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The impact of occupants' behaviours on building energy analysis: A research review

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ABSTRACT

Over the past 15 years, the evaluation of energy demand and use in buildings has become increasingly acute due to growing scientific and political pressure around the world in response to climate change. The estimation of the use of energy in buildings is therefore a critical process during the design stage. This paper presents a review of the literature published in leading journals through Science Direct and Scopus databases within this research domain to establish research trends, and importantly, to identify research gaps for future investigation. It has been widely acknowledged in the literature that there is an alarming performance gap between the predicted and actual energy consumption of buildings (sometimes this has been up to 300% difference). Analysis of the impact of occupants' behaviour has been largely overlooked in building energy performance analysis. In short, energy simulation tools utilise climatic data and physical/ thermal properties of building elements in their calculations, and the impact of occupants is only considered through means of fixed and scheduled patterns of behaviour. This research review identified a number of areas for future research including: larger scale analysis (e.g. urban analysis); interior design, in terms of space layout, and fixtures and fittings on occupants' behaviour; psychological cognitive behavioural methods; and the integration of quantitative and qualitative research findings in energy simulation tools to name but a few.

1. Introduction

Over the years, the need to be more sustainable has significantly increased global focus towards energy related analysis. Climate change is foreseen to be the greatest environmental threat and challenge of modern times. International agreements such as the Kyoto Protocol; European agreements such as the European Emissions Trading Scheme and European Directive on the Energy Performance of Buildings (EPBD); and UK national measures such as the United Kingdom's Climate Change Programme (UKCCP) and the Climate Change Levy (CCL); all demonstrate its prominence. Thus, government, businesses and wider society all have a pivotal role to address human impact (hence, occupant behaviour) on the environment. In this regard, predicting energy demand is becoming more important in the design and construction of buildings, from early design stages to post occupancy. According to Janda [1], the growth in knowledge and public concern with regards to climate change has ensured increased attention towards energy consumption in relation to buildings. Statistics have affirmed that buildings are colossal consumers of energy. As published in the "International Energy Outlook" by the U.S. Energy Information Administration [2], 20% of the total energy consumed worldwide is within the building sector (including residential and commercial). Another study [3] demonstrated that from 1970 to 2014, the domestic sector alone used between 24% and 27% of the total energy consumption in Europe. Likewise, a separate study undertaken by the European Environment Agency (EEA) [4] presented similar results in their analysis. In 2015, EU statistics [5] reported that buildings (including services and households) consumed around 40% of the total energy use in 2015. In China and India, the building sector accounts for 37% [6] and 35% [7] of the total energy consumption, respectively.

Such that is the acute need to drive down energy consumption, in 2002, the Energy Performance Building Directive (EPBD) announced new regulatory conditions for all EU countries to decrease the energy needed for heating, cooling, ventilation and lighting in buildings. Therefore, estimated energy efficiency level of buildings has to be considered in the design of buildings, and subsequently in construction documentations [8] as part of the planning process.

Energy consumption of buildings is related to various factors including: the thermo-physical properties of the building elements,

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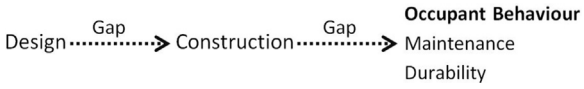

Fig. 1. The gap between the predicted and actual use of buildings.

its construction technical details (energy-efficient building elements may not perform efficiently if poorly-constructed), climatic location characteristics, the quality (and maintenance) of the installed HVAC system, and occupants' behaviour and activities towards energy utilization [9,10]. During the design stage of buildings, energy simulation is used to predict energy consumption of buildings based on design information, however, several studies [8,11–16] showed that there was a considerable discrepancy between the predicted and actual energy consumption of buildings. The studies demonstrated that the actual energy consumption of buildings is sometimes up to 3 times greater than the estimated calculation. Thus, this performance gap is due to the difference between the building design and the as-built building in terms of the technical workmanship and installations, choice of equipment and material during the construction stage, and the energy behaviour of occupants, which has been disregarded in the energy simulation process [8,16] (Fig. 1).

