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A Critical Review on Questionnaire Surveys in the field of Energy-Related Occupant Behaviour

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ABSTRACT
Occupants perform various actions to satisfy their physical and non-physical needs in buildings. These actions greatly affect building operations and thus energy use. Clearly understanding and accurately modelling occupant behaviour in buildings are crucial to guide energy-efficient building design and operation, and to reduce the gap between design and actual energy performance of buildings. To study and understand occupant behaviour, a cross-sectional questionnaire survey is one of the most useful tools to gain insights on general behaviour patterns and drivers, and to find connections between human, social, and local comfort parameters. In this study, thirty-three projects were reviewed from the energy related occupant behaviour research literature that employed cross-sectional surveys or interviews for data collection from the perspective of findings, limitations and methodological challenges. This research shows that future surveys are needed to bridge the gaps in literature but they would need to encompass a multidisciplinary approach to do so as until now only environmental and engineering factors were considered in these studies. Insights from social practice theories and techniques must be acquired to deploy robust and unbiased questionnaire results, which will provide new, more comprehensive knowledge in the field and therefore occupant behaviour could be better understood and represented in building performance simulation to support design and operation of low or net-zero energy buildings.

Keywords: occupant behaviour; questionnaire survey; energy use in buildings; energy efficiency; behaviour modelling

1. INTRODUCTION

To achieve acceptable indoor comfort, building occupants perform various actions to satisfy their physical and non-physical needs. They adjust the thermostat settings to be warmer or cooler, open windows for ventilation, turn on lights, pull down the window blinds and move around, among many other actions that greatly affect the built environment and energy use. Technology alone does not necessarily lead to low-energy buildings; occupant behaviour plays a decisive role in building design, operation, and retrofit (Hong et al. 2015d).

Currently, predictions from building energy simulations cannot fully represent actual building energy use. Significant gaps between the real and predicted energy performance of buildings are caused by differences between the designed and actual construction quality, technical installations, weather conditions, model simplifications, the actual performance of the built systems, and occupant behaviour (Norford et al. 1994) (Hoes et al. 2009) (Bourgeois 2005) (Polinder et al. 2013). As buildings become more energy efficient, reducing this gap becomes more important (O'Brien et al. 2013).

Understanding and modelling occupant behaviour in buildings is crucial to reducing the gap between design and actual building energy performance (Yan et al. 2015) (Hoes et al. 2009) (Turner and Frankel 2008) (Gunay et al. 2013).

The literature shows that residential and commercial buildings of the same type, scale and with similar control options, even in similar climates, demonstrated significant variability in actual energy use. This may be caused by differences in occupant behaviour. (Fabi et al. 2012) (Gunay et al. 2013) For example, Nicol conducted a survey in different countries on the window, lighting, blind, space heaters, and fan usage in office buildings. He found some remarkable congruencies in lighting, heating and fan use, but significant variations as well in terms of window and blind use (Nicol 2001) (Nicol, J. Fergus; Humphreys 2004).

However, there are still very limited data to help understand occupant behaviour and its impact on building performance quantitatively. The International Energy Agency's Energy in Buildings and Communities Program (IEA EBC) Annex 66 project, definition and simulation of occupant behaviour in buildings (Yan et al. 2017), aims to collect more data on the topic, set up a standard occupant behaviour definition platform, and establish a quantitative simulation methodology to model occupant behaviour in buildings.

1.1 Gaps in Energy-Related Occupant Behaviour Literature

With respect to contextual gaps, an unbalanced geographical distribution can be observed among independent studies using cross-sectional surveys, mainly deployed in Europe, U.S., China, and Japan. Cross-sectional studies are defined as experiments in which a single measurement is made on a sample of individuals at a single point in time (Leeuw et al. 2008) as opposed to longitudinal surveys where questionnaires are open and data is collected for a longer period of time to capture tendencies in time. A limited number of large-scale cross-sectional questionnaire surveys are carried out worldwide, and these focus more on measuring and predicting human comfort than investigating occupant behaviour and motivational drivers. Consequently, the current literature lacks the general understanding of differences in occupant behaviour among diverse cultures, countries, and climates. Most of the questionnaire surveys reviewed were carried out before 2010, and since then both office and residential appliance usage has changed significantly, as most buildings are now equipped with more electric appliances. In view of this, an improved survey would provide better and more updated data coverage, asking new questions that would be more relevant today.

With respect to the behavioural gaps, since the 1970s survey studies in the field of building science have been used to gain a better understanding of multidisciplinary drivers of occupant behaviour with respect to comfort and energy requirements in buildings. Research has aimed to uncover the variables

that drive occupants' comfort satisfaction, needs, acceptance, and energy concerns. Existing surveys have typically focused on only one or two specific occupant action types, while surveys discovering the correlation on a wide spectrum of adaptive actions are needed (Fabi et al. 2012), (Gunay et al. 2013). Similarly, limited information is available on multiple drivers of behaviour by independent literature reviews. Arbitrary conclusions have been drawn from scattered and limited national datasets on occupant behaviour drivers that are then considered to be valid worldwide. How occupant behaviours differ between cultures, countries, and climates is still little understood. Finally, no study so far provides knowledge about the order of actions undertaken by the occupant in order to restore comfort condition (thermal, visual, IAQ) when exposed to certain indoor and outdoor variables. In addition, energy-related group behaviour has been little observed and understood, and innovative insights on the behavioural interaction among social groups in office environments are also needed.
A recently-published big-picture paper summarised the gaps of this field of research as well (Hong et al. 2016). Researchers articulated the main gaps here as: (1) oversimplified or disregarded occupant behaviours throughout the building operation process, (2) lack of common agreement on validity and applicability of occupant behaviour modelling and simulation approaches, and (3) unclear human-centred interdisciplinary solutions.

1.2 Behavioural Models and Studies from Social Sciences

Researchers have used a variety of behavioural models as a basis for occupant behaviour simulation algorithms. General psychological behavioural models such as the MODE model (motivation and opportunity as determinants) of attitude-behaviour processes, which assumes that the link between attitude and behaviour comprises both emotional aspects and irrational decision-making processes (Fazio 1990), have been developed. Ajzen, and later Netemeyer, introduced the theory of planned behaviour (TPB) (Ajzen 1985) (Netemeyer et al. 1991) based on the theory of reasoned action, which was derived from the field of social psychology. This model tries to predict behaviour as a result of a variety of predictors that determine a person's intention towards a specific behaviour. This framework is widely used in many different fields of pro-environmentalist, occupant and consumer behaviour and in building energy research fields as well (Chen and Knight 2014) (Chen et al. 2016) (Gao et al. 2016) (Oladokun and Odesola 2015) (Staddon et al. 2016).
Schwartz and Bilsky defined values as beliefs pertaining to desirable end states or mode of conduct that transcend specific situations and guide choices and actions (Schwartz and Bilsky 1990). The Values-Beliefs-Norms framework focuses on normative considerations and proposes that relatively stable and general factors, namely values and environmental concerns, affect behaviour specific variables (i.e., problem awareness, outcome efficacy and personal norm), which in turn influence behavior (Stern et al. 1985). Also, the social practice theory is widely applied in the field of environmentalism, which was developed as a framework for analysing and understanding the social phenomena and the dynamics of transition that exist in human societies (Reckwitz 2002) (Shove et al. 2012).
The modified norm activation model, which was developed to explain altruistic/moral decision making (Matthies et al. 2011), integrates external influences (e.g., comfort, possible energy costs of behaviour, and social expectations) with internal influences (e.g., moral motivations, personal norms). This model assumes that, especially in contexts of the highly-repetitive activities of daily living, occupants develop stable patterns of behaviour. The "knowledge-desire-ability-action" model (final report De Nationale DenkTank, 2009 (De Nationale DenkTank 2011)) stated that various stages that lead to certain behaviours can be identified, and thus it is possible to investigate behavioural change.
In one model, developed by Van Raaji and Verhallen (Van Raaij and Verhallen 1983), the determinants of household energy use are described in detail, including socio-demographic factors, family lifestyle, energy prices, energy-related behaviour, cost-benefit trade-offs, effectiveness and responsibility,

