survey questionnaire: household profiles, housing conditions, and occupants towards retrofit

Dear Sir/Madam,

This questionnaire is carried out by University of East London with permission from the London Borough of Newham, designed to develop an understanding of home energy performance, and residents' attitudes and behaviour during refurbishment works ([redacted]).

The questionnaire is developed to investigate current conditions of homes, occupants' attitudes and knowledge towards home performance improvement, and households' socio-economic issues. Consequently, a clear understanding of the impact upon both properties and their residents will provide valuable information, both locally and nationally. This will help develop appropriately tailored approaches that support and maintain effective delivery of current and future policy schemes. The questionnaire should only take 15-20 minutes and will be extremely useful in this research project.

To complete the questionnaire is optional. But we sincerely appreciate for your participations as your own properties and finance will be immensely benefited from it. **Your responses will be confidential. Feedbacks will be used for research purposes only and not be shared with third parties including the council.** No individual will be identified as a result of completing this questionnaire.

If you have any questions or comments about this questionnaire, please use the contact details below. Your comments will be greatly appreciated.

Yours Sincerely,
Wei SHI
PhD Researcher, University of East London
u1034799@uel.ac.uk

Appendix III: Focus group interview structure and template

1 . Welcome, introduction and instructions

Welcome and thank you for volunteering to take part in this focus group. You have been asked to participate as your point of view is important. I realize you are busy and I appreciate your time.

Introduction: This focus group discussion is designed to assess your current thoughts and feelings about using energy efficiency applications on your smart phone and your preferences of a number of energy saving aspects in it. The focus group discussion will take no more than two hours. May I tape/take notes of the discussion to facilitate its recollection?

Anonymity: Despite being recorded, I would like to assure you that the discussion will be anonymous. The tapes will be kept safely in a locked facility until they are transcribed word for word, then they will be destroyed. The transcribed notes of the focus group will contain no information that would allow individual subjects to be linked to specific statements. You should try to answer and comment as accurately and truthfully as possible. I and the other participants would appreciate it if you would refrain from discussing the comments of other group members outside the focus group. If there are any questions or discussions that you do not wish to answer or participate in, you do not have to do so; however please try to answer and be as involved as possible.

Notes

- The most important rule is that only one person speaks at a time. There may be a temptation to jump in when someone is talking but please wait until they have finished.
- There are no right or wrong answers.
- You do not have to speak in any particular order.
- When you do have something to say, please do so. There are many of you in the group and it is important that I obtain the views of each of you.
- You do not have to agree with the views of other people in the group.
- Does anyone have any questions? (answers).

OK, let's begin.

2 . Warm up

Warm up

- Q1: First, I'd like everyone to introduce themselves. Can you tell us your name please?

- Q2: Do you know what is a smart meter and do you have it at home? (show a slide)

(Smart meter is an electronic device that records consumption of energy and send the information to the electricity supplier for monitoring and billing. Besides, we can read our energy usage through smart meters by connecting it to an energy app.)

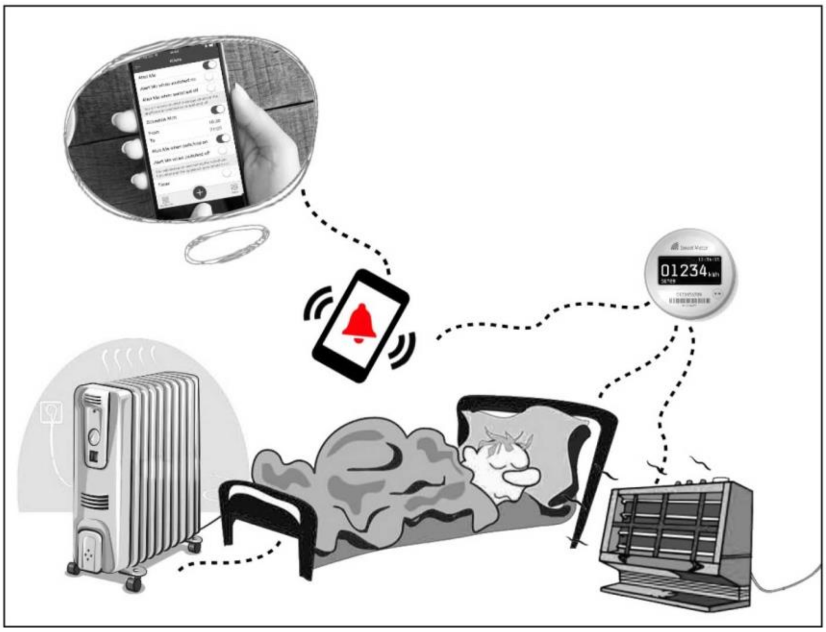
- Q3: Can you think about your experiences of using the energy apps on your smart phone for energy saving? If you do not like using energy app on your smart phone, can you think about the reason?

(What if they do not know the energy app, show a short video)

3 . Main interview questions

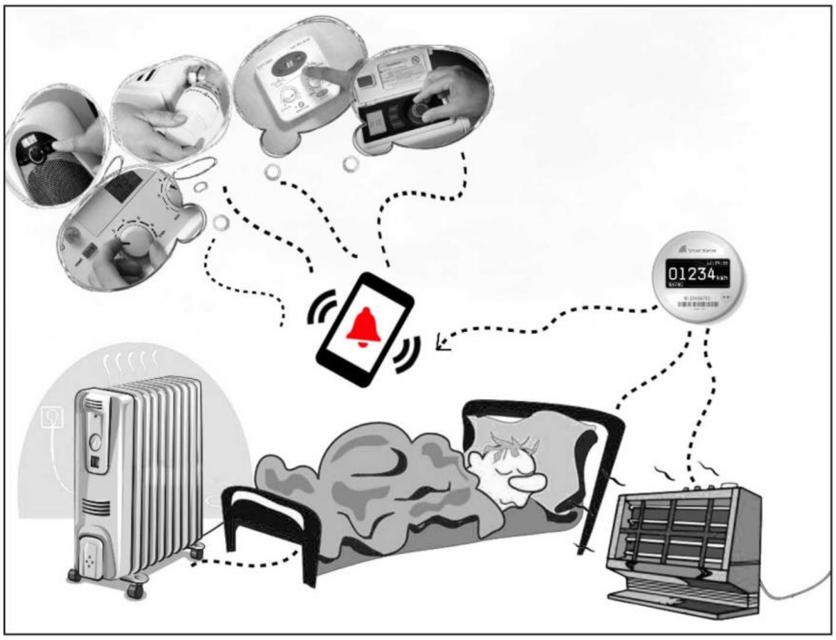
- Q4: Do you think you pay similar gas & electricity bills across different seasons every year?
- Q5: What do you think of your current energy use? Do you think you can pay less if you change the ways you use energy in your home?
- Q6: Did you try to change the way of using electrical appliances (fans, heaters, etc.) in recent years? If yes, did you notice a change in your bill?
- Q7: Did you try to avoid using energy at peak time? If not, why?
- Q8: Is there any component that you have never touched in your home, such as extractor fans, trickle vents, thermostat, etc.?
- Now, I will show you three pictures of how the energy app will help you to reduce your energy use: (Illustrations: Scenario 1, Scenario 2 & Scenario 3)
- Q9: What are your thoughts on the three different application features? Which would you think more helpful for you to save energy? and Why?

<u>Scenario 1: Manually set up the threshold</u>
(You can manually set up the baseline and turn on the alert on the app. It will notify you when your energy consumption exceeds the baseline.)



Scenario 2: Getting alert based on historic patterns

(The app will automatically map your historic energy use pattern and notify you when unusual consumptions are detected.)



