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Review

The interaction between humans and buildings for energy efficiency: A critical review

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ABSTRACT

Buildings consume energy for different purposes. One core function is to provide healthy and comfortable living conditions for the humans that inhabit these buildings. The associated energy use is significant: taken together, buildings are responsible for roughly 40% of the world's total annual energy consumption. This large percentage makes the built environment an important target for researchers, policy makers, innovators and others who aim to decrease energy consumption and the associated emissions of Greenhouse Gases (GHG). Unfortunately, the significant body of research on energy efficient buildings conducted since the 1970s has had only a limited impact on the overall energy use of the sector, and this remains a serious concern. The energy use of buildings shows a strong correlation with the activities of the building occupants. A key factor that makes it hard to curb building energy use is a lack of understanding of building occupant behaviour. This paper reviews research on building occupant behaviour in two stages. The first stage reviews important issues, milestones, methodologies used, building types analysed and progress achieved related to the topic, as reported in the most frequently cited papers. The second stage focuses on recent work in the area and investigates 'state of the art' developments in terms of questions asked and solutions proposed. The aim is to identify problems and knowledge gaps in the field for future projection. Recent research on the topic is analysed, taking account of methodologies, building types, locations, keywords, data sampling and survey size. Based on a critical analysis of the literature, the following outcomes can be reported: research on building occupant behaviour relies strongly on quantitative methods, but studies are mostly located in the northern hemisphere and in developed and high-income countries. The dominant research topics associated with occupant behaviour are energy demand and thermal comfort, followed by retrofit and renovation. Most research focuses on technical aspects rather than socio-economic issues. Current research is mostly limited to studies of single buildings and typically lacks data-gathering standards, which makes it hard to conduct cross cultural data comparisons. Most research concentrates on individual topics, such as window, door and blind adjustments, effects of Heating Ventilating Air Condition (HVAC) systems etc. and does not provide a wider, holistic view that can be linked to social and economic factors.

1. Introduction

The increasing need for energy is among the key challenges facing the economic, environmental, societal, industrial and academic development of humanity. The International Energy Agency (IEA) regularly reviews the state of the art in this field. In a report from 2018, two important points were made: (i) In that year, the average global energy consumption increased by almost twice the average rate of

Abbreviations: BEMS, Building Energy Management Systems; DFL, Device Free Localization; EIA, Energy Information Administration; EPBD, Energy Performance Building Directive; EU, European Union; GHG, Greenhouse Gas; HVAC, Heating Ventilating Air Conditioning; ICT, Information and Communication Technologies; IPCC, The Intergovernmental Panel on Climate Change; IEA, International Energy Agency; LCA, Life Cycle Assessment; NASA, National Aeronautics and Space - Administration; NOAA, National Oceanic and Atmospheric Administration; NZEB, Nearly Zero Energy Buildings; PIR, Passive Infrared Sensors; POE, Post Occupancy Evaluation; RF, Radio Frequency; SCI, Science Citation Index; SCI-E, Science Citation Index-Expanded; SSCI, Social Science Citation Index; TUS, Time User Survey; UK, United Kingdom; UN, United Nations; USA, United States of America.

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growth since 2010 and (ii) a historic high was reached with energy related CO_2 emissions, which increased by 1.7% to 33.1 Gt CO_2 [1].

Since people are spending more and more time indoors [2,3] there is a strong need to save energy from buildings. It is well-known that 1/3 of primary energy [4] and 40% of energy resources worldwide is consumed by the built environment [1,4,5,6,7]. Contrary to general belief, "*buildings do not use energy: people do*" [8]. Janda [8] comments that there is a deficiency in the understanding of occupant behaviour, but this factor is often ignored in the built environment. Although occupant behaviour plays an essential role in driving the building energy consumption through heating, cooling, ventilation and artificial lighting systems [9] and has a strong impact on the general thermal performance of buildings [4,10], there is still a lack of understanding of the intricate interaction between humans and buildings. Generally, the amount of research published on this topic has been limited [11]. However, there has been a strong increase in interest [12] since the beginning of the new millennium, leading to a significant growth in research on occupant behaviour and its outcomes (Fig. 1).

Different publications emphasize various aspects of occupant behaviour. For instance, D'Oca et al. [13] analysed human dimensions, while Stazi et al. [14] reviewed driving factors and Naylor et al. [15] analysed occupant-centric energy control systems. Amasyali and El-Gohary [16] classified papers on occupant behaviour based on data driven energy consumption prediction, while Delzendeh et al. [17] analysed papers based on parameters influencing occupants' energy behaviour. Jung and Jazizadeh [18] classified review papers based on their topics, while de Bakker et al. [19] focused on lighting, Guyot et al. [20] on ventilation and Khosrowpour et al. [21] reviewed papers based on their data analysis methodologies.

