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Influencing Human Behaviour to Optimise Energy in Commercial Buildings

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Research in Progress

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Abstract

This paper discusses the impact of user energy choices on building energy demand, and how energy choices could be influenced to minimise building energy consumption using information systems. Accordingly, a socio-technical framework is designed and presented, which draws upon the use of energy interventions. A novel Social-Economic-Environmental (SEE) model is presented within the socio-technical framework which is aimed at nudging inhabitants enabling them to conserve energy in the university buildings, thereby making the world a sustainable place to live. The framework takes into account the Agent-based Modelling (ABM) approach to model user energy choices and their willingness to conserve energy in buildings. This research intends to test the socio-technical framework in the next stage of this study. Finally, this paper highlights gaps and the significance of understanding how user behaviour and their energy consumption can be influenced to optimise energy in university buildings, thereby reducing global greenhouse emissions.

Keywords: Building User, Energy Use Behaviour, Agent-Based Modelling, Energy Interventions, Energy Optimisation

1 INTRODUCTION

Climate change is one of the key challenges faced globally that has posed increasing risks to natural world resources, impacting the quality of human life. Climate change and its implications have remained core topics of discussion for the past decade. However, no consensus has been built on its existence. Some believe that it is barely a natural phenomenon which is temporarily happening as it used to millions of years ago. However, recent scientific investigations and studies published in reputed books and journals such as the one in recent study (Bogdanov et al. 2019) warns about the catastrophic effects of climate change and emphasise on humanity being the source of such occurrences. Rising ocean levels, ice melting in North Atlantic, increased droughts in Australasia, and unexpected heavy snowfall in Northern Americas are all alarming indicators to human beings that climate change is real. Studies suggest that human environmental interactions and their patterns of living, consumption and extraction of natural sources are the foundations of rapid change in climate (Raymond et al.). These natural sources can be agricultural plants, poultry, animal meat, seafood and also man-made sources including, electrical energy and manufacturing factories, which cause direct or indirect creation of gases and emissions. These emissions in particular carbon emissions add in the atmosphere and boost the temperatures of air and oceans which in turn make them acidic or polluted. This natural addition of gaseous materials changes the original state of air and oceans and makes their behaviour unnatural thereby becoming the reason for climatic catastrophes on earth.

Climate scientists and experts have proposed many computational and mathematical models for estimating temperature rise, which has become one of the main causes of global warming. Also, the empirical studies on global warming explicitly prove the influence of human beings and their activities among the main causes. Many recommendations are in place for addressing global warming created by humans, among which an important one is to reduce energy use in the built environments using information systems (Bisadi et al. 2018; Curry et al. 2018; Hannan et al. 2018). Most of the energy supplied in dwellings is generated from fossil fuel operated plants that generate a large amount of emissions and thus degrade the environment. The problem of energy supply and demand has remained a fascinating topic for researchers and scientists (Hannan et al. 2018). However, less attention has been paid on consumer-related energy intervention strategies for reducing overall energy demand. Furthermore, the solution for reducing energy consumption and using renewable energy resources have been proposed in different papers mostly focusing on households. However, commercial high/low-rise buildings have not been comprehensively considered, in particular, the buildings operating all year round, e.g. university buildings. This paper proposes a socio-technical framework highlighting potential opportunities for human behaviour induced energy conservation. The proposed socio-technical framework will assist the building stakeholders including the building managers and the end users to conserve energy in university buildings by plugging the framework into Energy Information Systems (EIS) (Granderson 2013).

2 LITERATURE REVIEW

Since last two decades, analysing and estimating demand side of energy in built environments has fascinated different research groups and centres to attain sustainability goals and create emission-free societies (Delzendeh et al. 2017). One promising solution to achieve environmental sustainability is by reducing energy consumption in buildings (Qiu and Kahn 2018) and by influencing consumer behaviour for shifting towards a greener economy (Niamir et al. 2018). Residential or non-residential buildings are substantial sources of producing greenhouse gas emissions (GHG). An estimation of 40% energy is being used by building sectors which accounts for up to 72% of US energy usage, and 38% of carbon emissions (Radhakrishnan et al. 2016).

