PLEA 2017 EDINBURGH
Design to Thrive

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: 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 socio-economic and cultural factors. One of the issues is that the predicted home energy use may not reflect the actual energy consumed – a phenomena acknowledged as the 'Building Performance Gap'. This study 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 connected to smart meters that addresses energy consumption habits and behaviour. As a result, occupants will be advised in 'real-time' with appropriate energy-related behaviour once inefficient energy consumption actions 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, reduce domestic energy consumption and ultimately reduce the Building Performance Gap (BPG).

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

Introduction

It has been reported that (Environmental Change Institute, 2005) the average growth of energy demand in the UK was 7.3 percent between 1990 and 2003. However, in the same report, it has been asserted that the growth of energy demand in the UK housing sector alone is 17.5 percent in the same period. Besides, due to the rapid growth of residential housing developments, the housing energy demand increased by 32 percent by 2008 (Climate Change Act, 2008). Heating is noted as the main energy consumption source which contributes with 60 percent of all housing energy demand (Climate Change Act, 2008). However, the energy efficiency in the UK existing dwellings has not improved much since 1970s.

This study focuses on possible routes for energy reduction in 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 for domestic buildings since the 1970s, householders have not always been supportive to effective delivery, 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 in regards to occupants' energy consumption behaviour and home energy performance during this process. A number of significant factors concerning Building Energy Simulation (BES) and Energy Efficiency tools are also discussed such as the imprecise results of building energy simulation, and the influences of smart metering devices on people's behaviour. One major issue highlighted is occupants' behaviour and its impact on building energy performance. The findings will contribute to the development of a smart application connected to smart meters that aims to address most energy consumption habits and behaviour.

Research Context - Low-carbon retrofit and occupants' behaviour

Along with the establishment of the Climate Change Act (2008) which set out the target of 80 percent CO_2 reductions by 2050, the UK government aims to accelerate the process of domestic energy conservation. For example, some energy efficiency standards (DCLG, 2013a) were tightened in order to meet the targets. There has also been a large variety of retrofit strategies and technologies that have been developed. A number of programmes 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, whilst a few scrapped, 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 feasibility 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, it is crucial to apply the most appropriate approaches; the housing physical conditions and socio-economic issues (Ma et al, 2012). In addition, the energy upgrade works 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 issue has also been reflected in several project reports (LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2012 and 2014) which are developed by London Development Agency (LDA) and Technology Strategy Board (TSB). Nevertheless, the retrofit projects still might not meet the expectations even if they are fully delivered, partially due to occupants' energy consumption which would then impact on the energy performance of their homes.

The energy performance of buildings is subject to a wider range of variables, such as technical, social and behavioural factors which are not thoroughly considered by the construction industry stakeholders from designers to policy makers. These factors are called the 'hard-to-quantify' factors. The patterns that occupants operate their homes significantly affects actual building energy performance compared to predicted energy performance (Greening et al., 2000; Khazzoom, 1980; Saunders, 1992). This phenomenon is called Building Performance Gap (Sunikka-Blank and Galvin, 2016). It is, therefore, crucial to consider these 'hard-to-quantify' factors 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).

Among issues identified above, the research focuses on investigating the correlations between occupants' behaviour and home energy performance. Several propositions have been raised such as providing instruction manuals and offering tailored training to 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' behaviour through the development of a smart application connected with smart meters. The methodological approach adopted to achieve this is explained in the section below.

Research Methodology

The research question is: How do occupants' behaviour, lifestyle patterns and socio-economic factors impact on the actual energy performance following energy-efficient retrofit project delivery? The research is based on the assumption that a number of 'hard-to-quantify' factors, such as occupants' energy-related behaviour and attitudes towards energy consumption, have not been thoroughly taken into consideration in building energy simulation tools leading to the BPG.