An examination of the scope of recent papers reveals that technical issues are the most prominent topics. Quantitative research that analyses data is increasing [17,21,22]. Residences and offices are the building types that are the most studied, while monitoring and surveying are the most common methodologies for data gathering [23]. Although diversity between different occupant groups in various regions and countries [24], as well as variation between socio economic groups [25], is mentioned, occupant behaviour is still mostly considered at the individual building-scale and not at the urban-scale [26]. Strikingly, it has been reported that the low energy consumption of buildings cannot solely be guaranteed by technology [13].

A related area of research that attracts a high degree of interest is the 'energy performance gap'. This gap is related to the difference between the predicted and actually measured amount of energy used in buildings [27,28]. Mostly there is a significant difference, which means building energy performance targets are missed. In one of several studies on the performance gap [29,30] de Wilde [31] identifies occupant behaviour as one of the main underlying reasons for its existence. Maintaining comfort conditions of occupants is the main reason for energy consumption in buildings. Variation in building design, building systems, weather, indoor air temperature, relative humidity, air speed and occupant-centric parameters such as clothing, metabolic rate, cultural habits, attitudes and life-styles all may contribute to varying comfort conditions in which occupants consume energy. Furthermore, occupants are individual human beings, and therefore it is hard (and often controversial) to group them into predefined categories using a classification based on their culture, location, society, status, lifestyles, income, vulnerability, age, gender etc. [4]. To conserve energy in buildings, occupant comfort conditions should be maintained while accommodating the occupants' habits, attitudes, profiles, lifestyles, demographics, socio-economic status, vulnerabilities, and other limitations. Although comfort conditions are targets and these target conditions may not always be achievable, overlooking topics such as lifestyles, vulnerabilities, and limitations with lack of their measures/metrics might be one the most important reasons for the energy performance gap in buildings (Fig. 2). However, some critical questions about the relation between occupant behaviour and building energy performance have been asked by Mahdavi [32].

Demographical change affects society in several ways. Since individuals spend a good portion of their life in buildings, a healthy and comfortable environment is vital for occupants' well-being and productivity, as well as energy conservation [33,34]. It is known that different age groups with different metabolism rates, health and vulnerability conditions tend to use different levels of building energy. Moreover, income and vulnerabilities may be listed as factors limiting the consumption of energy. The increasing life expectancy of humans due to developing technology, better health care and effective public precautions also has an impact on building energy consumption. Buildings, like people, inevitably age. Close to 64% of the European Union (EU) building stock is over 35 years old. Average consumption was 185 kWh/m^2, while space heating constituted 60 – 80% of consumption [24]. Income, type of ownership, size, and respondent's age are household characteristics that are known to have an influence on the use of energy [35]. Resilience of buildings, along with occupant behaviour, may be another topic for the coming decades. Older populations occupying older buildings may lead to increased energy consumption in the near future.

As buildings are omnipresent, addressing the performance of the existing building stock has become a major challenge [36]. In principle, the reduction of energy use in buildings can be achieved in two ways. The first is to invest in technology and the second is to invest in changing occupant behaviour. In general, human beings can be considered as quite flexible to changes of climate conditions, lifestyles, developing technology, attitudes etc. Buildings, on the contrary, are a lot less flexible than humans over their operation period. Technological

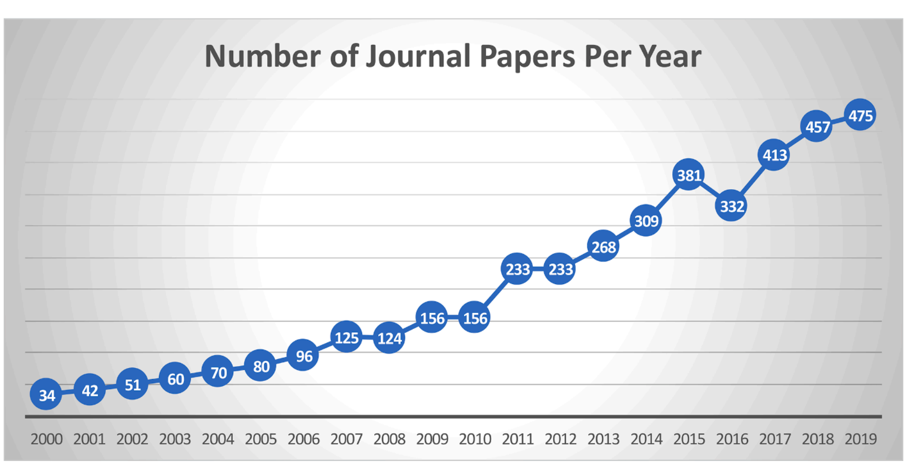

Fig. 1. Journal Papers published in English related to Occupant Behaviour between the years 2000–2019, based on Scopus records.