The highest population resides and/or works in households and commercial buildings. Adequate research has been conducted in the context of energy use in the residential sector, however few studies have been conducted in the commercial sector and particularly in the university buildings (Jindal et al. 2018). Delzendeh et al. (2017) show the breakdown of total number of studies conducted in each building type as shown in Figure 1. Considering a huge number of educational buildings around the world, only 7% of studies were conducted in these buildings. Hence, researchers need to focus on educational buildings too to conserve energy. Numerous occupant-oriented building services lead to energy use in the built environments, among them, heating, ventilation and air-conditioning (HVAC) systems demand high powers (Khan et al. 2017). Literature reports some of the findings on HVAC systems in the commercial buildings, and an exceptionally little number of findings on university buildings (Jindal et al. 2018). A recent study addressing cost-effective HVAC optimisation for Australian buildings has been proposed by (Vishwanath et al. 2019). Also, the use of linear modelling and prediction techniques is presented in (Gómez-Romero et al. 2019).

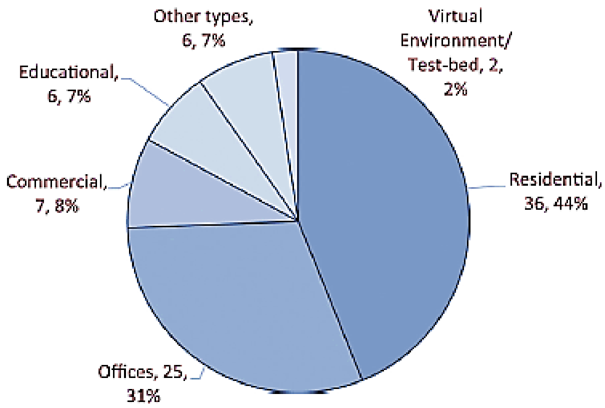

Figure 1: Percentage of studies conducted in different buildings types (adapted from (Delzendeh et al. 2017).

Moreover, the stochastic user behaviour (Jia et al. 2018) has not been thoroughly considered in studies and haven't remained the focus of building designers. This random behaviour could potentially be influenced to optimise building energy through building management systems. Such systems should be featured with user energy recommendations by using persuasive methods in order to efficiently engage and periodically remind inhabitants to minimise building energy use while maintaining their comfort at the same time. Some recommendations such as (Law et al. 2018) have been put forwarded by the utility companies and government organizations to motivate people to minimally use their home/commercial building appliances (Fogg 2009). The proposed research presents a framework to develop such user-oriented systems with dynamic features to improve user motivation for minimising energy use in buildings.

Moreover, a modelling approach is suggested in this paper that can help in penetrating policy and design aspects in response to a broader goal of building energy optimisation by influencing consumer choices. To investigate the user energy preferences of inhabitants and to test the implication of user intervention strategies for energy conservation in the built environment, the agent-based modelling (ABM) seems to be one of the viable solutions. One way is to model and simulate complex human behaviour using ABM paradigm (Koch 2016) and to appropriately estimate energy usage in buildings (Jia et al. 2018) by considering user lifestyles (Delzendeh et al. 2017) and conserve energy by applying some energy intervention strategies (Moglia et al. 2018).

It has been studied that complex behaviours form nonlinearity in systems due to heterogeneous combination of various interrelating components (Joslyn and Rocha 2000). Considering the non-linearity in complex systems, the shift from macroscopic to microscopic modelling (Crooks et al. 2008) will create an opportunity for explicitly exploring individual components and their relationships (Koch 2016). However, this approach can be in the opposite way i.e. shifting from microscopic to macroscopic modelling. The microscopic modelling is one possible way for breaking down large scale complex behaviours into small entities. These entities would ease in investigating the impact of their individual responses on the overall system and can help in tuning the system model for desired outcomes. For instance, exploring the influence of energy-related interventions on individuals (microscale) and then on the aggregated (macroscale) community. Agent in the ABM tool can be developed in a way to behave like actual inhabitant (Lee and Malkawi 2014). The applications of ABM have been found in (Alfakara and Croxford 2014) for simulating occupant behaviour with the help of some rules. However, they do not fully address human behaviours. In addition, different techniques have been proposed by (Putra et al. 2017) for building energy modelling using inhabitants behaviours.

Also, Predicted Mean Vote (PMV) model in (Lee and Malkawi 2013) and few other algorithms have been tested using ABM in different built environments and to a certain extent, they endorse the suitability of ABM for user preference modelling. However, some limitations in ABM due to its early phase do not clearly indicate its applicability to successfully develop a comprehensive model of user behaviour in built environments (Langevin et al. 2015). Hence, it is critical to further unfold the potential opportunities of ABM in response to modelling occupant behaviour and evaluating the use of possible energy-use interventions to develop polices for persuading inhabitants for changing their energy preferences in buildings.