Scenario 3: Getting alerts based on the found correlations

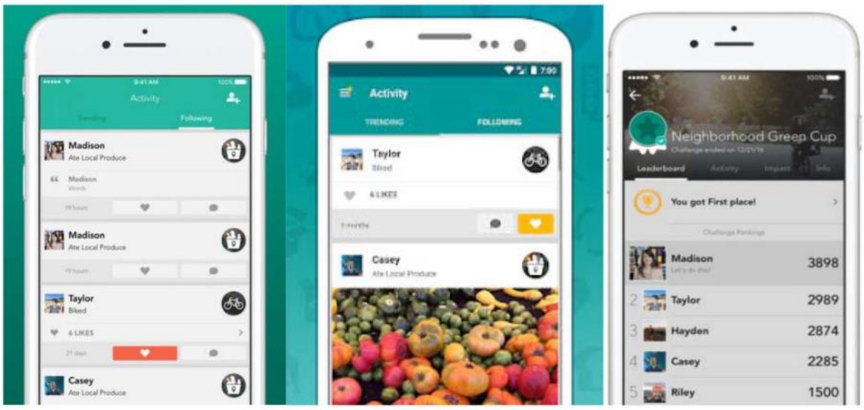
(The app will work out how much energy you should spend for you by considering 'number of people at home', 'employment status', 'ages' and other relevant factors. Then it will notify you if your current usage is not within the proper range.)

Scope of the app

- Q10: Do you know that you can save your energy for free, such as 'go out to avoid heating', 'put on a jumper instead of heating' and 'turn off TV when leave the room'? And how do you feel of doing them?

Social networking

- Q11: What if on the energy app, you can post your pictures and energy saving achievements on the platform, 'like' and make comments on others posts and make friends there. Just like Facebook.

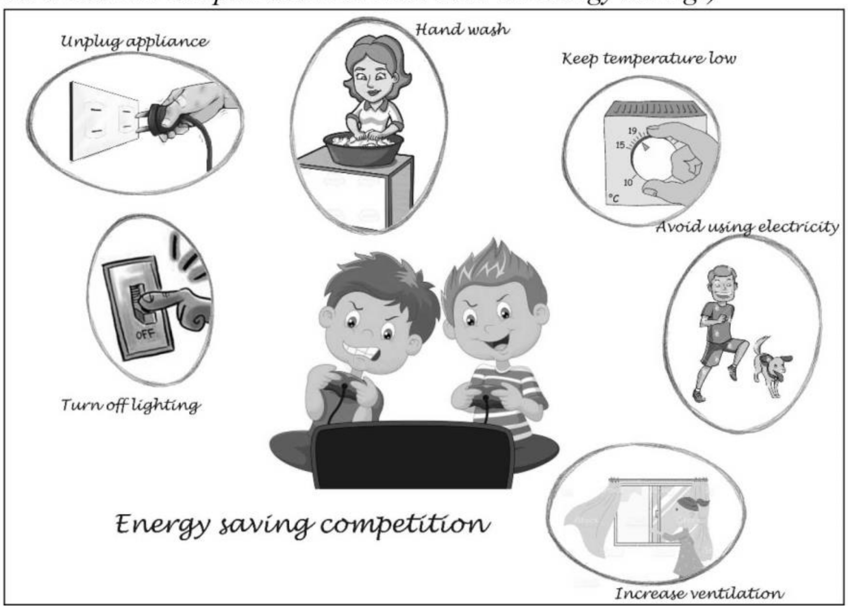


- Q12: What are your thoughts on the illustrated application features?

- Q13: Would you think it is helpful for you to save energy? Why?

Gamification design

(We want to create a platform that provides interactions between you and your neighbours. You can compete between each other on energy savings)



- Q14: Would you be more interested if you and your neighbours are in the same platform to learn from and compete to each other on energy savings?

- Q15: How would you feel if you know somebody else in your tower block has paid much less bill than you in the same condition?

- Q16: For example, if you find that you are always at the bottom of the rank no matter how much efforts you made, do you trust the ranking system, points and rewards?

- Q17: How do you feel if the rewarding system is not reliable?

4 . Conclusion

Concluding question

- Q18: Of all the things we've discussed today, what would you say are the most important issues you would like to express about the energy app or any other things?

Conclusion

Thank you for participating. This has been a very fruitful discussion. Your opinions will be a valuable asset to the study. We hope you have found the discussion interesting.

I would like to remind you that any comments featured in this report will be anonymous. Before you leave, could you complete the personal details questionnaire and return it back to me? Thank you!

FOCUS GROUP: DEMOGRAPHIC DETAILS QUESTIONNAIRE

Please answer the following questions in the spaces provided, circle or tick the most appropriate options.

1 ***Age:***

☐ 19-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65 yrs or over

2 ***Gender:*** ☐ Male ☐ Femal

3 ***What is your economic status?***

☐ Full-time employed ☐ Part-time employed ☐ Self-employed

☐ Unable to work ☐ Unemployed ☐ Retired

☐ Other, please specify:

4 ***What is your ethnicity background?***

☐ White ☐ Indian ☐ Mixed ☐ Pakistan or Bangladeshi ☐ Asian or Asian British

☐ Chinese ☐ Black or Black British ☐ Other, please specify:

5 ***Your level of education:***

☐ Secondary (GCSE) Level 1&2 ☐ A, AS Level (Level 3 award)

☐ Diploma, teaching, nursing (Level 4 award) ☐ Level 5 certificate

☐ Degree with honors (Level 6 award) ☐ Masters or PhD degree Level 7, 8 qualifications

☐ No degree

Thank you for taking the time to complete this questionnaire!

<u>**Appendix IV: Interview leaflet**</u>

UEL
University of East London

Newham London

Dear occupants,

The University of East London (UEL) has conducted questionnaire based survey in your tower block since July 2017. The progress has completed with a great number of responses. We appreciate for your participations and the valuable information provided. They are immense supports to our research and home energy efficiency.

As an extended investigation, UEL would like to invite you to an informal interview at the meeting room of [redacted], for one hour. During the interview, you will be asked to express your feelings of a few energy saving activities on the smart phone (They will be demonstrated by simple charts and images). The reason of this is that we want to identify the most attractive application features in order to inform for our future research.

As stated on our former leaflets, we believe that the way of operating homes significantly impacts on energy performance. So we aim to help occupants improve their energy related behaviours through the interactions with smart phone applications. Your participation will be crucial part of the research and on your own benefits.

We aim to organise the interview during the weekends' time by April 2018. To thank you for your participation, we also prepared lovely household gifts for you. To participate or obtain detailed information, please contact Wei Shi (Email. U1034799@uel.ac.uk / Tel. 07443644898) at the Environmental Design Research Centre at University of East London, Docklands Campus, University Way, London E16 2RD.

Thank you for your attention.

a place where people choose to
live, work & stay

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London E15 3LX

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W www.newham.gov.uk

UEL
University of East London

Newham London

Dear occupants of Flat _______,

Hope this letter finds you well! The University of East London ran a questionnaire based survey at your tower block last year. Your participation during the process has been a huge support to us. Thank you again for your enthusiasm and collaboration.

According to the questionnaire you completed, you indicated you would be happy to take part in a focus group as a follow up to the project. We aim to organize a short and informal group interview event soon to understand your views concerning developing a tailored smart application to help you reduce your energy bills. We will invite a group of occupants to simply express their feelings on a few topics within one hour's time. This will be the final stage of our research. We are delighted to invite you to join us at the event as we are working to improve your home conditions and reduce your energy bills. To save your time, the interview will be taken place just at the meeting room of [redacted] during weekends time by the end of April or beginning of May.

To participate or for more information, please contact Wei Shi (Email. U1034799@uel.ac.uk / Tel. 07443644898) at the Environmental Design Research Centre at University of East London, Docklands Campus, University Way, London E16 2RD.

Thank you for your time and we look forward to meeting you at the event.

a place where people choose to
live, work & stay

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Appendix V: Review of energy management applications in the market

The Voltaware Energy Monitor application:

Voltaware Energy Monitor was developed by Voltaware Services Ltd in 2015 and has gained a huge progression in recent few years. It has been shortlisted for three awards at the European Smart Energy Awards 2016 and won tender of deploying its real-time monitoring system in the commercial developments of Unibail-Rodamco and ENGIE group. Voltaware Energy Monitor is one of the typical real-time monitoring applications in the current market which performs excellent in a great number of aspects. The application constantly monitors energy performance by installing its sensor component into the fuel box. It is able to categorise the usages of energy and mapping energy consumption histories. Besides, the tailored behavioural suggestions are given based on the historic energy patterns and the alerts can be customized by users. The application is suitable for both smart phone and desktop and it has different versions which are suitable for home, office and public buildings.