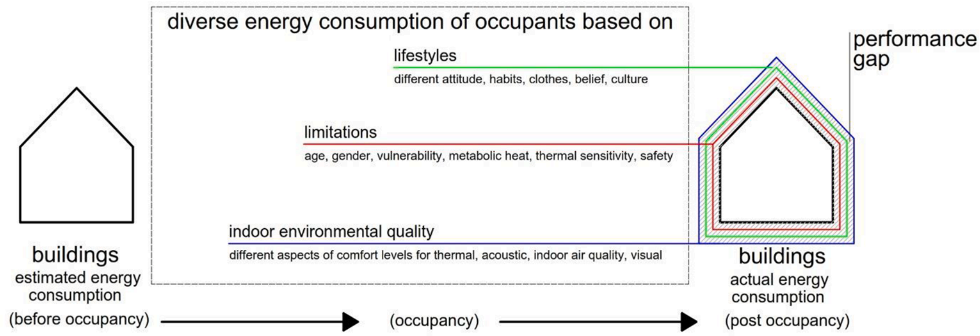

Fig. 2. Effects of Occupant Behaviour on the building energy performance gap.

modifications of buildings take time, need a serious amount of investment, and payback times cannot fully be estimated. Using the human capacity for adaptation may allow societies to get fast paybacks and efficiency results. This is not expensive and has a fast response time. Supporting this idea, Yue et al. [37] argue that promoting the use of energy-efficient technologies, as well as further developing such technologies, is not enough to tackle high levels of environmental pollution and energy consumption. Occupants should not be considered as the only actors who will solve the problems. It is obvious, however, that the challenges of reducing energy consumption and bridging the energy performance gap in buildings require a deep understanding of occupant behaviour.

1.1. Aim and objectives

This paper explores the current knowledge based on occupant behaviour in relation to the energy consumption of buildings. It discusses the current 'state of the art,' identifies research challenges, and reviews ongoing research efforts. The contribution of this review paper is twofold. Firstly, it provides an extensive and deep literature review to understand current research in this field. Secondly, it outlines what needs to be investigated next in order to progress the domain.

In more detail, the paper has the following objectives:

1. To investigate the current body of knowledge on building occupant behaviour, specifically homing in on the interaction between humans and buildings, occupant attributes, and different categories of occupants.
2. To explore current efforts in the field of building occupant behaviour in terms of the coverage of the domain, with specific attention to knowledge gaps, underexplored areas, and hyperbole in some areas.
3. To review the methodologies used in building occupancy studies reported in the literature in terms of research focus, methodology used, building types studied, geographical coverage, data sampling, and dataset size.
4. To identify areas that need further work.
5. To develop suggestions for future research.

1.2. Overview of the paper

The paper is organized according to the objectives and covers the five main themes, namely, introduction (Section 1), literature review (Section 2), followed by ongoing efforts (Section 3), discussion (Section 4) and conclusion (Section 5).

The introduction gives an overview of the research area and defines specific problems based on review and research papers. The section is built on developments and milestones in the field from the publications that are most often cited.

Further literature is reviewed in seven different sub-sections by defining the role of occupants in building energy use, scrutinizing occupant and occupants attitudes, the importance of occupant behaviour, discussing the differences between energy efficiency, consumption and conservation, focusing on the importance of data for analysing occupant behaviour and reviewing building types used in previous studies by concentrating on the near future and its challenges. The literature is reviewed on the basis of review and research papers published in the field.

'Ongoing efforts' is the deep analysis of research published in the last two years in seven internationally indexed – Social Science Citation Index (SSCI), Science Citation Index (SCI), Science Citation Index-Expanded (SCI-E)- journals, namely Building and Environment, Building Research & Information, Energy and Buildings, Energy Research & Social Science, Energy Policy, Journal of Building Engineering, and Renewable & Sustainable Energy Reviews. The journals that have been selected are all listed in the Scopus database and have been chosen on the basis of their impact factor and on earlier publication numbers related to occupant behaviour. This chapter is followed by discussions that critically analyse up to date research and conclusions based on the outcomes of the review.

