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An investigation into energy consumption behaviour and lifestyles in UK homes: Developing a smart application as a tool for reducing home energy use

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Abstract: The research asserts that several domestic retrofit programmes in the UK have not achieved the expected levels of energy saving. Energy consumption is not only reliant on physical characteristics of buildings, but also on the consideration of socio-cultural and economic factors. One of the issues is that the predicted home energy use does not reflect the actual energy consumed – a phenomena acknowledged as the 'Building Performance Gap'. This research examines the factors that impact on domestic energy performance in response to this phenomenon. It adopts a concurrent mixed-method research design where the research method is primarily questionnaires to understand occupants' energy consumption behaviour and lifestyle and develop a viable methodology to improve this. The solution could be the development of a smart application that addresses most energy consumption habits and behaviours connected to smart meters. As a result, occupants will be advised in real-time with appropriate energy-related behaviours if inefficient energy consumption is detected. Besides, the application will also comprise of a simplified Building Energy Simulation (BES) interface to provide building energy simulation results and evaluation. It is believed that this tool could potentially increase occupants' awareness of energy consumption behaviour and reduce the Building Performance Gap.

Keywords: Smart Application, Building Energy Simulation (BES), energy efficiency application, domestic building stock, occupants' behaviour

1. Introduction

Recent report (Environmental Change Institute, 2005) shows that the average growth of energy demand in the UK is 7.3% in 1990 – 2003. However, the growth of energy demand in the UK housing sector alone is 17.5% in the same period. Since 1970, the energy efficiency in the UK old existing dwellings has not improved too much. Due to the rapid growth of residential housing developments, the housing energy demand has increased by 32% (Climate Change Act, 2008). Heating is noted as the main energy consumption source which contributes with 60% of all housing energy demand.

This study focuses on the energy reduction of existing domestic buildings in the UK. Although the UK government has been proactively developing policies and programmes aiming to improve the uptake and delivery of retrofit schemes since the 1970s, householders have not always been supporting it, partially, due to lack of knowledge, awareness, financial and technical support (Long et al, 2014). The paper investigates the current conditions and problems of the low-carbon retrofit market with respect to occupants' energy consumption behaviours and home energy performance during this process. A number of issues concerning Building Energy Simulation (BES) and Energy Efficiency tools are also discussed such as the inaccurate results of energy simulation, and the influences of smart metering devices on people's behaviour. One major issue highlighted is occupants' behaviour and its impacts on building energy performance. The findings will contribute to the development of a smart application that aims to address most energy consumption habits and behaviours connected to smart meters.

2. Research Context - Low-carbon retrofit and occupants' behaviours

Along with the establishment of the Climate Change Act in 2008 which sets out the UK's ambitious target of 80 percent carbon dioxide emission reductions by 2050, the UK government accelerates the process of domestic energy conservation. For example, the energy efficiency standards (DCLG, 2013a) were tightened in order to meet the targets. A number of initiatives have been launched to support the successful delivery of low-carbon retrofit projects, such as the Decent Homes, the Warm Front, the Green Deal, the Carbon Emissions Reduction Target (CERT), the Community Energy Saving Programme (CESP), and the Landlord Energy Saving Allowance (LESA) (Dowson et al, 2012). Although the majority of the schemes have already been completed, the current major policies, such as the Feed-in Tariff (Fit) and the Renewable Heat Incentive (RHI), are still playing important roles in the retrofit projects (Dowson et al, 2012).

To evaluate the feasibilities of the abovementioned programmes, several issues have been assessed. One of the issues is to identify proper project scale and approach. It is suggested that the wider the project spread, the more efficient the project will be (Webber et al., 2015; Smith and Swan, 2012). Besides, there is a large variety of retrofit strategies and technologies that have been developed, it is crucial to apply the most appropriate approaches; the housing physical conditions and socio-economic issues (Ma et al, 2012). In addition, the projects have to be delivered in high standards as it will directly impact on the success or failure of the project (Gilbertson et al., 2008 and Long et al., 2014). This point of view has been also reflected in several project reports (LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2012 and 2014) which are developed by the specializing organizations, such as London Development Agency (LDA) and Technology Strategy Board (TSB). Nevertheless, the retrofit projects still do not meet our expectations even if they are successfully delivered. The energy performance of buildings is subject to a wider range of issues, such as technical, social and behavioural issues which are not thoroughly considered by the construction industry stakeholders from designers to policy makers. We call these factors 'hard-to-quantify' factors. The way that occupants operate their homes will hugely impact on the energy performance (Greening et al., 2000; Khazzoom, 1980; Saunders, 1992). It is, therefore, crucial to get these 'hard-to-quantify' factors considered in the earlier project stages (Sorrell and Dimitropoulus, 2008; Hadjri and Crozier, 2009; Preiser et al., 1988; Zimring and Reizenstein, 1980; Chiu et al., 2004). This phenomenon is called Building Performance Gap (Sunikka-Blank and Galvin, 2016).