[redacted]

Figure 1. Voltaware Energy Monitor application features 1 (Voltaware, 2018).

(Source redacted, available online at: https://www.voltaware.com/)

The Voltaware sensor components are able to identify energy usage from different appliances and categorise them for illustration and analysis. By knowing the energy consumption composition, users can more effectively save their energy. In addition, energy consumption will be presented with local currency and compared with last month's use. Energy consumption in daily average and peak day are also available.

[redacted]

Figure 2. Voltaware Energy Monitor application features 2 (Voltaware, 2018).
(Source redacted, available online at: https://www.voltaware.com/)

Carbon footprint caused by energy consumption will also be converted into number of trees to be easily understood by users. When dramatic increase of energy consumption is detected, intelligence advice of the application will pop-up constantly in order to let user take actions. Besides, the application interface is also carefully designed to be friendly to the users.

Although the Voltaware Energy Monitor application has a lot advantages, there are a few issues still can be discussed. A constant and long-term provision of energy feedback can ensure energy efficiency (Aldous and Whitehead, 2016). The real-time behavioural suggestions will be one of the most effective way to ensure that feedback provided is constant and long-term. However, using historic data as a benchmark to evaluate current energy usage and provide suggestions may be not appropriate enough. It only proves that the current energy consumption behaviour does not keep consistent with occupants' conventional patterns. And occupants' conventional energy use patterns may be inappropriate due to lack to knowledge and sustainable awareness. Thus, a better way of identifying energy benchmark need to be considered by taking account of occupants' socio-demographical information, such as number of occupants, occupations, ages, income levels, health conditions, etc.

Furthermore, the behavioural intervention provided by Voltaware Energy Monitor application is based on the data collected from electrical appliances. There is huge potential of energy savings can be achieved apart from electrical appliances, such as windows, extractor fans and the change of attitudes.

Wink:

Wink application was developed as a control system of smart homes. It tightens up the connections between occupants and smart home components and tries to influence occupants' energy consumption behaviour by doing this. Wink Hub has been expending its compatibility to a great number of smart product brands, such as CONNECT, ONE, PLAYBAR, PLAY:1, etc. Besides, the application developer is also in collaboration with some initiatives to strengthen its application aspects, such as the provision of voice-controlled assistant by working with Cortana. Additionally, Wink aware that 71 per cent of Americans wish to monitor their homes. Besides, the adapting rate of connected products, such as sensors, has dramatically increased in recent years (Wink, 2018). By working with variety of connected products, Wink has also been given a new function for security issues. The application users can open the door, lock it, and surveillance their homes when they are away.

[redacted]

Figure 3. Wink features 1 (Wink, 2018).

(Source redacted, available online at: https://www.wink.com/)

The Wink application works in collaboration with Google home and Cortana, Microsoft to develop its voice-recognition feature. By covering all major desktop and smart phone systems, users are able to command on lights, outlets, switches, and thermostats from anywhere using their Windows PCs, Cortana on Androids and iOS. Besides, smart locks which are compatible with Wink also can be controlled through Amazon Alexa-enabled devices. It includes Wink Shortcuts, August Lock, etc.

[redacted]

Figure 4. Wink features 2 (Wink, 2018).

(Source redacted, available online at: https://www.wink.com/)

To control your home smartly, Wink hub which allows diverse collection of smart products speak same wireless language needs to be installed firstly. Then users will be able to control the smart products on their smart phones even they are away. In the Wink application, users will be able to monitor and control lightings, powers, locking, Sonos products and temperatures depending on the smart products connected. The operations of each smart product will be analysed at the level of different living spaces, such as living rooms, bedrooms or kitchen. Therefore, users can easily address them and make decision. Besides, by connecting the thermostat with Wink hub, users can adjust temperature manually or leave it to ‘auto-control’.

[redacted]

Figure 5. Wink features 3 (Wink, 2018).

(Source redacted, available online at: https://www.wink.com/)

Except the smart control function, Wink also aims to provide a secure home for its users.

The connected sensors and locks will report detected motions to the users for security purposes. Users are able to lock the access of their homes remotely if they forgot to do so before travelling. Additionally, users can even select different mode to ‘make your home look like someone is in’ or ‘turn on the light when it is dark outside’.

There are plenty of inspirations are obtained from Wink application. Firstly, in order to increase the influence, Wink has been dedicating to be compatible to as much initiatives as possible. The great compatibility of it makes it adopts to intensive competitions. In order to be special among its competitors, Wink does not only work as a smart control system, but also a tool for home security. People may not pay attention to energy savings, but definitely and highly regards to home security. Wink’s ultimate goal is to influence people’s energy consumption behaviour to achieve energy conservation by providing constant feedback. Due to its limitations, the users cannot connect to each other to form a public platform for ideas sharing and energy saving competitions.

JouleBug

JouleBug encourages users taking sustainable actions through gamification design. It aims to facilitate sustainable behaviour by providing a ‘fun’ platform to the users. It is an award-wining application and has been featured in Apple Store.

[redacted]

Figure 6. JouleBug features (JouleBug, 2018).

(Source redacted, available online at: https://joulebug.com/)

JouleBug creates an excellent atmosphere to compete with each other and win prizes with its distinct gamification design. In the application, users are asked to accomplish a great number of sustainable actions, such as carpool, use green cup for coffee, take shorter shower, etc. Pints are awarded to users by completing these actions. Different levels of achievements and challenges are set up for users to achieve and compete to each other. People who are doing same activities will be ranked in a wider scoop. In addition, users are encouraged to create their own communities within neighbourhood, family or companies to strengthen relationships and increase engagement.

As one of the most successful tool with gamification design, JouleBug has captured attention from a great number of users and successfully impact on their daily lives. However, due to the broad scoop of sustainable actions it focuses, it is hard to judge the truth of the completions. Users presses 'BUZZ' button once action has been completed. The application also asks users to upload pictures to proof their completions. But it cannot effectively proof the actions. To prevent cheatings of competition and winning awards need to be focused to make the behavioural intervention more effective.

On the other hand, taking energy conservation as the criteria of the competition will be more measurable as it can be read from the meters and prevent cheatings. Although focusing on a large scope of users will increase the influence, it may be not as efficiency as only focusing on a small community, such as a local neighbourhood in which users have similar housing characters and socio-demographical backgrounds. It definitely stimulates the user if somebody else living close by saves much more energy and facilitate energy savings behaviour.

HomeBeat application:

HomeBeat was developed by the energy analytical company, Bidgely, in collaboration with United Energy. It also aims to provide behavioural intervention to occupants thorough gamification design. The application more focuses on reducing energy consumption in peak times. The reason why HomeBeat has been selected to conduct thoroughly evaluation is that HomeBeat gets attracted by the crowd and it helped customers to reduce 30 per cent of the energy consumption (Greany, 2016). As a result, its application features are explained, and its success and falls are also discussed below.

[redacted]

Figure 7. HomeBeat features 1 (HomeBeat, 2018).

(Source redacted, available online at: https://www.elucidat.com/blog/gamification-mobile-homebeat-app/)

According to Figure 3-11, HomeBeat facilitate behavioural changes through a series of gaming elements, such as personalised targets, timescales, rewards and competition. With user-friendly interface, it provides tailored energy saving goals to the users based on historic energy consumption patterns at ‘pre-event’ stage. Then, HomeBeat is able to provide real-time suggestions and guidance to ensure that your energy consumption is within appropriate range during ‘in-event’ stage. If the personalized goals have been achieved by users, the application will praise the users with recognition and rewards in form of badges during ‘post-event’ stage. HomeBeat is also able to group the users with similar background and organize gentle competitions to influence on behavioural change.

[redacted]

Figure 8. HomeBeat features 2 (HomeBeat, 2018).

(Source redacted, available online at: https://www.elucidat.com/blog/gamification-mobile-homebeat-app/)

Apart from smart phone application, HomeBeat also desktop and tablet friendly. By logging into account on desktop and tablet, user will be able to receive detailed analysis of their energy consumption patterns and. Besides, the application also provides convenient communications to solve technical issues.