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 survey questionnaires to understand and analyse occupants' energy consumption behaviour and lifestyle to help develop a viable tool to improve this. The target group is occupants of two case studies in London Borough of Newham due for retrofit. Data will be analysed to find the correlations between occupants' behaviour and energy performance by using **Statistical Package for the Social Sciences** (SPSS). Research findings will help inform the design specifications of the innovative smart application. On the other hand, the review of Energy Efficiency Applications in the market has been undertaken to assess their successes and failures to help direct the new application developed by the study. Innovative aspects and methods for behavioural interventions will be thoroughly considered to inform the design specifications of the smart application.

Review and study of energy efficiency applications

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 rapidly developing. 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 behaviour. Similar results were supported by Stromback et al (2011), Zhang et al (2016) and Wesley Schultz et al (2015).

On the other hand, a few 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 feeling of invasion of privacy, increased energy bills due to smart meters and the lack of willingness to invest in it (Rajagopalan et al., 2011). In addition, Schultz et al (2015) proved that real-time feedback from Internal Home Displays (IHDs) has not helped reduce energy consumption effectively if the IHDs are only focussed on energy consumption and costs. A 7 percent electricity reduction was achieved only in the homes where IHDs were installed with comparison energy consumptions. This result has also been supported by studies 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 but time consuming. 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 factors have not been thoroughly accounted for as those factors are typically 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 prefer outdoor activities will spend less time in their homes and use less energy than others who prefer/ have to stay at home. As a result, number of occupants, their energy use patterns and lifestyles need to be analysed and converted into parameters for the energy consumption calculation. Besides, as real-time monitoring systems have become one of the well-established smart home technologies, to provide real-time behavioural suggestions to occupants becomes more conceivable. In addition, due to the success of Homeselfe (EXPLAIN briefly what this is) 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.

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 feedback back to the transmission centre. The importance of this feedback mechanism has been realized for a few decades (Darby, 2010). As a bi-directional network, the development of a 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 detailed energy consumption and credit balance (The Cabinet Office et al, 2011). The smart meter captures real-time energy consumption of each household and transmits data back to energy companies, who are responsible for fitting the smart meters, for monitoring purposes. 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).

Table 1. Comparison table of major energy efficiency apps in the current market developed by researcher

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			●							

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 Table 1. The applications are evaluated against innovativeness and influenceon 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 advice is 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 as one of the most effective ways to reduce energy consumption, 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 specialist companies, such as energy saving advice and anticipative 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.

In the current study, both BES tools and energy efficiency applications are applied for achieving the aim of reducing building energy consumption. The review of these tools provides fundamental and comprehensive knowledge on 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 development. 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 successful (Barrett, 2016) in the USA, it has not been adopted in the UK, yet. In addition, a potential conflict has been identified by Hannon et al (2013) that energy efficiency applications developed by energy companies are not reliable. The reason of this is that energy companies make profit by selling energy units to the occupants. So they may not fully work on reducing energy consumptions while compromising their profits. More efforts can be made on facilitating the developments of Energy Service Companies (ESCo) as they do not sell energy units.

Discussion

In order to effectively tackle retrofit programme effectiveness and BPG, several issues have been discussed above, such as occupants' behaviour and energy efficiency tools. Although some limitations are found in different stages of the project, the research primarily focuses on how occupants operate their homes. The study attempts to provide possible solutions for retrofit delivery by regulating occupants' behaviour in a more innovative and effective way rather than conventional education and training initiatives. Besides, the evaluation of energy efficiency and smart metering systems helped provide the preliminary step to develop the innovative smart application as a tangible deliverable of the research.

Table 2 The packages of the app and components required (Author)

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

Table 2 shows the proposed 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 retrofit project uptake rate through the energy 'mock-up' in the 'Potential Mode' of the application for those whose homes are due for retrofit. Without in-depth professional knowledge, occupants need an application with a simplified procedure, visualized results and user-friendly interface. Comparison scenarios is also incorporated into the application suite.