Among issues identified above, the research focuses on investigating the correlations between occupants' behaviours and energy performance. Few suggestions have been raised up such as the providing instruction manuals and training occupants (LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2012 and 2014). As supplementary of the existing approaches, more efforts can be made on changing occupants' behaviours through the development of a smart application connected with smart meters. The methodological approaches tackling these issues will be explained in the section below.

3. Research Methodology

The research question is: How do occupants' behaviour, lifestyle patterns and socio-economic issues impact on the actual energy performance after the low-carbon retrofit project delivery? The research is based on the assumption that a numbers of 'hard-to-quantify' factors, such as occupants' energy-related behaviours and attitudes towards low-carbon retrofit, have not been thoroughly taken into consideration of the development of energy simulation tools.

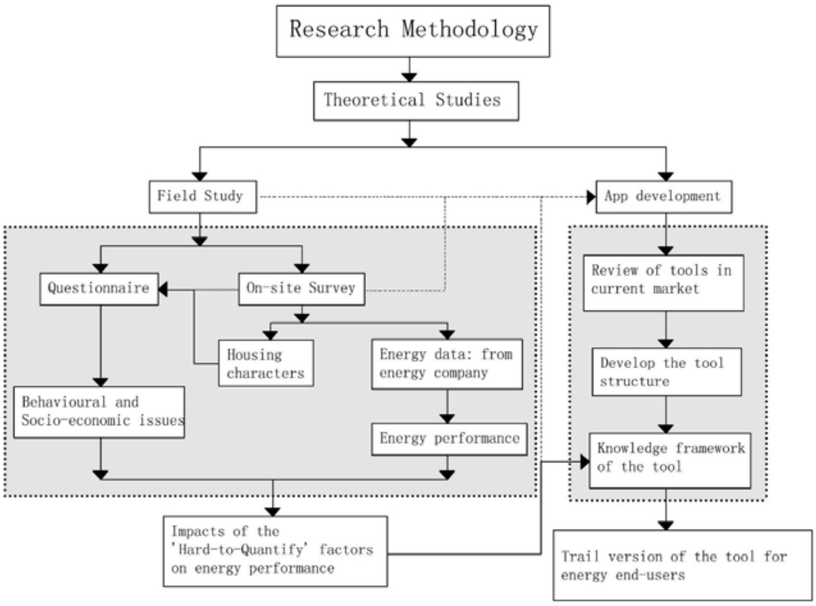

Figure 1. Research methodology

This research examines the factors that impact on domestic energy performance in response to BPG. It adopts a concurrent mixed-method research design where the research method is primarily semi-structured questionnaires to understand occupants' energy consumption behaviour and lifestyle and develop a viable methodology to improve this. Collected data will be analysed to find out the correlations between occupants' behaviour and energy performance by using Excel and SPSS. Research findings will help to inform the design specification of the innovative smart application. On the other hand, the review of Energy Efficiency Applications in the market is being conducted to assess their successes and falls. Innovative aspects and the way how the behavioural interventions they bring to the occupants will be thoroughly studied to inform the design specification of the smart application.

4. A review of energy efficiency applications

4.1 Advanced Metering Infrastructure (AMI) and smart meters

Due to the transition of the UK's energy network, the Advanced Metering Infrastructure (AMI) and smart meters has been developing fast. Through an experimental, large-scale case study, Gans et al (2013) monitored residential electricity consumption since April 2002 when the pre-payment meters were applied. Data collected between two different periods (with pre-payment meters and with advanced metering systems) show 11 to 17 percent decrease in energy consumption. The reason of this is that the new advanced metering system reveals real-time electricity usage to the occupants. It was also proven (Gans et al, 2013) that the occupants do respond to the provided information by using less energy with more careful behaviours. Same point of view is also supported by Stromback et al (2011), Zhang et al (2016) and Wesley Schultz et al (2015).