Similar to JouleBug, both of the tools aware the importance of gamification design and aim to provide behavioural interventional through competitions and awards. However, JouleBug is better at creating a platform for socializing between each other and thus has much stronger impacts from social norms. So, JouleBug also can be treated as a social tool such as Facebook and Instagram. On the other hand, although HomeBeat has the function of competition with community, this element is not as distinct as JouleBug. Thus, it more focuses on user's own. Besides, according to Figure 6, the behavioural suggestions are too generic and may not effective enough for specific situations.

Appendix VI: The 34th PLEA International Conference on Smart and Healthy within the 2-degree Limit (PLEA 2018), Hong Kong, China, 10-12 December 2018.

Zahiri, S., Elsharkawy, H. and Shi, W. (2018). The Impact of Occupants' Energy Use Behaviour on Building Performance: a case study of a tower block in London. In: the 34th PLEA International Conference on Smart and Healthy within the 2-degree Limit (PLEA 2018). Hong Kong, China, 10-12 December 2018.

Source redacted, available online at:
http://web5.arch.cuhk.edu.hk/server1/staff1/edward/www/plea2018/download/Proceedings/Conference%20proceedings_TOC_3Volumes.pdf

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Appendix VII: The Building Simulation and Optimization 2018 (BSO 2018). Cambridge, United Kingdom, 11-12 September 2018.

The Importance of Occupancy and Energy Use Patterns on Predicting Building Energy Performance: A Case Study of a Residential Building in London

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Abstract

This paper studies a building energy performance of a council housing tower block in London, which was found to consume significant energy for heating. The aim of this study is to explore the impact of the occupancy and heating energy use schedules of the building units in predicting the building performance using DesignBuilder (DB) dynamic simulation tool. This study adopts a quantitative research design based on a survey questionnaire, and dynamic simulation modelling and analysis. The predicted building performance using the dominant occupancy and energy use profiles was compared against the simulation outputs using the approved benchmark methodologies. The results show that the building's physical issues including damp and mould, as well as the occupants' patterns of operating their homes have a considerable impact on the heating energy use in the winter season and demonstrate the importance of incorporating the exemplary occupancy and energy use schedules into the building simulation tools to predict feasible building performance.

Introduction

Building energy consumption accounts for more than 40% of the global energy use (BEIS, 2017; Song *et al.*, 2017). In addition, the occupants' energy consumption patterns play a significant role in the intensity of the energy used in buildings (Rouleau et al., 2018). This can cause the discrepancies between the predicted energy consumptions in comparison to the actual energy use (Heidarinejad *et al.*, 2017). In fact, the occupancy schedules associated with the energy consumption patterns have a considerable impact on evaluating and predicting building performance using dynamic building simulation software. Using the representative occupancy and energy use patterns may yield reliable simulation outputs and help to reduce the gap between the predicted and the actual building performance. However, there is a lack of consensus on recommended methodologies to input occupants' energy consumption behaviour in the simulation tools (Yan *et al.*, 2017).

This research assesses building energy performance of a high-rise residential block in London, which uses significant energy for heating due to its inefficient building envelope. The aim of this study is to explore the impact of several potential occupancy and energy use schedules on predicting building energy performance using DesignBuilder (DB) simulation tool. This study compares building simulation results using different profiles based on the actual dominant energy and occupancy patterns of the case study building in comparison to the predicted results using standardised methodologies.

The effect of occupants' energy use behaviour on building performance

One of the main factors of uncertainty in predicting the building performance is the occupancy and the energy use schedules associated with the energy consumption (University of Southampton, 2016; Stazi, Naspi and D'Orazio, 2017). The energy consumption level highly associate with the energy use patterns and the occupants' presence within the buildings (Ahmed *et al.*, 2017). In addition, mechanical cooling and heating systems dominate the buildings energy consumption levels in domestic building sector, while lighting and domestic hot water (DHW) contribute next (ADEME and Agency, 2015). Studies also assert that the occupants' energy use behaviour and their socio-economic background may have a significant impact on the intensity of energy used in buildings (Stazi, Naspi and D'Orazio, 2017).

To optimise the building energy performance, it is necessary to predict the feasible energy use. However, the lack of understanding the occupants' impact on the total buildings energy consumption can result in a gap between the measured and the predicted building performance (Chang and Hong, 2013; Ahmed *et al.*, 2017). According to Song et al. (2017), there are a few barriers to predict the building energy performance using occupants' energy use data. These barriers include occupants' diversity and the correlation with the energy use relating to the different energy consumption behaviour. There is also a lack of consensus on approved methodologies of occupants' energy use patterns to be incorporated into building simulation tools (EBC, 2016; Yan *et al.*, 2017).

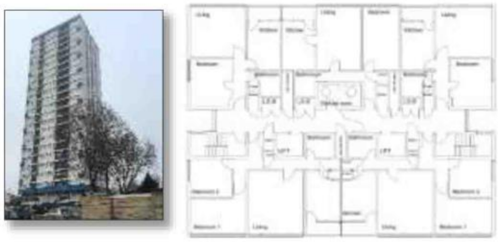
Aerts et al. (2014) studied the effect of occupancy schedules and the users' behaviour on the energy consumption of the building to define an approach for building simulation tools. The occupancy patterns of more than 3400 Belgian households were studied considering the details activities of around 6500 occupants. Seven occupancy profiles in three states were also defined to be used in the simulation analysis and modelling. These profiles include "home and awake", "sleeping" and "absent" states but it was found that these schedules are simple to be applied to the simulation modelling, as they are very general and there is a lack of information regarding the interaction between the occupants and the internal spaces. Ahmed et al. (2017) also studied the development of the occupancy, lighting, appliances schedules and input data for new energy calculation methods. The identified profiles were applied to 10 different building types and could be easily applied to the simulation tools. In this study, the occupants' hourly patterns were defined based on the culture and their local background. The study showed that the average and constant general schedules can not predict the actual energy required and highlighted the importance of realistic hourly schedule for different building sectors. Song et al. (2017) also examined the effect of occupancy related behaviours on predicting buildings energy performance. A data mining based prediction model was created to adapt building thermal behaviour and to select representative end-user groups. The model gave more insight into the daily energy peak demand and daily energy use patterns. It was found that identifying the occupancy related behaviours considerably help in predicting reliable building energy performance.

Moreover, a methodological framework for occupants behaviour study has been launched (Annex 66) aiming to set up a standard occupant behaviour definition platform, provide a quantitative simulation methodology to model behaviour in indoor environments and understand the impact of behaviour on building energy consumption (Yan *et. al*, 2017). It consists of application guidelines to help in building design operation and policymaking using interdisciplinary approaches to reduce energy use in buildings and improve the occupants' indoor comfort. It also shows the importance of integrating the occupants' behaviour with the building lifecycle (Yan *et. al*, 2017). Considering the use of the actual and prominent occupancy and energy use patterns of the buildings in the thermal simulation model can reduce the gap between the predicted and the actual building performance.

Methodology

The aim of this research is to examine the impact of different occupancy and heating energy use patterns on predicting the energy consumption of a residential tower block in London Borough of Newham (LBN) during the winter season and select the representative profiles to be incorporated into DB simulation tools for energy simulation modelling and analysis.

The case study is a 22-storey high-rise building constructed in 1966 and consists of 108 one-bedroom and two-bedroom flats (Figure 1). The structure is in-situ reinforced concrete frame construction with floor slabs spanning between shear walls, and pre-cast concrete panels covering the flank wall. Externally the building envelope is fitted with asbestos cement over-cladding panels. All flats have double-glazed windows with UPVC frames. The internal partition walls consist of concrete blocks of 100 mm thickness and the external walls include external over-cladding of 9 mm thickness, 80 mm air gap, 200 mm pre-cast concrete panels and 20 mm internal wall insulation boards and plaster finishes. In addition, internal floors consist of 150 mm reinforced concrete slabs as well as wall and ceiling plaster finishes. Heating is provided by natural gas-fired hot water boilers and there are also two extractor fans in each flat; one in the kitchen and another in the bathroom.