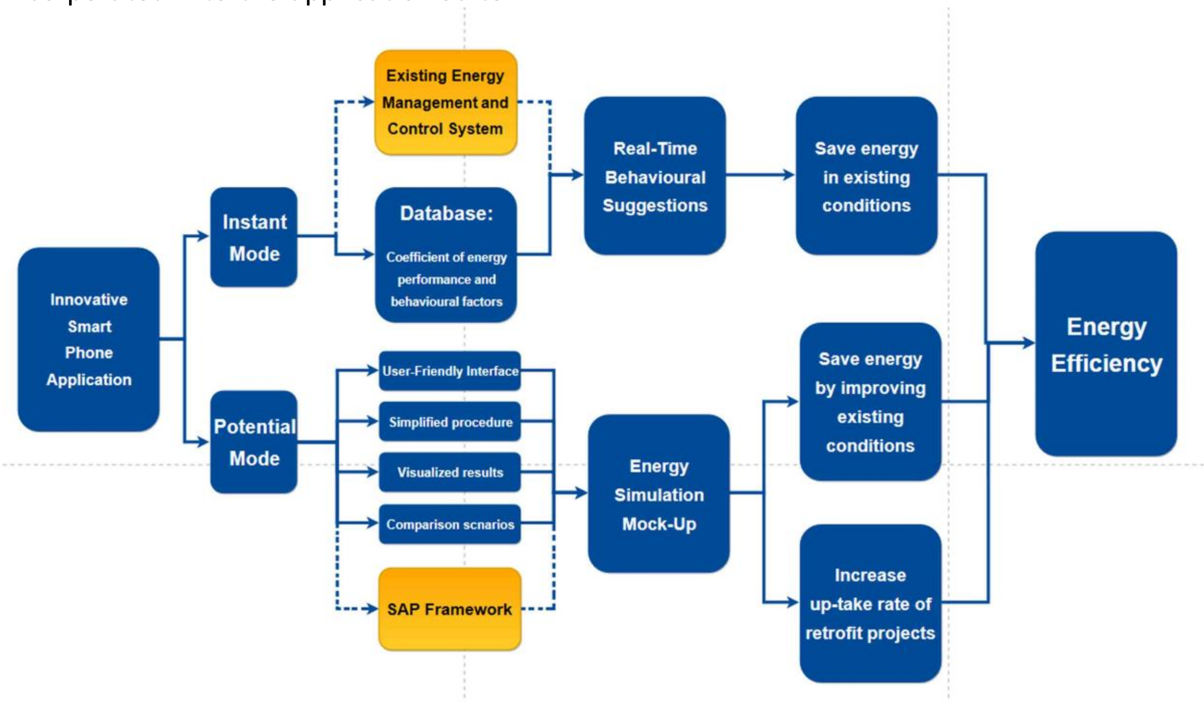

Figure 1. The proposed structure of the innovative smart phone application

As demonstrated in Figure 1, 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.

As discussed, occupants with different demographic and socio-economic status will differently operate their homes. The smart application will quantify these factors and automatically identify the appropriate range for energy consumption accordingly. From a list of particular energy-related behaviours, the most efficient pattern and range of energy consumption will be consolidated and suggested to the occupants when over-use of energy is detected.

5. Conclusion

In this paper, a design specification of an innovative smart application to increase energy efficiency of homes has been presented. The concept developed from the interactions between occupants and smart metering systems aiming to reduce the BPG by improving occupants' energy consumption behaviour. The research starts with a comprehensive literature review to highlight some significant aspects. This will be followed by the investigation of the correlations between occupants' behaviour and energy performance by collecting and analysing 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 correlations 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 of the energy consumption patterns and behaviour of the homes due for retrofit. Appropriate interventions can be made from energy companies to investigate potential problems to be addressed. So the implementation of the innovative smart phone application will also help strengthen 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].

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.

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.

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.

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.

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.

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