A number of scholars (Rajagopalan et al., 2011; Schultz et al., 2015; Carroll et al., 2014; Hargreaves et al., 2017) disagree with the positive role that smart meters play in energy conservation. The general reasons include the invasion of privacy, increased energy bills due to smart meters and the lack of willingness to invest on it (Rajagopalan et al., 2011). In addition, Schultz et al (2015) proved that real-time feedback from IHDs did not help to reduce energy consumption effectively if the IHDs are only framed with energy consumption and costs. A 7 percent electricity reduction was achieved only in the homes where IHDs were installed with comparison energy consumptions. Same point of view is also supported by Carroll et al (2014) and Hargreaves et al (2017). Besides, it has been asserted (Hargreaves et al, 2017) that training occupants and making them familiar with new technologies are important and time consuming. However, there are not sufficient supports available at this moment. Based on the reviews above, the knowledge gaps have been identified as below.

One of the reasons of BPG is that occupants' behavioural and socio-economic issues have not been thoroughly accounted for as those factors are usually unquantifiable (Sunikka-Blank and Galvin, 2016). More methodical efforts can be made in considering these 'hard-to-quantify' factors into the energy use reduction equation. For example, self-employed occupants will spend more time in their houses and use more energy than employed occupants in weekdays. Besides, occupants who love outdoor activities will spend less time in their houses and use less energy than the ones like staying at home. As the result, number of occupants, their energy use patterns and lifestyles need to be analysed and converted into parameters for the energy calculation. Besides, as the real-time monitoring system has become one of the well-established smart home technology, to provide real-time behavioural suggestions to occupants becomes possible. In addition, due to the success of Homeselfe in the USA, more effort can be made on developing a simplified energy mock-up application for occupants in the UK in order to increase their energy awareness and the uptake rate of retrofit projects.

4.2 Energy Efficiency tools and applications in the domestic sector

In the UK, the smart grid is a bi-directional energy system that does not only transmit energy demands from transmission centre to users, but also transmit energy feedbacks back to the transmission centre. The importance of this feedback mechanism has been realized for few decades (Darby, 2010). As a bi-directional network, the development smart grid requires installations of smart devices in each home to effectively manage energy. The smart metering device can connect to an in-home display (IHD) for checking the consumptions and credit balance (The Cabinet Office et al, 2011). The energy companies are responsible for installing smart meters in the aspects of privacy, security, product quality and the needs of vulnerable consumers. The smart meter captures real-time energy consumptions of each household and transmit data back to energy companies for monitoring purposes. In addition, energy efficiency applications are developed based on the smart metering devices to help occupants understanding energy consumptions and effectively saving energy (Zhang et al, 2016).

Features	British Gas	EDF Energy	E.ON	Npower	YourEnergy	OVO	Hive Active Heating	Carbon Calculator	efergy engage	Homeselfe
user-friendly interface	●	●	●	●	●	●	●	●	●	●
meter readings (manual)	●	●	●	●	●	●				
meter readings (automatical)									●	
real-time monitoring and					●		●		●	
visualized results	●	●	●	●	●	●	●	●	●	●
perspective use				●		●		●	●	●
energy consumption	●			●				●		●
energy-related behaviours								●		
energy saving			●	●	●			●		●
account management	●	●	●	●	●	●			●	
contact energy company	●	●	●	●	●	●	●		●	
switch supplier	●	●	●	●	●	●				
voice recognition						●	●			
rewards			●							

Figure 2. Comparison table of major energy efficiency apps in the current market developed by researcher

Several energy efficiency applications available in the market from major energy providers in the UK (British Gas, 2017; EDF Energy, 2017, E.ON UK, 2017, Npower, 2017, and Scottish Power, 2017) (such as British Gas app, EDF Energy app and E.ON app) and a number of applications developed from specializing companies (OVO Energy, 2017; apkpure, 2017; efergy engage, 2017 and Homeselfe, 2017) (such as efergy engage, OVO and Homeselfe) are compared and demonstrated in Figure 1. The applications are evaluated against innovativeness and influences to occupants. According to Figure 1, applications developed by energy companies have similarities in most of the aspects: user-friendly interfaces, simple operation, easy-to-understand graphics and illustrations, and improved customer services. Besides, energy saving advices are available in E.ON UK App, Npower App and YourEnergy App. It is noticed that only YourEnergy app can provide real-time energy monitoring and control for heating and hot water. Comparison scenarios, which has been proven one of the most effective way to reduce energy consumptions, are only found in British Gas App and Npower app among all applications developed by energy companies. On the other hand, more innovative aspects can be found in the applications developed by specializing companies, such as energy saving advices and perspective energy consumptions in Lotus Green Carbon Calculator, efergy engage, OVO Energy and Homeselfe. Furthermore, the energy consumption comparisons are provided by Lotus Green Carbon Calculator and Homeselfe. In addition, the behavioural suggestions, which is not available in major energy companies' applications, are provided by Lotus Green Carbon Calculator.