(a) (b)

Figure 1: Case study (a) and the typical floor plan (b) (Newham Council, 2007)

The case study has the significant damp, mould and condensation problems. In order to identify the problematic areas within the tower block, Newham Council conducted a water ingress survey in 2016 (Newham Council, 2016). It was found that at least one fourth of the properties experienced serious damp, mould and condensation issues. To identify the cause of damp penetration, the internal damp survey was conducted in two sample flats (Flat A and Flat B) using a damp meter. It was found that the jet washing of external over-cladding in 2012 may have damaged the over-cladding and as a result, the moisture would have transferred through gaps into the building and caused dampness issues (Medhurst, Turnham and Partners, 2016). An structured interview and a field monitoring of indoor air temperature and relative humidity levels (RH) were also performed in the sample flats during the winter season from Dec 2016 until March 2017 in order to evaluate the building performance (Zahiri and Elsharkawy, 2017). It was found that although the indoor air temperature and RH levels were normally within the comfort zone in the occupied rooms, the occupants were not satisfied from the indoor thermal comfort and they used more heating energy than required in the cold season to reduce the effect of the damp and condensation. Newham Council has planned for the energy efficient and the cost effective retrofit in the short term.

The research methodology is based on quantitative research methods; mainly a questionnaire-based survey on the occupants' energy use behaviour, as well as building simulation analysis. A questionnaire-based survey was conducted in autumn 2016 to gain more insight into the occupants' patterns of operating their homes. A dynamic building simulation modelling using the dominant occupancy and energy use patterns was also undertaken to identify the impact of different occupancy schedules on predicting the building energy consumption in the winter season. The predicted energy consumption using the representative energy-use scenarios was compared against the standard occupancy and energy use methodologies (SAP 2012 and TM 59). SAP 2012 is the UK government's procedure developed for the energy rating of dwellings (DECC, 2014) while CIBSE TM 59 is a newly developed guideline for the assessment of overheating risk in new and refurbished dwellings (CIBSE, 2017). As overheating risk will form one of the main concerns of the study for retrofitting and the next stage of the study focuses on the whole year, TM59 occupancy patterns along with SAP 2012 heating patterns were applied to the DB model. The results of this study will help to select the most reliable occupancy and energy use patterns to predict the building performance and support the Newham Council's retrofit plan.

Results and Discussion

Questionnaire-based Survey

A questionnaire-based survey on the occupants' energy use behaviour was conducted to get more insight into the occupants' patterns of operating their homes in the case study tower block during the cold season. 108 questionnaires were distributed to all the properties and 37 responses were received for the dwellings (30% response rate, which is acceptable). The results of the survey show that around 32% of the occupants are aged below 19 and around 50% of them are aged between 19 and 44, while the rest are older generation including 65 years old occupants (Figure 2). According to the survey results, 31% of the properties are occupied by a single occupant (low occupancy) while 31% of the properties are occupied by four to seven people (moderate to high occupancy).

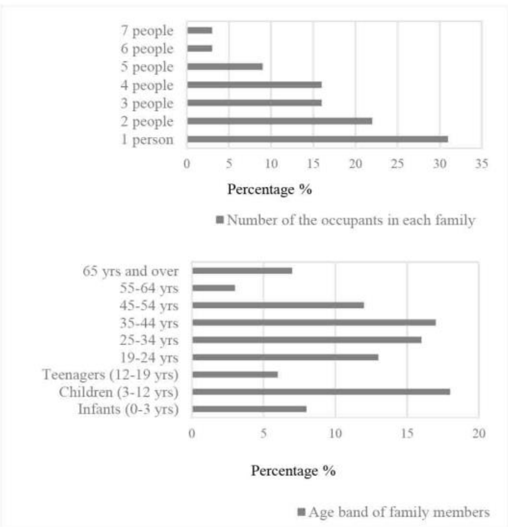


Figure 2: The number of the occupants in each family as well as their age band in the surveyed flats

The results also demonstrate that as the occupants' age band increases, they tend to use less heating in the winter season, while the households with more number of children tend to spend more on energy bills (Table 1). Table 1 shows that the heating energy use in the winter season negatively correlates with the age of the occupants but strongly correlated with the members of the households with children. This is mostly due to provide better indoor thermal environment for the children. The occupancy schedules also positively correlates with the age of the households.

Table 1: Correlation between occupancy, energy use and the age of the occupants

Hrs heaters on	**Coefficient**	**Sig.(2-tailed)**
Age of household	-.322*	.022
Members of household with children	.412**	.006
Hrs occupied	**Coefficient**	**Sig.(2-tailed)**
Age of household	.392*	.032
* Correlation is significant at the 0.05 level (2-tailed)		
**Correlation is significant at the 0.01 level (2-tailed)		

The survey results also present that although 63% of the respondents are full-time employed, the income level of 58% of the households is below £12K per annum (Figure 3) which highlights fuel poverty as a significant issue and the importance of the energy efficient retrofit. Studies show that in LBN, there is a high rate of fuel poverty at 13.8%, with 13,372 households suffering, which is among the highest rates in the UK (Walker and Ballington, 2015).

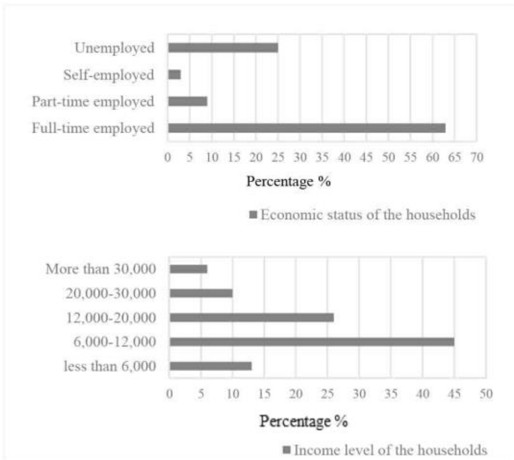


Figure 3: The economic status and income levels of the households of the surveyed properties

As mentioned previously the tower block experiences the significant damp, mould and condensation issues and at least around 40% of the respondents stated that they usually experience the dampness, mould, condensation and draught issues within the flats (Figure 4). It should be noted that 44% of the households admitted that they feel they had to use more heating energy to reduce the condensation and cold and the rest asserted that they open the windows to provide comfortable indoor environment due to illnesses or for the children's comfort. Table 2 shows that as the level of the dampness and condensation issues increases in the surveyed properties, the occupants' tend to pay more gas bills to reduce the issues experienced.

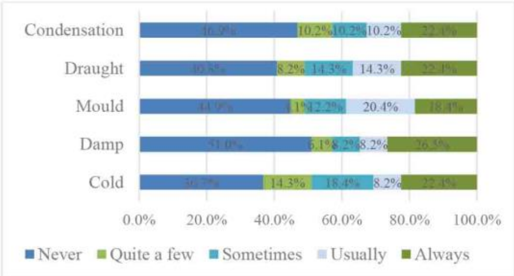


Figure 4: Questionnaire responses in regards to damp, mould, condensation, draught and cold issues experienced in the surveyed properties

Table 2: Correlation between damp, moulds, condensation issues with the Energy bills

Experiencing Damp	**Coefficient**	**Sig.(2-tailed)**
Gas bills	.626**	.005
Experiencing Condensation	**Coefficient**	**Sig.(2-tailed)**
Gas bills	.379*	.033
* Correlation is significant at the 0.05 level (2-tailed) **Correlation is significant at the 0.01 level (2-tailed)		

Furthermore, half of the respondents admitted that they never use extractor fan while taking the shower mainly there is no extractor fan within the properties or they are out of order. However, a few of the occupants never use the extractor fan due to the noise level. The result shows that using the extractor fan have a significant impact on reducing the damp and condensation and the occupants energy use behaviour have an effect on the levels of the issues experienced. From the in-depth analysis of the survey results, it was found that occupancy data including energy use behaviour, socio-demographic backgrounds as well as physical issues of the properties including dampness and mould contribute to the total building energy use as well as energy consumption and occupancy schedules.