feedback, information, and home characteristics. The Needs-Opportunity-Ability model was developed for consumers (S. Ferguson, A. Siddiqi, K. Lewis 2007). In this framework, energy consumption is driven by five kinds of forces: technological, economical, demographical, institutional, and cultural developments. Needs and opportunities determine the motivation to consume; opportunities and abilities determine the degree of behavioural control people have. People need to have both behavioural control and motivation to do so. Opportunities are external conditions and abilities are the internal capacities of an individual.

Among others, Fransson and Garling summarised, compared and provided links between the conceptual definitions of models used in this field, highlighting the pros and cons of each theory in practice, and declaring the need for a new, more widely applicable model (Fransson and Gärling 1999). This is outside the scope of the current paper, and requires further research to evaluate their level of applicability in an interdisciplinary research framework.

Social science literature presents projects with quantitative methodological descriptions on survey research related to human subjects, such as a survey project on the intentions of employees intentions to conserve energy at work, where TPB was used to explain the relationship between intentions and behaviour (C. Chen and Knight 2014). Another study investigated the adoption of solar thermal collectors and electric vehicles (C. F. Chen et al. 2016). Bamberg's focus was the influence of environmental concerns on behaviour (Bamberg 2003). An extended TPB framework was used to test the intentions of park and ride facility usage (de Groot and Steg 2007).

These studies serve as great examples for the field of energy-related occupant behaviour from the aspects of model-building, methodology development, and variable measurement. Well-established behaviour models are used to build a system of variables that the researchers are interested in. In addition, the risk of bias in survey results is minimised, and therefore the findings of these studies are more reliable.

1.3 Tools Used to Investigate Energy-related Occupant Behaviour

There are many approaches and tools to collect data, observe and investigate occupant behaviour in buildings. In literature, categorization of these tools can be seen according to different aspects. Making observations without interfering with the occupants' natural behaviour is always a challenge. In this sense, observation techniques can be categorised as either invasive or non-invasive. For example, in Gunay at al.'s shading use observation review study (Gunay et al. 2013), observational field surveys are mentioned as non-invasive tools. In this case, researchers ~~simply~~ observe a group of subjects and their personal adaptive behaviours in their daily routines for a certain period of time. With invasive self-reported questionnaire surveys, ~~for example,~~ subjects are recruited participants in that they are aware of the scope of research and that they are being observed.

Another approach of observation tool categorization was presented recently by Hong et al. (Hong et al. 2016). Physical sensing techniques are presented to be used for objective measurements, such as smart metering, BMS data, indoor and outdoor environmental data, and occupant interaction with control systems. Non-physical sensing techniques (such as survey questionnaires and self-reported data) are used to conduct subjective measurements. The collection of data on occupancy can fall into each of these categories.

In most of the cases, objective measurements are used in energy-related occupant behaviour research, as parameters are considered to be more reliably usable and environmental parameters can be directly linked to a certain behaviour type. However, for survey studies, social, economic, cultural and even political aspects can be examined to understand contextual factors to a larger extent.

To study and understand energy-related occupant behaviour in buildings, a cross-sectional questionnaire survey is a useful tool to gain insights into general behavioural patterns, drivers, causes

and the perceived effect of behaviour, as well as finding connections between human, social, and local comfort parameters (Yan et al. 2015). To describe occupant actions in time, indoor environmental and weather measurements are needed to complement longitudinal subjective surveys. However, the sample size of these types of projects is not large enough to represent the entire population of a region in focus. With such little data, it is hard to draw general conclusions from these datasets and compare occupant behaviour between countries, climates, and cultures (Yan et al. 2015).
Even though cross-sectional surveys are commonly used to collect data on building occupants' comfort-related and subjective perception of their environment ("CBE Occupant IEQ Survey" n.d.) (Dykes and Baird 2013), their use is still limited in research on occupant behaviour. However, their large sample size makes them one of the most powerful tools available to learn occupant behaviour patterns and draw general conclusions on drivers, motivation, and the decision-making processes of occupants.

2. GOALS

Occupant behaviour in buildings is a complex and stochastic issue and requires a multidisciplinary approach to be better understood and represented. As ~~the~~ cross-sectional survey is not yet widely used in the field of energy-related occupant behaviour research as a tool, while social and contextual interferences of occupant and group behaviour (the consistency of behaviours among cultures, climates, and social and contextual interactions) can be studied through its proper application, the goal of this review is to show the reasons for this and the shortcomings of cross-sectional survey studies in energy-related occupant behaviour research as currently used by providing several insights into the following important questions on projects reviewed that used cross-sectional surveys or interviews for data collection:

- What was the focus of these occupant behaviour surveys?
- What are methods used in these surveys?
- What are key findings from these surveys?
- What are the challenges in conducting these surveys?
- What are the limitations of these surveys ~~and what future work should be done~~?
- How can cross-sectional survey data be used to inform occupant behaviour modelling and simulation programs?

After answering these questions, the second goal was to provide guidance for researchers in this field on the methods and research focus area for future survey studies. Previous survey studies only considered environmental and engineering factors, ignoring social and behavioural factors which are critical to understanding occupant behaviour. Studies that lack standardization and consistency and are scattered geographically around the world have emerged, thus leading to difficulties when compared with one another. Both energy-focused building engineering groups and human-centred social scientists use these techniques separately. Although this field of research requires a multidisciplinary approach, researchers publish their work in separate journals with different focus. It is also rare that scientists from a particular background reference the studies and findings of researchers from a soft science background.

The authors' intention is to demonstrate the common challenges and research questions asked in these fields, and to form a solid basis with this study for a core statement: the future of occupant behaviour research calls for a ~~single~~ standardised practice, which necessarily encompasses a multidisciplinary approach to the diverse fields of investigation.

This work is part of the International Energy Agency's Energy in Buildings and Communities Program, Annex 66: Definition and simulation of occupant behaviour in buildings (Yan et al. 2017).

3. METHODOLOGY

In this paper, first cross-sectional survey projects are individually analysed to reveal their main focus and findings; following this, their methodology is ~~then~~ investigated.