Both BES tools and energy efficiency applications are applied for reducing energy consumptions. the review of these tools provides fundamental and comprehensive knowledge on the developing the innovative smart application. In general, energy efficiency applications provide more straightforward information and less in-depth professional knowledge than BES tools. Several issues have been found for its future developments. For example, some innovative aspects have been found but have not been widely spread, such as comparison scenarios and behavioural suggestions. Besides, more effort can be made on providing real-time behavioural suggestions to occupants based on the existing energy monitoring system. Although energy consumption mock-up and audit has been proven success (Barrett, 2016) in the US, it has not been adopted in the UK. In addition, a potential conflict has been identified by Hannon et al (2013) that energy efficiency applications developed by energy companies are not reliable as they make profit on selling energy units. More efforts can be made on facilitating the developments of Energy Service Companies (ESCo) as they do not sell energy units.

4. Discussion

To tackle retrofit efficiency and BPG, several issues have been addressed above, such as practical retrofit delivery, occupants' behaviour and energy efficiency tools. Although problems are found in different stages of the project, the research primarily focuses on how occupants operate their houses in the maintenance stage. We try to maintain high-stand retrofit delivery by regulating occupants' behaviours in more innovative way rather than educations and trainings. Besides, evaluations of energy efficiency and smart metering systems helped to develop the innovative smart application as a tangible deliverable of the research.

Innovative Smart Phone Application	Components required
Instant Mode	Database: occupants' behaviour & energy performance
Potential Mode	Simplified simulation framework
	Comparison scenarios
	Visualized results
Both	User-friendly interface

Figure 3. the packages of the app and components required

Figure 3 illustrated above shows the design specification of the innovative smart phone application. To provide real-time behavioural suggestions to the occupants, the correlations between energy performance and occupant's behaviour need to be thoroughly investigated. In addition, the experience feedback completed by occupants will also help to decide the options and of the application design specifications. Besides, the application also aims to provide an opportunity for occupants using energy simulation tools to increase their awareness and consequently increase project take-up rate through the energy 'mock-up' in the 'Potential Mode' of the application. Without in-depth professional knowledge, occupants need an application with simplified procedure, visualized results and user-friendly interface. Comparison scenarios is also incorporated into the application suite.

As demonstrated in the Figure 4, the application is split into 'Instant Mode' and 'Potential Mode'. As the tool is designed for occupants, its development will be based on simplified building energy simulations, user-friendly interface and visualized results. The real-time energy consumption will be monitored and advised with tailored behavioural advice according to the real-time energy use patterns in the 'Instant Mode'. On the other hand, occupants will be able to visualise and understand energy performance of their homes and potential savings by applying different retrofit approaches in the 'Potential Mode'. The most appropriate retrofit approaches will be presented with straightforward results such as predicted energy savings, financial savings, and pay-back period for the investment. It is to be noticed that the 'Instant Mode' needs to be connected to smart meters. On the other hand, the 'Potential Mode' can be operated independently and will be available for all types of homes.