Building performance modelling

In order to evaluate the building performance in the winter season and validate the monitored data against the predicted results, building simulation modelling and analysis has been performed using DesignBuilder software (DB). DB is an advanced building environmental simulation tool that uses EnergyPlus dynamic simulation engine for the simulation analysis (DesignBuilder, 2018).

In order to calibrate the building performance, as well as the building materials and components that were adopted in the simulation model, the measured indoor environmental data in the monitored flats (flats A and B) were scrutinised in conjunction with DB simulation results. As there has not been detailed specifications available concerning the building materials of the case study, the specifications of the construction materials of typical 1960s council housing tower blocks in the UK were adopted to the case study to develop a representative simulation model. The typical U-values for this type of buildings in the 1950s/1960s are 0.78 W/ m^2K for external walls, 1.82 W/m^2K for internal floors, 0.28 W/m^2K for roof, 2.67 W/m^2K for glazing, 2.82 W/m^2K for internal doors and 2.93 W/m^2K for internal partitions (Malpass and Walmsley, 2005, Harrison and De Vekey, 1998, Colquhoun, 2008).

To increase the accuracy of the predicted building performance, a modified weather data set in EnergyPlus weather format (epw) was incorporated to DB model using Met Office outdoor environmental data of the nearest weather station to the building location along with the actual occupancy and energy use patterns of the representative flats including lighting, heating and ventilation. The airtightness of the case study flats were also defined "poor" as there were many complaint regarding damp and draught inside the properties during the winter months. The occupants of these properties also reported about the significant increase of the heating energy consumption since these issues were noticed. It should be noted that natural gas-fired boilers facilitate heating in the properties by wall mounted radiators, which were also defined in the simulation model.

Figures 5 illustrates the monitored indoor air temperature against the DB predicted results during the coldest week of the monitored period in the winter season.

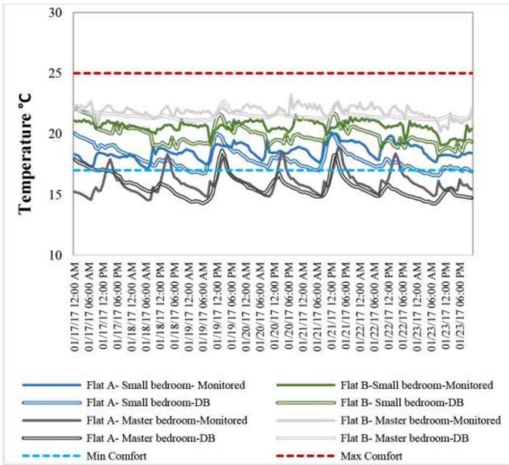


Figure 5. Indoor monitored air temperature against DB predicted results in the representative flats

It can be seen that the percentage variation between the monitored and the predicted indoor air temperature is between 5% and 15%, which has been asserted as an acceptable variation (FEMP, 2015) and demonstrated that the simulation model matched the real building.

The impact of occupancy and energy use patterns on the predicting energy use

The results from the survey questionnaire combined with the outcomes from the water ingress survey conducted by the council informed the selection of two exploratory sample flats (flats A and B), which are characterised by having the (lowest and highest) dominant occupancy profiles, both had relatively high energy bills, and experienced similar issues with their indoor environment. Both flat occupants also felt they tended to use more heating energy to reduce discomfort caused by damp, mould and condensation. Flat A is occupied by a retired occupant (representative for low occupancy pattern) and Flat B is occupied by a young family of five including three children (representative for high occupancy profile). The socio-demographic status of the occupants indicate that 31% of the properties are occupied by a single occupant (low occupancy), while 31% of the properties are occupied by four to seven people (moderate to high occupancy).

The occupancy and energy use patterns of the exploratory sample flats were incorporated into the simulation model separately as two dominant scenarios to predict the energy use of the tower block. The building performance using the representative occupancy and energy use profiles was also compared against the building performance using CIBSE technical memorandum 59 (TM59) occupancy patterns and Standard Assessment Procedure (SAP 2012) energy use patterns. CIBSE TM 59 is a newly developed guideline for the assessment of overheating risk in new and refurbished dwellings (CIBSE, 2017) while SAP 2012 is the UK government's procedure developed for the energy rating of dwellings (DECC, 2014). As the subsequent phase of this study is to determine an energy-efficient retrofit strategy, overheating risk will form one of the main concerns of the study.

Table 3 presents the schedules of heating energy use as well as occupancy patterns using three different scenarios (dominant patterns vs. Standardised patterns) in the main rooms of the properties that were applied to DB simulation tool. As presented in Table 3, Flat A occupant, an elderly person, keeps the heating off in both bedrooms whilst keeping the heating on from 8:00 am until 10:00 pm in all other zones of the flat with the thermostat set at 19 °C. The occupant also never opens any windows during the winter season for ventilation purposes. On the other hand, Fat B, occupied by a family of two adults and three children, always turn the heating on from 8:00 pm until 7:00 am in both bedrooms with the thermostat temperature at 25°C, whilst heating is turned off in all other zones in the flat during a typical winter day. However, the recommended heating schedule in SAP is for 9 hours during the weekday.

Figure 6 shows the predicted the heating energy loads of the tower block in a cold winter month of January using the three different scenarios of the occupancy and the energy use patterns including the dominants scenarios as well as standardised patterns.

Table 3: Dominant low and high heating and occupancy patterns (Flat A and Flat B) of the case study and the Benchmark Patterns (SAP and TM)

Scenarios		Flat A	Flat B	SAP and TM
Bedroom	Heating	-Off	-6:00pm to 8:00am. -On for extra hours from 12pm or 1pm for 3 h in winter.	-Weekdays: Heating on from 7am-9am and 4pm-11pm -Weekends: Heating on in all rooms from 07:00-23:00
	Occupancy	-10pm to 8am	-7pm to 7am	-70% occupancy from 11pm to 8am -Full occupancy from 8am to 11pm
Kitchen	Heating	-8am to 10pm	-Off	-Weekdays: Heating on from 7am-9am and 4pm-11pm -Weekends: Heating on in all rooms from 07:00-23:00
	Occupancy	-1/2h at 8am, at 12:30pm and at 5:00pm	-1h at 6:30am, at 12:30pm and at 6:00pm	-25% occupancy from 9am to 10pm
Living room	Heating	-8am to 10pm	-Off	-Weekdays: Heating on from 7am-9am and 4pm-11pm -Weekends: Heating on in all rooms from 07:00-23:00
	Occupancy	-8am to 10pm	-8am to 10pm	-75% occupancy from 9am to 10pm

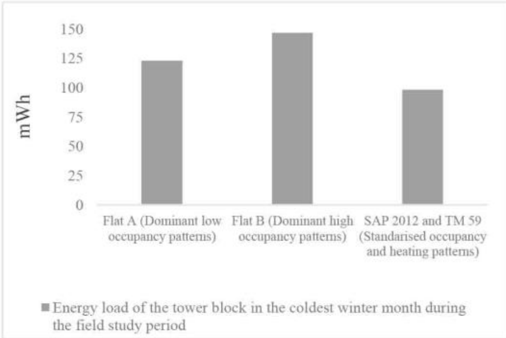


Figure 6: Predicted heating energy use of the tower block in a winter month in Jan 2017 using three scenarios; dominant low and high patterns as well as standardised patterns

It can be seen that the predicted heating energy consumption of the tower block using Flat A scenario (low occupancy patterns) is 20% less than Flat B scenario (high occupancy patterns). In addition, the standardised patterns (TM and SAP), predicted the lowest energy use, which is around 40% less than Flat B' scenario.

The study presents that the occupancy and energy use profiles of the building can be affected by the energy use behaviour of the occupants as well as the buildings physical issues, which in this case are dampness, mould and condensation. These dominant energy and occupancy patterns result in predicting a different heating energy use during the winter season compared against the standardised patterns, which shows the importance of incorporating the exemplary schedules into the building simulation tools to predict feasible building performance.

Conclusion

This study investigates the effect of occupancy and energy use patterns on predicting the building energy performance during the winter season in a residential tower block in London Borough of Newham (LBN). The study used a questionnaire-based survey on the occupants' energy use behaviour, as well as building energy simulation modelling and analysis in order to assess the effect of people's energy use patterns on the buildings energy performance. The focus of this paper is on the winter season as it was found that the building uses significant heating energy in the cold seasons mainly due to the hyghrothermal issues.