In this work, thirty-three studies on occupant behaviour questionnaire projects that used cross-sectional surveys were reviewed. These studies covered the years 1977-2014, taken from 13 countries. The primary focus of these studies was energy-related occupant behaviour in buildings, particularly adaptive comfort actions. Surveys were selected from the literature based on the criteria of how well their topic fit into the scope (i.e. whether their core area of interest is energy-related occupant behaviour investigation) and whether they used survey questionnaire or interview results from one time-step (cross-sectional) to draw overall conclusions on occupant behaviour. Our investigation covered only studies that were conducted in the authors' native language (e.g., English, Danish, Chinese, German), but the results were all published in English.

This paper is structured in the following way: first, the contextual factors (e.g.: building type, climate, environment), research area and core findings of these surveys are introduced in section 4. After a brief overview of geographic distribution, timeline and focus area, project findings are discussed, starting with studies focusing on one type of behaviour and then on those with multiple action types.

In section 5, methodological issues and limitations found in the cross-sectional survey studies are discussed. Detailed information on methods, respondent numbers, sample buildings used, additional datasets, response rate and incentives are summarised in Table 1.

Finally, in the discussion section, the findings of our review are summarised, and based on our review results, thorough guidance is provided for future research both in terms of research questions to be posed and methodology.

4. REVIEW OF SURVEYS

An overview of the survey projects selected for review is shown in Figures 1 and 2.

Figure 1 *Geographic distribution of survey projects reviewed*

The current cross-sectional datasets are geographically unbalanced. The majority (74%) of the studies were conducted in Europe and the USA (Figure 1). Nine out of the 33 were carried out in the UK. Most of the survey studies were conducted between 2003-2010, the majority of projects (86%) were conducted before 2010.

Both surveying methods and office environments change quickly in the 21st century with the widespread use of digital and web-based tools. Therefore, special attention should be paid to these parameters of survey methodology and findings. In 63% of the studies, the sample size was lower than 500 and primarily focused on one or a group of buildings.

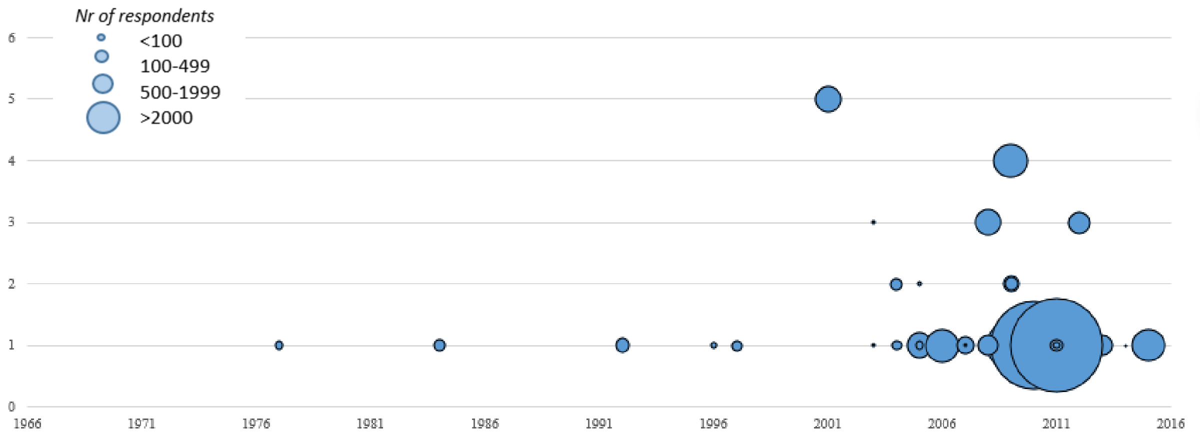

***Figure 2** Cross-sectional surveys by year*

4.1 Review of Research Focus Area

Most of the studies reviewed were conducted in residential (43%) and commercial (43%) buildings. Drivers are defined as motivating factors that have influence on a given type of behaviour (Fabi et al. 2012). Drivers were analysed only in 11% of all cases. 74% of the studies focused on only one type of occupant action (e.g., either window opening or thermostat usage). In cases where more types of behaviours were examined, the following combinations were used:

- Multiple control types and plug loads.
- Light use and plug-load.
- Small-power equipment use and air conditioning.
- Windows, doors and fan use.
- Window, shade, lighting and heating use.
- Thermostat and window use.

~~In 63% of the studies, the sample size was lower than 500 and primarily focused on one or a group of buildings. The majority of projects (86%) were conducted before 2010.~~

4.2 Review of Project Findings - Focus on One Type of Behaviour

This section provides a short summary of the core findings of the selected studies that focused on only one type of behaviour. All of these studies used cross-sectional surveys to provide greater insight into human behaviour. The results here show how diverse and sometimes even contradictory these findings are, and how hard generalising results from these studies would be.

4.2.1 Opening windows

An early study (Brundrett 1977) focused on window opening drivers during three seasons. Brundrett found that opening windows during winter strongly correlates to outdoor air moisture levels, while during the summer the mean daily temperature is a more important driver. Conducting a cross-sectional survey allowed him to look more closely at the motivation behind window opening: he found that in winter the goal is to remove body odour, in spring and autumn it is to provide moisture control, and in summer to allow for space cooling. Warren and Parkins (Warren and Parkins 1984) showed that a significant amount of heating energy was consumed in connection with occupants opening windows. They showed that occupants try to ventilate the room by opening the windows; a significant motivation during summer was to avoid overheating. In a Japanese study (Iwashita and Akasaka 1997), surveys helped researchers find a correlation between measured environmental parameters and occupants' window opening behaviour. The Japanese study showed that 87% of the total air change rate was caused by occupants opening windows. Price and Sherman published cross-sectional survey results in 2006 (Price and Sherman 2006) on window use and general indoor air quality. They found that neither indoor pollutant sources nor health issues appeared to influence opening windows. For window closing, security and energy saving were the main motivating factors.

Rijal (Rijal et al. 2007) investigated the effect of window opening behaviour on comfort and energy use in offices to build an adaptive algorithm and implement it into ESP-r. He found that the number of windows open depends on indoor and outdoor conditions. These predictors were tested on the original survey data as well. A large-scale cross-sectional survey and interview project was carried out on air change rate (ACR) in residential buildings, specifically how ACR influenced children's health levels (Bekö et al. 2011). This study showed that variables related to occupant behaviour were stronger predictors of ventilation rate than those related to building characteristics.

4.2.2 Window blind use

Four studies dealt with the use of window blinds. Inkarojrit developed thirteen predictive models for window blind control in offices based on two cross-sectional and one longitudinal questionnaire survey, where dataset was complemented with measurements (Vorapat 2005). Survey results showed that the main reason for closing the blinds was to reduce glare on computer screens (64.6%), and to reduce the brightness of work surfaces as a second reason (30.9%). A conventional and an energy-efficient office building in the UK were compared from thermal, acoustic, and visual comfort points of view, with a special focus on window blind use (Zhang and Altan 2011) (Zhang and Barrett 2012). The comparison showed differences in driving variables of comfort perception, blind operation patterns, and blind usage. They found that occupants' preferences for the blind position are based on a long-term perception of sunlight and the built environment they are accustomed to. Window blind use patterns and motivations, and their impact on building energy consumption, was studied in Canada across five geographical regions (Veitch et al. 2013). The study concluded that the choice of shading use is influenced more strongly by other factors than solely energy and thermal considerations.