1.3. Methodology

The literature review in this paper has been conducted in two rounds. In the first round, papers in the field are reviewed from a wider timeline, covering the one hundred papers most often cited in the field. The first two sections inspect the literature for contextualization, providing an overview and describing recent developments to clarify the main topics and challenges in the field. Review and research papers related to occupant and building interaction, performance gap, hot topics of discussion and overlooked issues are categorized.

The second round of reviews conducts a critical analysis of work published in the last two years in seven internationally indexed (SSCI, SCI, SCI-E) journals. This review analyses the ongoing efforts to understand cutting-edge developments and current innovations in the field. The discussion section critically analyses up to date research and discusses what has recently been done and what action will be carried out next. The paper concludes with outcomes of the review, followed by future work projection. The research reviewed around 300 papers in total to provide projections for future research. Most, but not all, of these papers are cited in this article.

2. Literature Review

This section of the paper reviews the existing literature on building occupant behaviour in the papers that are most often cited. The papers used in this chapter are carefully chosen from research and review articles in the Scopus database under the term "Occupant Behavio(u)r". Papers with a different focus area, such as fire safety, health sciences, accident analysis, transportation, which are included in the term, have been excluded. The section lays out the main issues to frame the developments and challenges to be discussed in seven sub-sections. The outcomes of this section contribute to drawing a framework of the analysis of the current practice for ongoing efforts in Chapter 3.

2.1. Role of occupants in building energy use

Descriptive statistics give a general feel for the important role of buildings and their occupants in the environmental challenges facing the world. Buildings consume approximately 80% of their life cycle energy during their operation [38] which is roughly more than 4 times the embodied energy [39]. Overall, 36% of the global final energy consumption is jointly attributable to existing buildings and building construction, and close to 40% to total direct and indirect CO_2 emissions [40].

The importance of occupant behaviour in the energy performance of buildings has been pointed out by many authors, such as Nicol & Humphreys [41] Clarke [42] Baker & Standeven [43], Nicol [44], and Mahdavi & Kumar [45]. The Report of IEA Annex 53, on occupant behaviour, lists triggers for occupant actions, such as biological, psychological, and social contexts, time of day, building/installation properties, and the physical environment [46]. This report positions occupant behaviour as addressing the first stage of Maslow's pyramid of need when considering energy consumption in buildings. A few years later, IEA Annex 66 [47], in a project related directly to occupant behaviour, reported that the behaviour of occupants plays an important part in their standard of comfort and their use of energy.

Building energy consumption is significantly influenced by the occupants' behaviour [48]. Yu et al. [49] define seven important factors influencing the total energy consumption of buildings, namely climate, building related characteristics, user related characteristics, building services systems and operations, occupants' behaviours and activities, social and economic factors and indoor environmental quality. Occupants, simply by their presence, passively affect the energy balance of buildings [50]. Occupants are also responsible for consumption, emission and waste produced, and consume energy in buildings for different reasons to maximize their comfort though their use of Heating, Ventilation, and Air Conditioning (HVAC) systems, cooling, lighting, plug loads/appliances, and domestic/service water heating [4].

Occupancy is difficult to measure and model in building research, even though it may be listed as a key factor in building energy use [51]. D'Oca et al. [13] defines occupancy patterns as the key driver of building performance for residential buildings. They are also important for energy related calculations and simulations considering specific issues [52]. The general profile of occupants can be used to further develop energy saving policies specific to certain sectors of society [52]. Consequently, while patterns are used mostly for individual research, profiles are also needed for larger scale implementations. Occupant profiles and patterns can be developed, based on detailed data analysis [35] and nationwide statistical analysis [53]. However, the literature does not provide an agreed profile or patterns for group populations in studies focused on Europe and the United Kingdom (UK) [54].

To conclude, occupants with their different profile and activity patterns are the main drivers of energy use in buildings. Occupants not only consume energy as a consequence of their presence but also with their operative control related to building type. Besides, occupants play an active role by changing thermostat set points, tuning radiator and light switches etc. to adjust the indoor air environment. However, due to variances in occupants' backgrounds, it is not easy to model or measure occupancy to determine energy consumption in buildings.