The results of the questionnaire survey presented that the occupants' energy use behaviour, and socio-demographic backgrounds have an impact on the energy use of the properties. It was also confirmed that having children in the family results in increasing the heating energy use. In addition, due to the significant damp and condensation issues, the occupants tend to use more heating energy to decrease the effective of dampness. This paper also attempted to compare, quantify and analyse the impact of occupants' energy consumption patterns on building energy performance using dominant scenarios based on real occupancy and energy use patterns obtained from the survey; Flat A and Flat B. The predicted energy use of the building using the dominant patterns were then compared against the outcomes from using the benchmark methodologies (SAP and TM). The results from the simulation showed that the energy consumption of the case study in the winter season is almost 40% less when using the benchmark patterns in comparison to when using the dominant high occupancy and energy use profile (Flat B), while it is 20% less when using the low occupancy profile (Flat A).

The study shows that it is not always possible to rely on standard methodologies for predicting a feasible building performance for a case study with hydrothermal issues as the occupants' energy use patterns might be different. In addition, the occupants' age and economic levels also have an impact on the energy use. To reduce the gap between the actual and the predicted simulation results, the occupants' energy use behaviour as well as the reliable energy use patterns need to be methodically considered in simulation modelling as a key parameter to ensure the low energy use during the operational stage.

Acknowledgement

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Appendix VIII: The International Conference on Sustainable Design of the Built Environment (SDBE) 2017

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 CO_2 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 CO2 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 CO2 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 efficiency.

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.

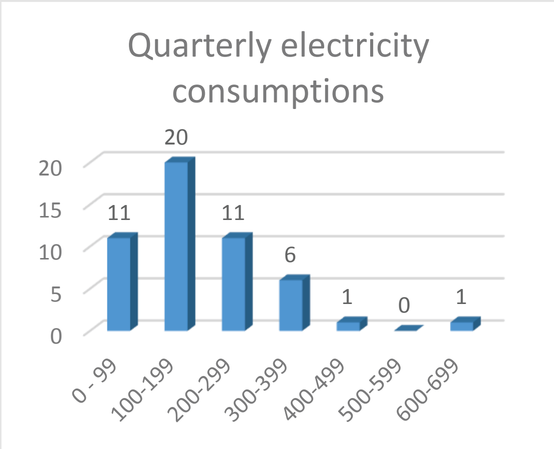
Based on the records presented above, the response rates of the questionnaires between the two estates are different. A few internal and external factors affecting occupants' willingness of collaboration were identified and discussed as below. Besides, lessons learnt and potential improvement for future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



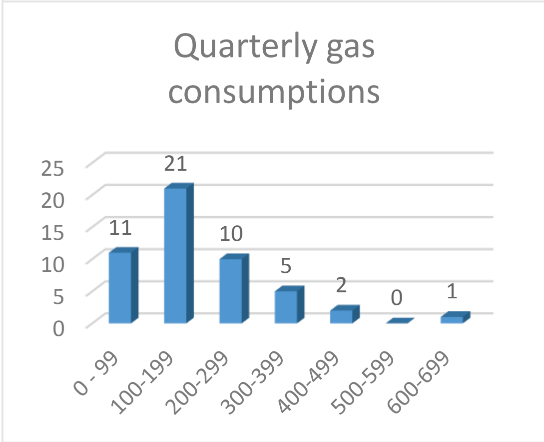
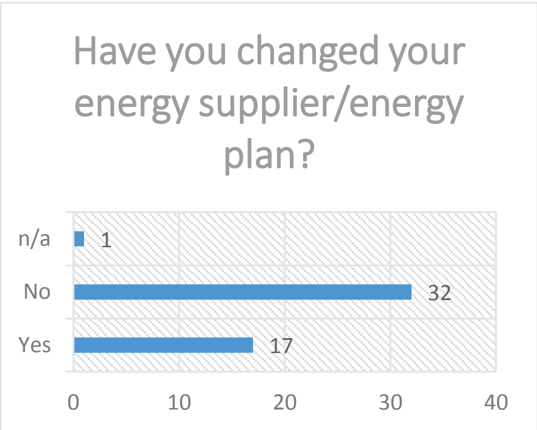


Figure 1. quarterly electricity bills

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?



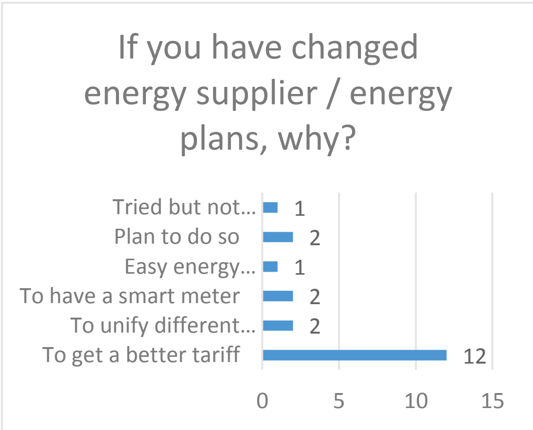
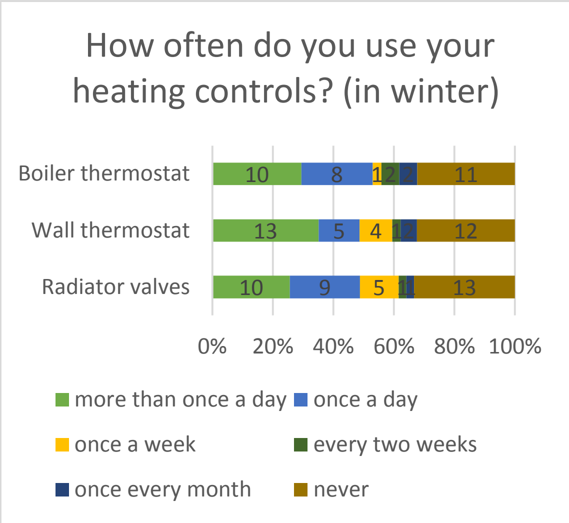


Figure 3. Have you changed your energy supplier/energy plan? If yes, why?

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



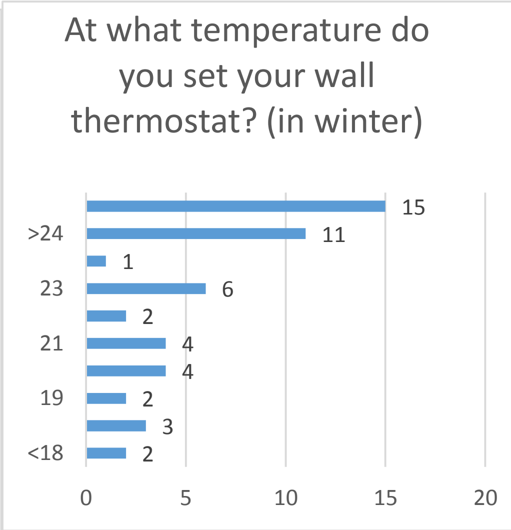


Figure 4. how often do you use your heating controls?