4.2.3 Lighting

A study of lighting controls (Pigg et al. 1996), showed that occupants didn't turn off lights when they left the office and also didn't use advanced lighting control strategies if they thought they could rely on occupancy sensors. The study showed that the energy-saving potential of occupancy sensors should be revised, taking into account this change in occupant behaviour. Daily and seasonal patterns of artificial light use were studied (Moore et al. 2003). Survey results showed a variety of reasons why occupants switched on lights, but primarily when they arrived in the office. The study showed that a significant amount of lighting energy can be saved with user-controlled lighting.

In a LEED Gold laboratory building (Hua et al. 2011), the effectiveness of daylight design strategies was studied during the building operations phase. According to the survey results, occupants were basically satisfied with the lighting conditions. They preferred task lighting and found it difficult to operate certain movable shading devices. At the same time, they reported having removed some fluorescent light tubes from their fixtures because they found the lighting level too high.

4.2.4 Heating, Thermostat Adjustment

Karjalainen studied the current use of office thermostats to understand why they are reported to be difficult to use (Karjalainen 2007). He concluded that designers frequently overestimate occupants' understanding of thermostat usage. Therefore, user guidelines should be developed and distributed to office workers. Determining factors of residential heating energy consumption were studied in Greece (Sardianou 2008). A significant association was found between dwelling size, annual income, the number of habitats, ownership, and rate of occupancy with heating energy consumption. The study proposed implementing an energy conservation strategy in Greek legislation to lower the heating consumption of households with higher income and larger homes. Another study also found connections between building characteristics and occupant behaviour, and the heating and thermostat usage of the dwelling (Guerra-Santin and Itard 2010). The number of usage hours had a stronger influence on heating energy consumption than temperature settings. It was also found that occupants kept radiators on longer if they had programmable thermostats (compared to manual valves) and if there were elderly people in the household. In the UK, it was found that income level and household size play an important role in heating usage and consumption patterns. The age of occupants and number of children affected heating expenses as well. (Meier and Rehdanz 2010)

Gender differences were studied regarding thermal comfort, temperature preference, and the use of thermostats (Karjalainen 2009). Females generally preferred higher room temperatures, but at the same time, they felt uncomfortably hot more often than males. This study also found that men often use the thermostats in households.

4.2.5 Air conditioning use

Manual and automatic control behaviour was studied in the use of air conditioning in student homes in California (Lutzenhiser 1992). Manual air conditioners consumed on average 21% less energy than automatic ones. Lutzenhiser proposes that appliance manufacturers and designers work on better operability and control strategies. A large-scale cross-sectional survey study was carried out in China on residential air conditioning use to categorise occupant behaviours and model air conditioning usage (Feng et al. 2015). Based on the results, five different groups of air conditioning usage behaviour were identified.

4.2.6 Appliances, electricity

A Greek study looked at occupant presence, domestic appliance usage, and the energy contribution of individual household members to the whole (Papakostas and Sotiropoulos 1997). As a result, occupant presence and activity schedules could be derived and used to calculate cooling loads. The power management and energy saving potential of office equipment were studied in Japan (Kawamoto et al. 2004). This study showed that 2% of Japan's commercial electricity consumption could be saved if power management delay times were shortened for the office equipment they examined. Results were also compared with data from the USA; they found that the manual-off rate at night was more than twice the level in Japan than in the USA. In Italy, a home energy management system was tested in 31 homes (D'Oca et al. 2014). Testing showed that persuasive communication strategies (e.g., competition between similar households) are effective in lowering energy use, with an average energy savings of 18%.

4.2.7 Occupant adaptive comfort

One study examined occupant behaviour and adaptive comfort in a naturally ventilated office building over two seasons (Brager et al. 2004). The focus of the study was to have a closer look at the theory that occupants with more control options (particularly opening windows) feel more comfortable in general. Data showed that occupants with different degrees of personal control had significantly diverse thermal responses. Another study looked at thermal comfort perception and adaptive occupant behaviour in five different countries (Humphreys 2005). Data from different countries allowed researchers to study the differences of comfort preference between countries. This study showed that it is impossible to build an internationally valid comfort rating index due to significant differences in preferences.

Another study examined predicted and actual thermal responses to determine a connection between indoor environmental and contextual variables (e.g., available control options, social factors), and thermal comfort perception (Becker and Paciuk 2009). Significant disagreement was found between standard, predicted (P. O. Fanger 1970) (Ole Fanger and Toftum 2002) and the actual comfort (PPD and PMV) levels. The study showed thatalso having information on contextual factors, to more accurately predict the thermal response of an occupant, was essential. In the UK, it was found that occupants have different preferences and order of actions when they use adaptive opportunities to adjust their surrounding thermal environment (Wei et al. 2010). Opening/closing windows and adjusting clothing insulation was a higher priority for them than opening/closing doors, adjusting solar shading devices and adjusting blinds/curtains or adjusting air diffusers, drinking cool/hot drinks, adjusting heaters, or operating private fans. Wei, et al. stated that the sample size should be increased to get a more reliable dataset.

4.3 Review of Project Findings - Focus on Multiple Types of Behaviour

This section is a summary of studies investigated using cross-sectional surveys to support research on multiple types of occupant behaviour. These studies provide a broader understanding of behaviour overall; the focus is not only one segment of a person's daily routine but multiple actions.

The goal of one study conducted in ~~summer~~ the hot season was to assess indoor thermal comfort and indoor control types used (Raja et al. 2001). The study found that opening windows and window blind use were the most extensively used control options. Additionally, a connection could be made and quantified between indoor and outdoor temperatures and controls used by occupants.

A study of Kuwaiti residences showed that Kuwaiti occupants consume more electricity than those in Western Europe (Al-Mumin et al. 2003). Occupant behaviour differs significantly from the Western behaviour used as defaults in building energy modelling software programs. Kuwaiti occupants usually leave all lights on in vacant rooms, prefer to cool rooms with lower setpoints (22°C) than European occupants, and leave the house twice a day (US occupants only leave once).

One study examined small power equipment loads and the use of air conditioning (Dunn and Knight 2005). The study showed that designers generally overestimate the peak loads of office equipment by up to 650%. A more accurate calculation method was proposed to support architectural and HVAC design decisions.

A study in Pakistan examined the use of windows, doors, and fans (Rijal 2008). Significant variations were found in occupant control behaviour across the seasons. During the summer, fans were used more often than opening windows; in autumn, cross ventilation was used for cooling. Algorithms could be developed to predict the occupants' adaptive behaviour and to represent adaptive user behaviour in energy modelling software.

Four types of occupant control actions (window, shade opening/closing, lighting, and heating use) were studied to quantify the factors that influence residents' behaviour (Andersen et al. 2009). It was found that both window opening behaviour and the heating turn-on rate were influenced most by outdoor temperature. The use of lighting was strongly correlated with available solar radiation, perceived illumination, and outdoor temperature.