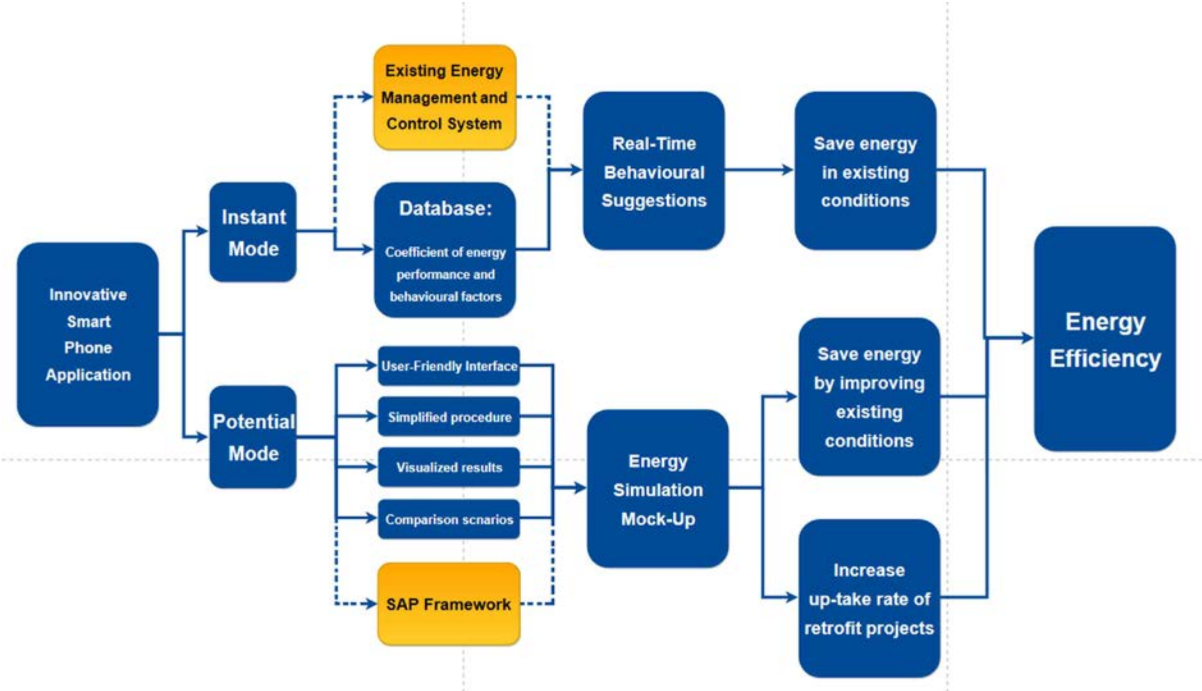

Figure 4. structure of the innovative smart phone application

Occupants with different occupants and socio-economic status will differently operate the houses. The application will quantify these factors and automatically identify the comfort zone of the energy consumptions accordingly. A full-time worker who loves outdoor activities may get alerted even less energy is being consumed than an unemployed mother who needs to look after her babies. From a list of energy-related behaviours, we will find out the most efficient one and suggest it to the occupants when over-use is detected.

5. Conclusion

In this paper, a design specification of innovative smart application to increase energy efficiency has been presented. The idea comes from the interactions between occupants and smart metering systems and aims to reduce the BPG by improving occupants' behaviours. The research starts with comprehensive literature review to identify problems. It followed by the investigation of the correlations between occupants' behaviour and energy performance through the distribution of the questionnaires in two residential tower blocks in London.

The research provides an innovative angle that facilitates the implementation and efficiency of the retrofit project through a 'bottom up' approach by focusing on the occupants. It allows occupants to run simplified energy simulation and provides them with real-time energy monitoring and advice on reducing energy consumption. Besides, the correlation between occupants' behaviour and home energy performance helps to form the new function of real-time behavioural suggestions by connecting with smart meters. As a result, energy companies will have better understanding on the occupancy patterns and behaviours of the homes. Appropriate interventions can be made from energy companies to investigate potential problems and make sure that energy is performed properly. So the implementation of the innovative smart phone application will also help to tighten the relationship between energy management level and energy end users.

6. References

Barrett, D. (2016). Be Successful & Inspired. [online] Available at: < http://danabarrett.com/success-owning-your-own-business/> [Accessed 14 March 2017].

Cabinet Office, Department of Energy and Climate Change and Department for Communities and Local Government. (2011). Behavioural Change and Energy Use. London: The Cabinet Office Behavioural Insights Team.

Carroll, J., Lyons, S & Denny, E. (2014). Reducing household electricity demand through smart metering: The role of improved information about energy saving, *Energy Economics*, 45 (2014), pp234-243.

Chaudhari, R. B., Dhande, D. P & Chaudhari, A. P. (2014). Home Energy Management System. In the International Conference on Modelling and Simulation in Engineering and Technology ICMSET-2014. Beijing, China. 15-16 Feb 2014. ICMSET: Beijing.

Climate Change Act 2008. London: HMSO.