Nevertheless, post occupancy energy-use evaluation has been analysed in numerous research projects. For example, the ROWNER project [14] considered three stages: design and construction, post-occupancy evaluation and overheating. The project analysis [14] demonstrated a significant difference between the total energy consumption between two flats within the same building block due to differing occupant behaviours, including: different presence at home, different occupancy levels, and variations in the occupants' thermal preferences. Similarly, major differences in energy consumption of similar building blocks were reported in another study [17]: Martinaitis, Zavadskas [13] conducted five different studies to highlight that buildings did not perform as predicted, even when the energy simulation was very accurate. They concluded that human behaviour and occupant preferences as an important contributor of the gap between the predicted and actual building energy performance. Furthermore, Schakib-Ekbatan, Çakici [12] identified occupants' behaviour as the most overlooked parameter that "might not be considered as part of the energy design" within the chain of design, construction, operation and maintenance. As such, a range of studies have ensued focusing on the influence of occupants' behaviour on building energy consumption with the focus to interpolate behavioural aspects into building energy simulation tools to improve their accuracy [18]. However, despite active research being undertaken in this area, the findings are fragmented and, therefore, there is a real need for international collaboration in the sharing of collected data and discovered findings [19]. This paper aims to undertake a comprehensive review of existing studies in this area to identify research trends and gaps for future studies.

2. Method and material

2.1. Research method

This review paper aims to provide a summary of the extant literature. The selection criteria of the literature used for this critical review paper was primarily based on the direct relevance to the subject, and also a number of studies which focused on related subjects due to their substantial importance.

Review papers usually follow a process of 'search' for relevant publications, utilising citation indexes against pre-determined criteria for eligibility and relevance to form an inclusion set relating to the research area. To reduce bias in this process, an objective and transparent approach for research synthesis was adopted, including both quantitative analysis and qualitative reviews. Therefore, Science Direct and Scopus databases, two of the leading citation index organisations, were used. For this study, the terms "building energy" and "occupant" were used to select any papers where it was found in the title, abstract and/ or keywords. In order to limit this wide scope (more than a thousand papers were identified by Science Direct and Scopus) and to focus closely on the influence of occupant behaviour on building energy consumption, a further search was made through the existing database using more relevant keywords. As a result, both "occupant behaviour" and "energy consumption" have been repeatedly used in the title, abstract and as keywords of various research papers that were considered as the closest key words for the topic of this research review paper. Following such, a search up to and including August 2016 identified more than 100 research papers for this review, with the majority directly related to the impact of occupant behaviour on building energy consumption were published between 2013 and 2016, to reflect this fast developing research area.

According to the reviewed papers, the most frequent key words used by scholars in this subject area are 'occupant behaviour', 'energy consumption or energy use', 'energy simulation or modelling' and 'energy efficiency or performance', followed by 'comfort' and 'behaviour' (Fig. 2). Thus, this identifies the notable relevance of comfort-related studies in occupant behaviour.

The papers identified were subsequently categorised in terms of the methodology used, building type (i.e. residential, offices, etc), occupants' interactions with buildings and the influential parameter(s) identified in the papers on occupants' energy behaviours (see Table 1).

Analysis of Table 1 is concluded as follows:

- Residential buildings and offices respectively account for 44% and 31% of the reviewed studies in this topic area. Less than 20% of these studies used commercial and educational buildings as their case studies, and cultural and recreational buildings and health centres have not been sufficiently researched and reported, and thus, require further investigation. The number and percentage of each building types used as case studies in the reviewed papers is illustrated in a pie chart (Fig. 3).

- The majority of studies focused on one or more particular types of occupant's interaction, such as the use of electricity and plug loads (31%), window opening behaviour (18%) and use of fans/ air conditioning (15%) (Fig. 4). Although the use of hot water (4%) is limited in the literature, it starts to appear in the more recent publications.

- Many studies focused on one or more influential parameters of the occupant's choice of behaviour and satisfaction. Among those parameters, climatic (environmental, physical) and personal (psychological and physiological) parameters have attracted more attention than other parameters, and accounted 33% and 28% respectively of the totally review papers. Other parameters, such as

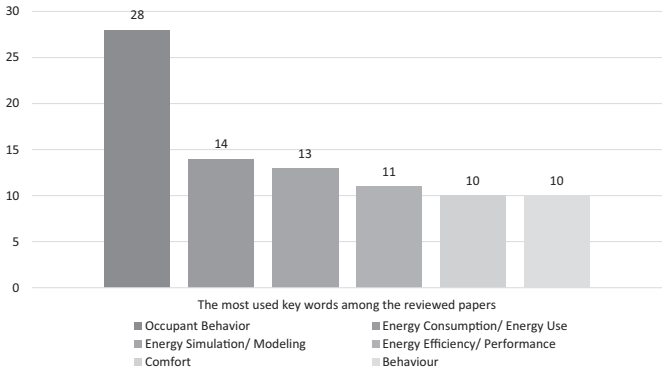

Fig. 2. Frequency of the key words among the 43 occupancy related papers.