A Chinese study focused on thermostat use and opening windows in residential buildings (Xu et al. 2009). The study showed that variations in occupant behaviour only slightly affected the total flow rate of the district heating system. At the same time, a significant amount of heating energy could be saved with a new heat metering billing system and education on effective thermostat usage. Another study in Denmark investigated window opening behaviour as well as thermostat and lighting use (Frontczak et al. 2012). The results showed that occupants preferred manual control over automatic controls. Their responses showed that occupants associate fresh air supply with the ability to open windows, not with mechanical ventilation. Also, the study recommended validating the data through studies with a bigger sample size.

5. REVIEW OF METHODOLOGIES USED IN SURVEYS

In Table 1, key information from each cross-sectional survey study reviewed is introduced, focusing on cross-sectional survey methodologies, the number of respondents, additional datasets, response rate, and motivating incentives.

In the following sections, the methodology of the surveys reviewed is analysed from various perspectives. Limitations of the methodologies used are discussed and also guidance and best-practice examples are provided for future studies. This study aims to highlight that designing a survey project requires extensive expertise. Simplification or omission of the methodological issues detailed below may result in less reliable results. However, this study does not provide a thorough step-by-step survey design set of criteria. For a more detailed description of survey methodology, readers can refer to the studies cited in each section.

5.1 Reliability and Validity

The most fundamental goal of researchers who conduct surveys is to draw conclusions and answer research questions based on valid and reliable results. In the projects reviewed, this issue is either simply not discussed or too little attention is paid to it. Reliability is the extent to which answers to a question provide consistent results at different times or for different respondents when the values of a construct are the same (Leeuw et al. 2008). Validity is the extent to which the answer to a question corresponds to the true value for the concept that is being measured (Cronbach and Meehl 1955). Fowler and Cosenza state that to ensure reliability and validity, researchers need to (1) ask the right question, one that is understandable for respondents, (2) make sure that respondents can retrieve information to answer and translate this information to an answer option, and finally (3) provide a way for respondents to write/enter their answers either on paper or on their computer, or by simply responding verbally to the interviewer. (Leeuw et al. 2008) See also other studies discussing validity issues: (Cook and Campbell 1979), (Ghiselli et al. 1981), (Kerlinger and Lee 2000).

Again, wording questions were clearly found to be essential. Therefore, conducting a pilot study with a small focus group is useful prior to administering questionnaire surveys. When surveys are administered in various countries that use more than one language, high-quality translation of the questions is essential. Also, researchers should investigate the cultural differences in terms of data sensitivity and privacy concerns. For example, paper and pencil surveys work better in China, where anonymity is important (C. F. Chen et al. 2016). In Europe, it is more effective to conduct surveys online, as building occupants are less concerned about personal data compared to the USA, for example, which can be due to different requirements and the approval process of studies using human subjects. There are also differences in the protocols applied for institutions subject to survey-type investigations. In the USA, approval by the Institutional Review Board is required to conduct human-subject studies at universities to safeguard the rights of research volunteers, including survey respondents (Leeuw et al. 2008). This process is usually lengthy and demands a great effort from the principal investigators. Whereas, in Hungary or Poland for example, no such additional review process is needed. There are many other aspects that can determine the type of survey most suitable for the scope of the project (phone, web-based, paper-based, interview, mail or mixed-mode). For further information see (Christian et al. 2014).

Table 1 Summary of key information of the surveys reviewed

							Additional dataset(s) used								
1st author	**Year of publ.**	**Country**	**Building type**	**Method of cross-sectional survey/interview**	**Respondents**	**Nr. of buildings**	**Primary interviews**	**Longitudinal survey**	**Field EQ measurements**	**Energy consumption**	**Weather data**	**Other**	**Questionnaire available publicly?**	**Response rate**	**Incentives provided for participants**
Al-Mumin (Al-Mumin et al. 2003)	2003	Kuwait	Residential	1 cross-sectional, students	30	30							N		None, students
Andersen (Andersen et al. 2009)	2009	Denmark	Residential	2 cross-sectional (summer/winter)	1569	933+636					+	Dwelling database	N		4*140 EUR lottery
Brundrett (Brundrett 1977)	1977	UK	Residential	Interview with owners	101	123					+	Window state monitoring	N		
Veitch (Veitch et al. 2013)	2013	Canada	Residential	1 cross-sectional	626	455							Y		None, NRC workers
D'Oca (D'Oca et al. 2014)	2014	Italy	Residential	1 cross-sectional, Google	12	12				+			N		None, volunteers
Frontczak (Frontczak et al. 2012)	2012	Denmark	Residential + partly office	1 cross-sectional, invitation letter, online link	650	650	+						N		2*130 EUR lottery

1st author	Year of publ.	Country	Building type	Method of cross-sectional survey/interview	Respondents	Nr. of buildings	Additional dataset(s) used						Questionnaire available publicly?	Response rate	Incentives provided for participants
							Primary interviews	Longitudinal survey	Field EQ measurements	Energy consumption	Weather data	Other			
Guerra-Santin (Guerra-Santin and Itard 2010)	2010	Netherlands	Residential	1 cross-sectional, paper based	313							Dwelling database	Y	5%	
Humphreys (SCAT) (Humphreys 2005)	2005	5 EU countries	Office	Cross-sectional. Survey/month	840	26			+		+		N		
Iwashita (Iwashita and Akasaka 1997)	1997	Japan	Residential	1 cross-sectional	8	1			+				Y		
Moore (Moore et al. 2003)	2003	UK	Office	1 cross-sectional	16	4			+				Y		
Raja (Raja et al. 2001)	2001	UK	Office	Cross-sectional. Survey/month	909	15		+	+		+		N		
Karjalainen (Karjalainen 2009)	2009	Finland	Residential +office	1 cross-sectional, computer assisted telephone interview, CATI	3094	3094							N	10%	

							Additional dataset(s) used								
1st author	**Year of publ.**	**Country**	**Building type**	**Method of cross-sectional survey/interview**	**Respondents**	**Nr. of buildings**	**Primary interviews**	**Longitudinal survey**	**Field EQ measurements**	**Energy consumption**	**Weather data**	**Other**	**Questionnaire available publicly?**	**Response rate**	**Incentives provided for participants**
Feng (Feng, Xiaohang; Da Yan, Ph.D.; Chuang Wang et al. 2015)	2015	China	Residential +partly office	1 cross-sectional	1426				+				N		
Lutzenhiser (Lutzenhiser 1992)	1992	USA, CA	Residential	1 cross-sectional	279	2				+		AC use observations	N		
Meier (Meier and Rehdanz 2010)	2010	UK	Residential	1 cross-sectional (UK central statistics database)	10000	5000	+						N		None, state survey
Papakostas (Papakostas and Sotiropoulos 1997)	1997	Greece	Residential	1 cross-sectional	158	25							N		
Price (Price and Sherman 2006)	2006	USA, CA	Residential	1 cross-sectional (with focus group before)	1448	1448							Y	30%	