Darby, S. (2010). Smart metering： what potential for householder engagement? *Building Research & Information,* (2010), 38 (5), 442-457.

Department of Energy and Climate Change (DECC). (2009). *The UK low carbon transition plan*. London: National strategy for climate and energy, DECC.

Department of Energy and Climate Change (DECC). (2013). *UK Renewable Energy Roadmap*, London: DECC.

Dowson, M., Poole, A., Harrison, D & Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal, *Energy Policy*, 50 (2012), pp294 – 305.

Environmental Change Institute. (2005). *40% house*, Oxford: Environmental Change Institute, University of Oxford.

Gans, W., Alberini, A & Longo, A. (2013). Smart meter devices and the effect of feedback on residential electricity consumption: Evidence from a natural experiment in Northern Ireland, *Energy Economics*, 36 (2013), 729-743.

Gilbertson, J., Green, G., Ormandy, D & Thomson, H. (2008). Good housing and good health? A review and recommendations for housing and health practitioners. UK: A Sector Study Housing Corporation.

Greening, L. A., Greene, D. L and Difiglio, C. (2000). Energy efficiency and consumption — the rebound effect — a survey, *Energy Policy*, 28 (2000), 389-401.

Hadjri, K and Crozier, C. (2009). Post-occupancy evaluation: purpose, benefits and barriers. *Facilities*, Vol 27 Iss: 1/2, 21-33.

Hannon, M. J., Foxon, T. J & Gale, W. F. (2013). The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition, *Energy Policy*, 61(2013), pp 1031-1045.

Hargreaves, T., Wilson, C & Hauxwell-Baldwin, R. (2017). Learning to live in a smart home, *Building Research & Information*, pp 1466-4321.

Khazzoom, J.D. (1980). Economic Implications of Mandated Efficiency in Standards for Household Appliances, *The Energy Journal*, 1 (4), 21-40.

Long, T. B., Young, W., Webber, P., Gouldson, A and Harwatt, Helen. (2014). The impact of domestic energy efficiency retrofit schemes on householder attitudes and behaviours. *Journal of Environmental Planning and Management,* 2014. Routledge: London.

Ma, Z., Cooper, P., Daly, D. & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, 55, pp 889-902.

Preiser, W.F.E. (1989). *Building Evaluation.* New York, NY: Plenum.

Raj Rajagopalan, S., Sankar, L., Mohajer, S & Vincent Poor, H. (2011). Smart meter privacy: A utility-privacy framework. *In the 2011 IEEE International Conference on Smart Grid Communications (SmartGridComm)*. Brussels, Belgium. 17-20 Oct 2011. IEEE: Brussels.

Saunders, H. D. (1992). The Khazzoom-Brookes Postulate and Neoclassical Growth, *The Energy Journal*, 4 (1992), 131-148.

Sorrell, S and Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics*, 65 (3), 636-649.

Stromback, J., Dromacque, C & Yassin, M. H. (2011). *The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison*. The European Smart Metering Industry Group (ESMIG): Brussels.

Sunikka-Blank, M and Galvin, R. (2016). Irrational homeowners? How aesthetics and heritage values influence thermal retrofit decisions in the United Kingdom, *Energy Research and Social Science*, 11 (2016), 97-108.

Technology Strategy Board. (2012). *Retrofit Revealed, The Retrofit for the Future projects – data analyse report*. Swindon: Technology Strategy Board.

Technology Strategy Board. (2014). *RETROFIT FOR THE FUTURE – Reducing energy use in existing homes*. Swindon: Technology Strategy Board.

United Nations. (1992). *United Nations Framework Convention on Climate Change*. New York: United Nations.

United Nations. (1998). *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. New York: United Nations.

Webber, P., Gouldson, A and Kerr, N. (2015). The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation, *Energy Policy*, 84 (2015), 35-43.

Wesley Schultz, P., Estrada, M., Schmitt, J., Sokoloski, R & Silva-Send, N. (2015). Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms, *Energy*, 90(1), 351-358.

Zhang, X., Shen, J., Yang, T., Tang, L., Wang, L., Liu, Y & Xu, P. (2016). Smart meter and in-home display for energy savings in residential buildings: a pilot investigation in Shanghai, China, *Intelligent Buildings International*, pp1-23.

Zimring, C. M & Reizenstein, J. E. (1980). Post-Occupancy Evaluation: An Overview, *Environment and Behavior*, 12 (4), 429-450.