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

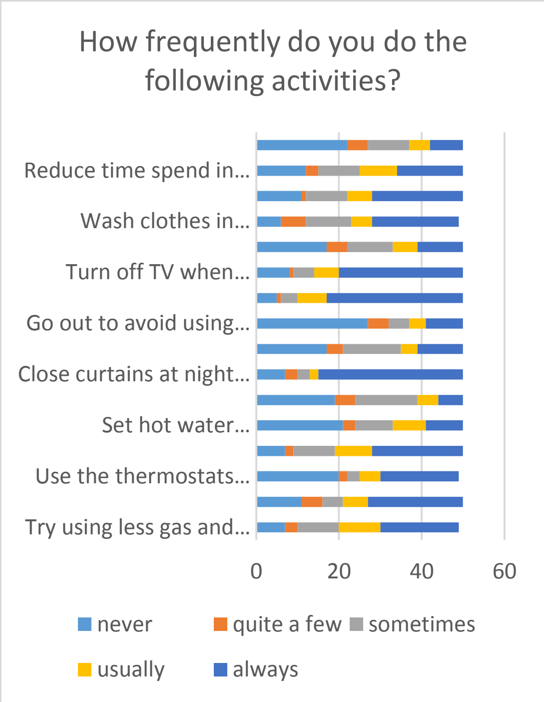


Figure 6. preferred energy related behaviours

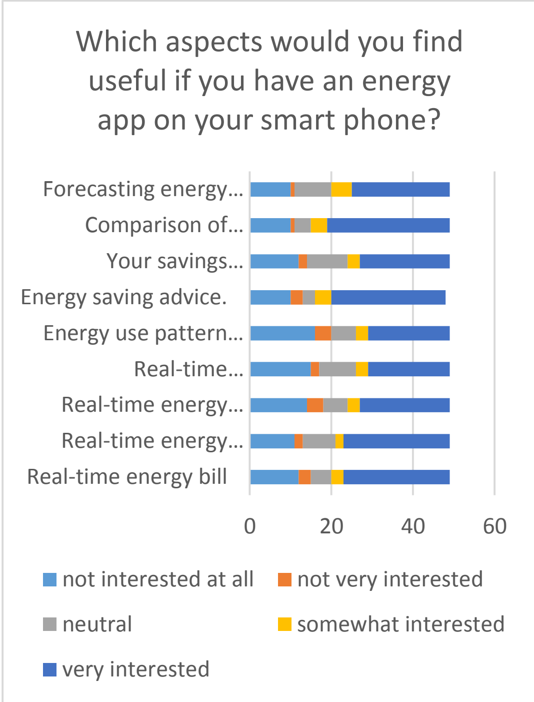
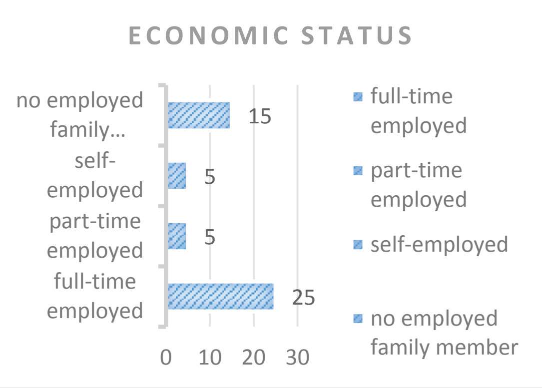


Figure 7. Preferred smart application aspects

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



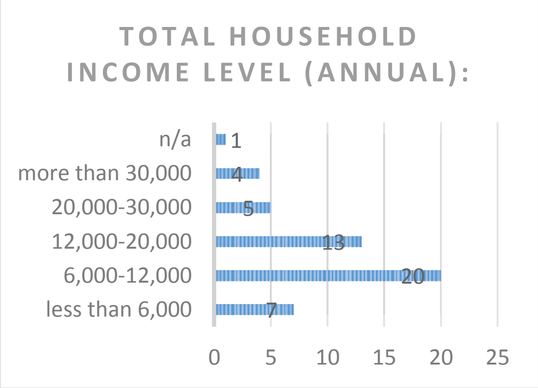


Figure 8. economic status of the family members

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 CO2 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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Appendix IX: The 33rd PLEA International Conference on Passive and Low Energy Buildings (PLEA 2017)

Shi. W., Elsharkawy, H. and Abdalla, H. (2017). An Investigation into Energy Consumption Behaviour and Lifestyles in UK Homes: Developing A Smart Application as A Tool for Reducing Home Energy Use. In: the 33rd PLEA International Conference on Passive and Low Energy Buildings (PLEA 2017). Edinburgh, United Kingdom, 2-5 July 2017. Edinburgh: Network for Comfort and Energy Use in Buildings (NCEUB).

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2nd February 2017

Dear Wei,

Project Title:	**Energy Performance Evaluation of 2 types of Domestic Housing Developments and their implications with Occupants' Behaviour**
Principal Investigator:	**Prof. Hassan Abdalla**
Researcher:	**Wei Shi**
Reference Number:	**UREC 1617 04**

I am writing to confirm the outcome of your application to the University Research Ethics Committee (UREC), which was considered by UREC on **Wednesday 14 September 2016.**

The decision made by members of the Committee is **Approved**. The Committee's response is based on the protocol described in the application form and supporting documentation. Your study has received ethical approval from the date of this letter.

Should you wish to make any changes in connection with your research project, this must be reported immediately to UREC. A Notification of Amendment form should be submitted for approval, accompanied by any additional or amended documents: http://www.uel.ac.uk/wwwmedia/schools/graduate/documents/Notification-of-Amendment-to-Approved-Ethics-App-150115.doc

Any adverse events that occur in connection with this research project must be reported immediately to UREC.

Approved Research Site

I am pleased to confirm that the approval of the proposed research applies to the following research site.

Research Site	Principal Investigator / Local Collaborator
UEL Campus	Prof. Hassan Abdalla

Approved Documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
UREC application form	3.0	1 February 2017
Debrief Sheet	3.0	1 February 2017
Annex 1	3.0	1 February 2017
Annex 2	1.0	29 August 2016
Survey schedule	1.0	29 August 2016
Permission letter from Newham council	1.0	1 February 2017
Questionnaire	2.0	1 February 2017

Approval is given on the understanding that the UEL Code of Practice in Research is adhered to.

The University will periodically audit a random sample of applications for ethical approval, to ensure that the research study is conducted in compliance with the consent given by the ethics Committee and to the highest standards of rigour and integrity.

Please note, it is your responsibility to retain this letter for your records.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Fernanda Silva

Fernanda Silva
Administrative Officer for Research Governance
University Research Ethics Committee (UREC)
Email: **researchethics@uel.ac.uk**

17th April 2018

Dear Wei Shi,

Project Title:	**Energy Performance Evaluation of 2 types of Domestic Housing Developments and their implications with Occupants' Behaviour**
Researcher:	**Wei Shi**
Principal Investigator:	**Dr Heba Elsharkawy**
Amendment reference number:	**AMD 1718 21**
UREC reference no of original approved application:	**UREC 1617 04**

I am writing to confirm that the application for an amendment to the aforementioned research study has now received ethical approval on behalf of University Research Ethics Committee (UREC).

Should you wish to make any further changes in connection with your research project, this must be reported immediately to UREC. A Notification of Amendment form should be submitted for approval, accompanied by any additional or amended documents: http://www.uel.ac.uk/wwwmedia/schools/graduate/documents/Notification-of-Amendment-to-Approved-Ethics-App-150115.doc

Approved Research Site

I am pleased to confirm that the approval of the proposed research applies to the following research site:

Research Site	Principal Investigator / Local Collaborator
UEL Campus	Dr Heba Elsharkawy

Summary of Amendments

Change of Principal Investigator from: Prof. Hassan Abdalla to Dr Heba Elsharkawy.

Extended focus-group interview, around 10 participants based on the same data sample will be invited to express their thinking on a number of smart phone app features. The interview will take less than two hours and only comprise a small proportion of the research.

the focus group is designed in order to assist in explaining data collected in the first phase (questionnaire survey):

Qualitative data will be collected during the focus-group to interpret quantitative data collected from questionnaire survey. So, both quantitative and qualitative data will be collected and sequential explanatory methodological design is applied to this research.

Correlations between occupants' behaviour and energy performance has been identified based on the 1st phase investigation. But how to reflect the research findings into reality and get occupants benefited is also significant. An innovative smart phone application is proposed to provide behavioural intervention to the occupants based on the above research findings. It is believed that focus-group interview will help to inform for the application development which is more suitable and adoptive for the occupants. in addition, the improved research methodology will add extra value to the research.

Ethical approval for the original study was granted on 2nd February 2017.

Approval is given on the understanding that the UEL Code of Good Practice in Research is adhered to.

With the Committee's best wishes for the success of this project.

Please ensure you retain this letter, as in the future you may be asked to provide evidence of ethical approval for the changes made to your study.

Yours sincerely,

Fernanda Silva
Administrative Officer for Research Governance
University Research Ethics Committee (UREC)
Email: **researchethics@uel.ac.uk**