							Additional dataset(s) used								
1st author	**Year of publ.**	**Country**	**Building type**	**Method of cross-sectional survey/interview**	**Respondents**	**Nr. of buildings**	**Primary interviews**	**Longitudinal survey**	**Field EQ measurements**	**Energy consumption**	**Weather data**	**Other**	**Questionnaire available publicly?**	**Response rate**	**Incentives provided for participants**
Sardianou (Sardianou 2008)	2008	Greece	Residential	Interview with owners	586		+			+			N		
Wei (Wei et al. 2010)	2010	UK	Office	Interviews	103	4							Y		
Rijal (Rijal 2008)	2008	Pakistan	Office	Cross-sectional. Survey/month, 17x	846	33			+		+		N		
Becker (Becker and Paciuk 2009)	2009	Israel	Residential	1 cross-sectional	394	6			+				N		
Beko (Bekö et al. 2011)	2011	Denmark	Residential	1 cross-sectional	11082	11082			+				N	63%	
Brager (Brager et al. 2004)	2004	USA, Berkeley	Office	2 seasonal cross-sectional	198	1	+	+	+				N		
Warren (Warren and Parkins 1984)	1984	UK	Office	1 cross-sectional	210	5					+	Façade photographs	Y		

1st author	Year of publ.	Country	Building type	Method of cross-sectional survey/interview	Respondents	Nr. of buildings	Additional dataset(s) used						Questionnaire available publicly?	Response rate	Incentives provided for participants
							Primary interviews	Longitudinal survey	Field EQ measurements	Energy consumption	Weather data	Other			
Pigg (Pigg et al. 1996)	1996	USA, Milwaukee	Office	1 cross-sectional	48	1						Presence, light use monitoring, walk-throughs	N		
Rijal (Rijal et al. 2007)	2007	UK	Office	1 cross-sectional	453	15		+	+				N		
Inkarojrit (Vorapat 2005)	2005	USA, Berkeley	Office	2 cross-sectional	113	9		+					Y		$20 gift cert. Chance: 1:20
Zhang (Zhang and Altan 2011)	2011	UK	Office	1 cross-sectional	223	2			+			Façade photographs	N		
Karjalainen (Karjalainen 2007)	2007	Finland	Office	1 cross-sectional, interviews	27	13							N		
Dunn (Dunn and Knight 2005)	2005	UK	Office	1 cross-sectional on walkthroughs	30	30							N		

1st author	Year of publ.	Country	Building type	Method of cross-sectional survey/interview	Respondents	Nr. of buildings	Additional dataset(s) used						Questionnaire available publicly?	Response rate	Incentives provided for participants
							Primary interviews	Longitudinal survey	Field EQ measurements	Energy consumption	Weather data	Other			
Kawamoto (Kawamoto et al. 2004)	2004	Japan	Office	1 cross-sectional, interviews	145	1						PC, screen, printer usage	N		
Xu (Xu et al. 2009)	2009	China	Residential	1 cross-sectional	251				+	+		District heating system performance	N		
Hua (Hua et al. 2011)	2011	USA, NY	Laboratory	1 cross-sectional, interviews	75	1			+			Photographs, daylight simulation	N	90%	
							+								

5.2 *Survey Structure*

Most of the questionnaire surveys are conducted in the form of an internet survey using online tools. These tools might allow researchers to create adaptive questionnaires where automated question skipping can be integrated based on previous answers. This is called a branching technique. Another adaptable feature is called piping, where answer options can be changed based on the respondent's previous answers (Leeuw et al. 2008).

The structure and branching of the surveys were not always clearly documented in the survey studies reviewed. One study, serving as an exemplary case of clear survey branching approach, was an online survey conducted to assess use and expertise of daylight simulation for building design that involved 185 participants from 27 countries (Reinhart and Fitz 2006).

It is essential to define a clear branching structure for a survey to eliminate any superfluous questions and also to better communicate the project methodology to the research community. In the case of online surveys, this aspect can be crucial in selecting the appropriate survey tool for the research since most of the free tools do not have adequate branching and/or answer piping capabilities (Wilson 2013).

5.3 *Sample Size*

In the projects reviewed, the method for choosing the sample size is rarely discussed. Sample size seems to be determined by available resources to reach respondents. From a statistical point of view, sample size should be based on the confidence interval and confidence level needed to achieve reliable results (see equation 1 (Dillman 2000)). Wei, et al. calculated the desired sample size but it was also assumed that they could not reach it due to the limited time available to conduct the survey (Wei et al. 2010). An inappropriate sample size can introduce a bias to the data that is obtained, with results less reliable and so less valuable. Therefore, we propose always using an accepted definition of an appropriate sample size for occupant behaviour questionnaire surveys. Also, it is necessary to understand the errors and limitations of a dataset when an appropriate sample size cannot be reached.

$$Ns = \frac{(Np)(p)(1-p)}{(Np-1)\left(\frac{B}{C}\right)2+(p)(1-p)} \quad (1)$$

Where Ns = completed sample size needed (notation often used is n)

Np = size of population (notation often used is N)

p = proportion expected to answer a certain way (50% or 0.5 is most conservative)

B = acceptable level of sampling error (0.05=±5%; 0.03=±3%)

C = Z statistic associate with confidence interval (1.645=90% confidence level; 1.960=95% confidence level; 2.576=99% confidence level)

It is also important to ensure sample diversity and appropriate geographic coverage to better understand the population under investigation and also to provide the opportunity to show local differences (Dillman 2000). The projects reviewed did not address this aspect of sample design, as most of the time the goal of the research was to obtain some behavioural data from a limited number of available buildings. To understand similarities and differences between countries, cultures, and climates in energy-related occupant behaviour research, it is essential to ensure appropriate geographical coverage. For example, Dillman (Don A. DILLMAN 1983) used local census regions and urban densities for the U.S. (Office of Management and Budget 2013) to form a basis for creating geographical balance and the reliability of survey results.

5.4 *Contact Information, Means of Contacting*

One goal of this study was to gather data on the different ways investigators contacted questionnaire respondents. However, this information was not included in most of the papers reviewed. Possibly, the

authors did not consider it important enough to publish. Obtaining an appropriate contact database can be essential for the success of a large-scale cross-sectional project, since both the quality and quantity of survey responses are crucial.
According to Leeuw et al., survey errors arise in almost every data collection effort. Survey errors can come from four sources: coverage, sampling, measurement and nonresponse errors (Leeuw et al. 2008). Minimising and quantifying these errors is key. If the contact database is appropriately constructed and covers every area of the population of interest, then coverage and sampling issues can be overcome. Nonresponse error occurs when a respondent does not or only partially answers the questions. This type of error can be minimised by optimizing response rates.