3 GAPS, ENERGY SAVING OPPORTUNITIES AND FUTURE DIRECTION

Many studies, experiments and projects have been undertaken to conserve building energy and mitigate carbon footprints. However, limited attention has been paid on the behavioural aspects of humans and their implications on the overall energy consumption. Table 1 illustrates various studies, their research designs, energy systems and their implications on building energy performance. The last two columns demonstrate the need for introducing behavioural influencing factors, including nudges and social networks which have or haven't been considered in various studies on building energy conservation. Moreover, the building design features such as building glare and open facades could potentially open new research opportunities. These design features can be used to motivate inhabitants to conserve energy in buildings. Considering these gaps, the proposed research intends to include all the behavioural influencing factors as part of an ABM model and will simulate their composite effect on building energy performance.

Citation	University Building	Glazed Window (Façade)	ABM and Simulation	Energy System(s) Investigated	Influence User Behaviour	Social Network Use
(Barbosa et al. 2015)	×	✓	×	Thermal	×	×
(Anderson and Lee 2016)	×	×	✓	--	✓	✓
(Rai and Henry 2016)	--	--	✓	--	✓	✓
(Petidis et al. 2018)	Student Residence	×	×	Lighting, HVAC	×	×
(Niamir et al. 2018)	×	×	✓	Household (Auxiliary Appliances)	✓	✓
(Paone and Bacher 2018)	✓	--	×	General Electricity, HVAC, Lighting	--	--
(Moglia et al. 2018)	×	×	✓	--	✓	✓
(Byerly et al. 2018)	×	×	×	--	✓	✓
(Castaldo et al. 2018)	×	✓	×	Lighting, HVAC	✓	×
(Reddy et al. 2018)	×	×	×	Lighting	✓	×
(Curry et al. 2018)	✓	×	×	--	✓	✓
Proposed Socio-Technical Framework	✓	✓	✓	Lighting/HVAC/ Escalator/Lift	✓	✓

Table 1. Research gaps –"Influencing consumer behaviour for building energy conservation"

4 PROPOSED SOCIO-TECHNICAL FRAMEWORK

This paper is based on ongoing research in a university building. The intended study will provide a roadmap for the stakeholders to develop policies to improve building energy efficiency. Figure 2 presents the proposed socio-technical framework which is divided into two distinct features. The first part is the top-down representation of a typical building (system), which includes the energy facilities within that building, and the occupants who interact with these facilities for acquiring their desired comforts. The second part is the comprehensive design of proposed Building Energy Conservation (BEC) model within the proposed socio-technical framework which presents its three parts (a) Occupant Characteristics, (b) Behavioural Influences based on Social-Economic-Environmental (SEE) Model and, (c) Occupant Recommendations.

Occupant characteristics intend to demonstrate quantitative information about the heterogeneous population within the university building. Occupants' information including their energy use, their awareness about climate change, and their motivation towards energy conservation will be acquired through a social survey. Based on the survey findings, the proposed study will test the effect of recommendations mentioned in Figure 2(c) by using agent-based approach and taking into account the SEE model as illustrated in Figure 2(b). The SEE model is developed to draw possible nudges for influencing building inhabitants to make wise energy-related decisions. The influencing factors may involve social-economic-environmental rewards that a user would receive in response to energy conservation in their offices or at workplaces as shown in Figure 2(b). The rewards can be in the form of earned incentives and/or social recognition that users' may attain for saving energy.

In addition to the aforementioned factors, the proposed model will also incorporate occupants' intentions for changing their energy behaviour even beyond their comfort. This includes the willingness of an occupant to possibly choose acceptable and tolerable energy-related discomforts in their surroundings. For instance, a user may or may not switch the lights off in a dwelling where exposure to natural lighting is low to moderate as it may cause discomfort to the occupant. This information can be provided to a user by a kind of recommendation system as shown in Figure 2(c). However, it is not guaranteed that the user will opt for the suggested recommendations and hence the success will depend upon the content and the frequency of such feedbacks. (Reddy et al. 2018) reveal that the lighting-related recommendations can variate energy use in dwellings. Hence, they suggest it is critical to consider user motivation, quality and content in such recommendations.

Moreover, literature reports that building users' comfort and their health to some extent have an influence on their productivity and acceptability of minor discomfort conditions (Castaldo et al. 2018). It can be implied that building user's acceptance for minimum discomfort has been related to their health and/or physiological status. However, maximum exploited comfort may negatively affect the user performance in buildings. Henceforth, it is highly desirable to rigorously consider heterogeneity among occupants and other influencing factors while modelling building occupant behaviour to conserve energy in buildings.