5.5 Response Rate, Incentives

In statistics, determining an appropriate response rate for questionnaire surveys can be complicated. However, with a confidence level of 95%, and with large sample sizes (>2000), a response rate of 25% or more is considered high (Nulty 2008). Keeping the response rate high is essential. Price (Price and Sherman 2006) reported a 31.2% response rate, which is attributed to persistence in pursuing respondents and the freshness of the topic for new homeowners. Beko's response rate was 63% (11082 answers out of 17500) (Bekö et al. 2011). Reasons for the high response rate were not investigated; it is assumed that the importance of the survey topic, the health of children, may have influenced the respondents.
Guerra-Santin, et al. (Guerra-Santin and Itard 2010) found that the low response rate of their large-scale residential cross-sectional survey project was caused by the length and details of the questionnaire, and by the fact that respondents felt uncomfortable with providing personal information about their lifestyle and personal belongings.
Three projects introduced in the scope of this review paper used some type of incentive to motivate respondents to complete the questionnaire. A monetary award (130-140 EUR lottery prize) was offered in two Danish projects (Andersen et al. 2009) (Frontczak et al. 2012). A $20 gift certificate was raffled in Berkeley with a 1:20 chance of winning (Vorapat 2005).
Keeping the response rate as high as possible for future cross-sectional questionnaires is critical, and the strategies of offering monetary incentives, choosing an attractive survey topic, and choosing clear and interesting wording on the invitation are recommended.

5.6 Data Analysis Methods

This study reviewed statistical data analysis methods that were applied when only one or two sets of cross-sectional survey data from which to draw conclusions were available. A study with a sample size of 30 (Al-Mumin et al. 2003) averaged the survey answers by general occupant characteristics, averaged and aggregated occupancy, lighting, and appliance usage schedules. Veitch, et al. applied frequency analysis and also determined percentile values of 25, 50, and 75 for 626 samples (Veitch et al. 2013). However, Veitch, et al. claimed that the sample size was still too low to report any statistical tests associated with cross-tabulations by region or by construction year on their dataset. Karjalainen used software (SPSS) to perform the statistical analyses on 3094 samples (Karjalainen 2009). The Wilcoxon signed-rank (2-tailed) test was used for interval data to determine if a significant difference existed between the home and office environments. A marginal homogeneity test was used for categorical data. In addition, the Pearson Chi-Square test was used to investigate associations between two different sets of observations. For Greek households, average occupant presence and domestic electric appliance use schedules were determined for five occupant types (Papakostas and Sotiropoulos 1997). Based on cross-sectional survey data, Wei, et al. built a preliminary human adaptive behaviour and preference model (Wei et al. 2010), but asserted that a larger sample size would be needed to make the model more robust.

Small equipment loads were calculated in office buildings based on cross-sectional survey data (30 respondents) (Dunn and Knight 2005). Average, standard deviation values and a nameplate-ratio method were used for calculations.

When the cross-sectional questionnaire survey data could be complemented with additional datasets, such as environmental measurements, more sophisticated statistical methods could be used to find a connection between variables. This connection was described through correlation in many studies (Brundrett 1977) (Iwashita and Akasaka 1997) (Moore et al. 2003) (Lutzenhiser 1992) (Price and Sherman 2006) (Guerra-Santin and Itard 2010) (Becker and Paciuk 2009) (Hua et al. 2011). Others also managed to build a regression model to describe the nature of the connection (Frontczak et al. 2012) (Humphreys 2005) (Raja et al. 2001) (Meier and Rehdanz 2010) (Sardianou 2008) (Rijal 2008) (Bekö et al. 2011) (Brager et al. 2004) (Warren and Parkins 1984) (Rijal et al. 2007). In a Danish study, four occupant action types were analysed separately by means of multiple logistic regression analysis using a generalized additive model with a binomial link (Andersen et al. 2009). Continuous covariates were modelled. The significance of variables was tested based on a likelihood ratio test. In identifying the final model for each outcome, only cases with all relevant questions completed were included in the analysis. For the statistical analyses, statistical software R was primarily used.

Most of the projects managed to gain more comprehensive datasets for analysis with additional longitudinal surveys, indoor measurements, energy sub-metering, and/or weather data. However, increased respondent numbers make collecting data on the immediate environment of each occupant answering the questionnaire more challenging. Some of the larger studies reviewed, with more than 1,000 respondents, supplemented their dataset with a local dwelling database (Andersen et al. 2009) or field measurements for certain respondents (Bekö et al. 2011) (Feng, Xiaohang; Da Yan, Ph.D.; Chuang Wang et al. 2015). Most studies used only the cross-sectional questionnaire dataset.

It can be concluded that even if there is only one set of answers for the cross-sectional questionnaire surveys, data analysis methods are available and connections between variables can be identified. However, a dataset that is complemented with any type of environmental observations or measurement, if possible, is beneficial. Larger sample sizes may .create more robust results.

5.7 Other Issues with Cross-sectional Surveys

Yan et al. (2015) summarised that, despite the revealing nature of surveys and interviews, some fundamental issues remain. These issues include: (1) participants knowingly or unknowingly misrepresenting their behaviour (also in Moore, et al. (Moore et al. 2003), Lutzenhiser (Lutzenhiser 1992) (Lutzenhiser 1993)), (2) participants may not recall their behaviour or their severity of discomfort (Burak Gunay et al. 2014), and (3) participants may respond the way they think they are expected . These error types are categorized as measurement errors by Lohr (Leeuw et al. 2008). These issues should be overcome in large-scale survey campaigns to ensure the reliability of the results.

5.8 Findings from Methodological Review

The review of methodologies used in the survey studies shows that researchers mostly used their own intuitions to build up a methodology for their questionnaires. In most of the cases, the reliability and validity of the results were not guaranteed. The authors suggest that when constructing a questionnaire project in the future, researchers use a multidisciplinary approach and use the findings and methods common to studies in social science fields to ensure the quality of data collected for occupant behaviour research. As a result, in the discussion section a number of studies were reviewed from the survey methodology point of view to provide additional insight for researchers who examine energy-related occupant behaviour.

6. DISCUSSION

This study found that the 33 survey projects that were reviewed covered and explored a considerable amount of information that forms the basis of our current knowledge of occupant behaviour in buildings. Cross-sectional surveys are among other useful tools used to gain information on energy-related occupant behaviour. However, the information in the literature to date is scattered, by occupant action, building type and geography. In most of the cases, researchers focused on a particular environmental or other physically tangible parameter that drives human behaviour. These projects were designed and conducted by researchers with backgrounds in technical and engineering fields. Therefore, important issues in social science fields were disregarded, and many other key aspects of human behaviour were not measured or considered. Collecting data in a more coherent framework and addressing as many aspects and types of behaviour as possible, is a critical next step. At the same time, this framework should be well grounded in behavioural and motivational theories. A multidisciplinary approach, and international collaboration is required to take the next steps in examining occupant behaviour with regard to energy use.

The field of energy-related occupant behaviour research could benefit from the adoption of surveying methods developed by experts in the social sciences to ensure that surveys are comprehensive and integrate relevant social and behavioural aspects.

6.1 Methodological Limitations of Surveys Reviewed

This study showed that it is highly important to construct validity and ensure the reliability of results. Moreover, the phrasing of the questions needs to be clear, and high-quality translations are needed in case of international studies. Defining a clear branching structure and using smart piping techniques for this type of survey to eliminate any superfluous questions and answer choices, and reducing the length of the questionnaire to 15-20 minutes is essential. This might also influence the appropriate survey tool selection for the research. With a clear structure, it is also easier to manage and process datasets from different countries. Some studies introduced monetary incentives to obtain higher response rates (lottery, raffle), which might help to motivate occupants to complete the questionnaire. At the same time, the phrasing of the invitation email should be perfectly clear as well, and must also introduce the research topic in an interesting way to get as high a response rate as possible from the occupants.

This review of survey distribution methods shows that obtaining an appropriate contact database can be essential for the success of a large-scale cross-sectional project, since both the quality and quantity of survey responses are crucial.

The sample size was rarely discussed in the studies reviewed. It appears likely that sample size was mostly determined by available resources to reach respondents. Therefore, it is highly recommended that in future cross-sectional questionnaire projects, statistically appropriate sample size calculations be provided to ensure the reliability of results obtained from datasets. In addition, understanding the errors and limitations of a dataset when an appropriate sample size could not be reached is necessary. Also important is ensuring sample diversity and appropriate geographic coverage. In addition to physical geographic location, another key element is accounting for similarities and differences in specific buildings and rooms within a single building where the questionnaire was completed. This can be easily tested by adding two further independent, dummy variables to the analysis.

Even with only one set of cross-sectional questionnaire survey data, data analysis methods are available and connections between variables can be identified. This connection can be illustrated for example with Veitch et al.'s study, where the main question concerned the conditions that drove occupants to open or close their window shades (Veitch et al. 2013). Question 27 of their survey asked about possible drivers of shading use:

27. In the summer season, how do you keep the window shadings (whether they are interior, exterior, or mid-pane) during the day?

Open, for the following reason(s): (If you keep the shadings open, please check all that apply)

- For a view of outdoors
- To let in daylight
- To let in solar heat
- For the plants
- To indicate whether someone is there (for security)
- Other (specify):

Closed, for the following reason(s) (If you keep the shadings closed, please check all that apply)

- For privacy
- To keep the house secure while we are away
- To keep the house cool
- To reduce heat discomfort from windows
- To stop glare from the sun
- Other (specify):

Figure 3 - Question 27 asking about drivers of shading use **(Veitch et al. 2013)**

Based on the answers, researchers were able to identify the main drivers that caused of Canadian residential occupants to open or close their window shades. In winter, most people opened their shades during the day, primarily to admit daylight, and secondarily to introduce solar heat gains to contribute to heating. They closed shades at night primarily for reasons of privacy and darkness, although a substantial number of occupants recognized that this also contributed to warming the home. In summer, although many households opened the shades to admit light and a view of outside, there was an awareness that keeping them closed during the day reduced cooling demand. These findings were essential for drawing conclusions and identifying future research needs.

However, if the dataset is complemented by any type of physical sensing technique that provides objective measurements (such as BMS data, indoor and outdoor environmental data), it makes it more valuable. In this way, subjective, non-physical, self-reported data can be tested and validated.

Complementary datasets are beneficial but difficult to obtain with large sample sizes. It is proposed to collect data on the environmental conditions of the responding occupant at the time of their answer as a part of the cross-sectional questionnaire. However, the quality of data obtained this way should be investigated.

Furthermore, the issues with cross-sectional surveys detailed in Section 5.7 (such as behaviour misrepresentation, occupants not remembering their comfort problems, and behaviour) need to be overcome to ensure the reliability of the results obtained. Since the wording of questions in the surveys is critical, pilot studies with a small focus group (20-30 people) are recommended before questionnaire surveys are conducted. If the survey is completed in different countries, a quality translator is essential. Also, researchers should examine cultural differences (data sensitivity and privacy concerns).

6.2 Summary - Future Research Path Proposed

Studies have showed that energy-related occupant behaviour research requires a multidisciplinary approach (Hong et al. 2016) (Fabi et al. 2012). Currently, specialists with behavioural and social science backgrounds are underrepresented in the field, which is partly due to the lack of specialized graduate programs, lack of common interests, and lack of collaboration of research institutes (Lutzenhiser 1993). In addition, a panel discussion has concluded that education and the employment of interdisciplinary environmental social scientists should be promoted (Stem et al. 1991). This can be extrapolated to the field of building occupant behaviour research as well.

By conducting a cross-sectional survey, the knowledge base in this field can be greatly enriched. A new questionnaire that applies the proposed techniques and methodology could provide reliable answers to current open questions in our field.

The authors hope that, based on the findings of a new, international survey project, occupant behaviour can be better understood and represented in building performance simulation to reduce the gap between predicted and actual energy use, and to improve the robustness of evaluating the energy savings of energy-efficiency technologies used in buildings.

A better understanding of an occupant's adaptive actions would support policy makers, designers, and the construction industry. The results can provide qualitative and partly quantitative data for occupant behaviour modelling tools used in building simulation programs such as EnergyPlus. For example, the recently developed standardized occupant behaviour XML (obXML) schema can be extended and refined to improve the representation of occupant behaviour models in building performance simulations (Hong, D'Oca, Turner, et al. 2015b) (Hong, D'Oca, Taylor-Lange, et al. 2015a) (Hong, Sun, Chen, Taylor-Lange, et al. 2015c). With more accurate occupant behaviour representation, building energy simulations can better support the optimisation of building performance in a building's design phase. Many stakeholders in a construction project can benefit from the enhanced optimisation process, which might not only result in decreased operational costs but also in lower initial investment costs due to fewer needs for HVAC machinery.

7. CONCLUSIONS

Thirty-three studies were reviewed from the literature on occupant behaviour that used cross-sectional surveys or interviews for data collection. Although these studies largely contributed to the field of energy-related occupant behaviour research, this review showed that many methodological aspects of constructing the questionnaire surveys were barely considered or neglected. This may introduce significant bias into the results of these studies. With respect to research gaps in our field, it was found that more data is required on multiple types of behaviours and driving factors to obtain generalizable knowledge on occupant behaviour. Currently, arbitrary conclusions are drawn from scattered and limited national datasets on occupant behaviour. How occupant behaviours differ between cultures, countries, and climates is still little understood. Similarly, limited information is available on the order of actions undertaken by the occupant in order to restore comfort conditions. In addition, energy-related group behaviour has also been little observed and understood.

To bridge such gaps, a more coherent framework would be necessary. At the same time, this framework should be well grounded in behavioural and motivational theories. The authors have found that a broader, cross-sectional questionnaire survey could be developed to improve and deepen the understanding of diverse occupant energy-related behaviours in buildings. Through such a project, some of the critical open questions could be answered in the field of occupant behaviour research, and the data gaps could be filled in for under-researched areas.

In the current study, a thorough recommendation was also given for such future cross-sectional survey studies both from the perspective of research methodology and its theoretical background. The future of occupant behaviour research calls for a single standardised practice, which necessarily encompasses a multidisciplinary approach to the diverse fields being investigated. This will ensure information, knowledge, and insight into energy-related occupant behaviour in buildings that is universally agreed-upon. By better understanding and representing occupant behaviour in buildings, the global energy performance of buildings can be improved. Better energy performance predictions would be beneficial for all stakeholders in a construction project, from business investors and building designers to building users and managers.

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