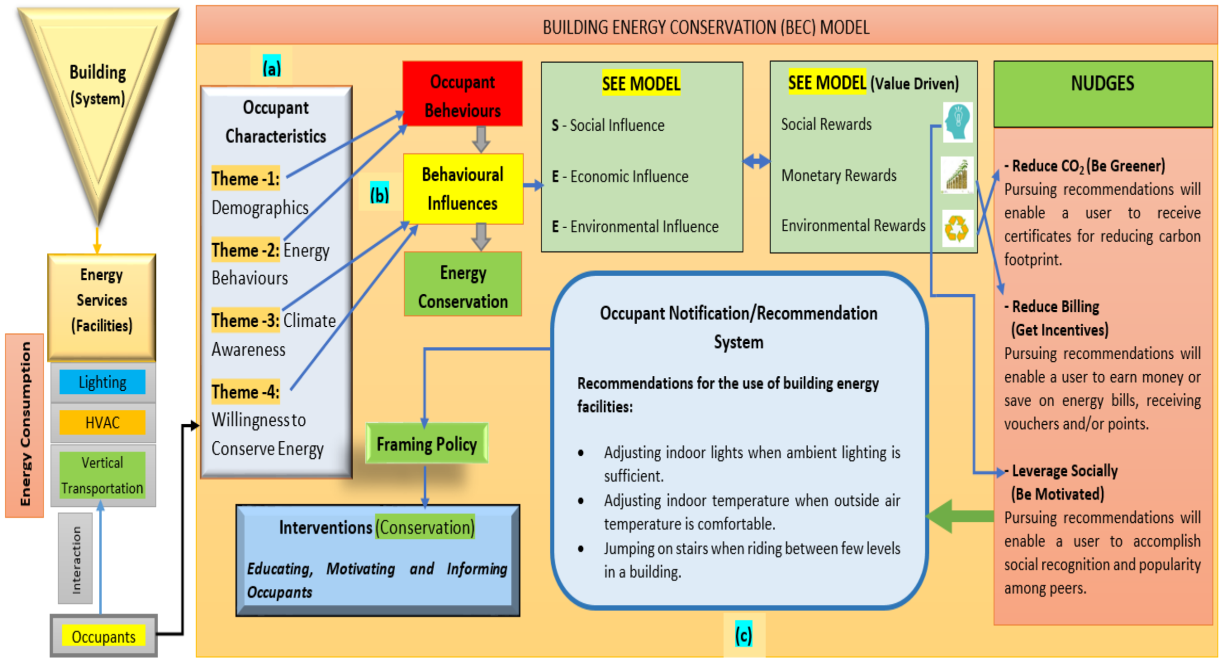

Figure 2: Proposed socio-technical framework

5 DISCUSSION AND CONCLUSION

Among the various challenges faced in optimising building energy performance, the key one is human interaction with building systems driven by their behaviour which is normative to indoor/outdoor circumstantial triggers. Recent findings (Jia et al. 2017; 2018) illustrate that occupant's goals, preferences and standards are set to their inputted contextual information in the built environment, which are also triggered by individual's ethnic, moral and personal characteristics. User perceived environmental conditions or building ambience prompt occupants to adjust their interactions with facilities in a built environment. Such stimulations that cause them to interact with building systems are actually triggered by psychophysiological states of the user.

As a whole, climate change is an inevitable reality and human activity is one of the key contributors to ecosystem depletion. These emissions are sourced by increased building infrastructure, consuming a massive amount of energy and located in the populated cities of the world. The increased energy consumed in buildings is due to increased human comfort requirements and their habit of luxuriously using smart appliances and gadgets. It has been investigated that only HVAC systems consume more than 60% of energy in low-rise buildings followed by lighting systems, lift systems and other auxiliary equipment housed in a typical building. There is significant evidence in the studies taken in response to reduce energy consumption in buildings using occupancy and appliances scheduling. Nevertheless, comprehensive research is needed to explore human-related energy choices and devise user-policy framework. In this direction, it is also likely to find opportunities for designing energy conservation policies using both technological and behavioural approaches owing to an increasing influence and continual presence of the occupants in built environments. This research, therefore, aims to investigate these underlying gaps by influencing overall user energy behaviour and building energy performance.

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