2.2. Occupants and occupant attributes

The term "occupant" stems from the Latin term verb "occupare" and is typically defined as a person who resides or is present in a house, vehicle, seat etc. [55]. Within the domain of buildings, a more specific definition may be: occupants are human beings who occupy a space within a building for some purpose, who have their own comfort requirements and expectations regarding the environment they occupy [47]. Occupants interact with the buildings, modifying the indoor environment to maintain their personal comfort, which is a necessary pre-condition for health, well-being and productivity [56]. In this respect, occupant behaviour can be defined as the presence of people in the building in relation to actions of adjustment to the indoor environment [57]. Nicol and Humphreys [58] state that people react to change in order to restore their comfort if a modification of their environment occurs. On the other hand, occupancy is not a singular term and does not only represent individuals. The term is also related to the presence of people in a building, occupying space, the number and location of people in a space, and all of these in relation to time [59]. Understanding the adaptive approach to thermal comfort; control by occupants might be viewed as a decision-making process that takes certain physiological and psychological assessments into consideration before any control action is carried out [60].

Behavioural change is a term that is used to describe a process whereby occupant behaviour is modified in some way. This is mainly considered to be achievable at little or no cost, without hi-tech knowledge, and to have the potential to decrease energy consumption. The opportunity is applicable to both new and existing buildings [61] and effects may be attained in the short term compared to other interventions. Each individual human being has a distinct personal history, attitude, sociocultural attributes (such as age, gender, education and wealth/income) and shows variations in physical and mental health, relationships with family and friends, and the amount of free time each has, all of which all have an effect on the energy-related behaviour in buildings [62]. In addition, socio-economic characteristics may affect lifestyle, attitudes and preferences [63]. Since occupants have different habits, attitudes and thus different influences on energy consumption in buildings, occupant profiles are often used to define segregation between clustered groups. Occupancy patterns, different from profiles, are used to define actions and reactions within a certain time scale.

To conclude, occupancy is the term given to humans who occupy a space and who interact with buildings. Occupants react to modifications in their environment to restore their comfort. The comfort conditions such as temperature, humidity, indoor air quality, sunlight etc. may vary due to the different profiles of occupants. Occupant profiles classify people based on demographics related to age, gender, single-family, vulnerability etc. Different profiles may have different activity patterns, which may change over time. However, there are as yet no cross-culturally agreed occupancy profiles or patterns to group building occupants.

2.3. Importance of occupant behaviour

An occupant's interaction with a building and its systems to adjust indoor air quality and thermal comfort plays a significant role in the total energy use [35,48,64], as well as the specific energy performance of buildings [65]. As reported by Fabi et al., [65], Kirsten [66] and Yan et al. [67] research exploring identical buildings and identical envelopes has identified occupant behaviour as a significant driver for variation of energy consumption, CO_2 emissions and waste production. A deep understanding of occupant behaviour is vital for the accurate prediction of operational energy use in buildings [68]. However, occupants are not homogenous groups of people. Moreover, occupants may not always react on the basis of logic but may also be driven by their emotions, which may reflect numerous variables. Occupant behaviour is listed as one of the important reasons for the performance gap [31] since its complexity and its dynamics make it difficult to capture.

Nguyen and Aiello [69] point out that occupancy-based control may allow for a significant amount of energy savings in HVAC and lighting systems. Ouyang and Hokao [62] state that occupant behaviour affects household electricity use directly. Similarly, Gill et al. [70] conclude that occupant behaviour in low-energy dwellings has a significant impact on heat and electrical energy consumption. Moreover, van Dam et al. [71] reported, on the basis of research by Brohus et al. [72] and Crosbie and Baker [73], that the behaviour of occupants played an important part in the varying degrees of consumption of domestic energy.

Even though the world's attention seems to be focused on improving technology for energy efficiency, poor occupants' behaviour in terms of wasting energy requires more serious attention [61]. Occupants may also change their behavioural patterns due to increased awareness. The European Environment Agency [74] reports that different measures targeting consumer behaviour may help to save up to 20% of energy demands. For example, positive effects of policy coverage of total final energy consumption in buildings led by lighting has effects on building sector energy intensity, which is decreasing [75]. Levy and Belaid [53] affirm that a better understanding of the processes of energy consumption can be obtained by paying more attention to the use of energy by individuals or groups and by applying anthropological, sociological and geographical methods to the study of residential practices and life-styles. Policy makers and researchers should not fall into the trap of blaming people and making no investment in buildings. Energy conservation in buildings should take occupants into account but cannot depend solely on changing occupants' behaviour.

Occupancy-related information is not only useful for building energy management but also for safety, security, and emergency response [76]. Occupants develop adaptive behaviours and interact with buildings. Human-building interaction based on passive and active control systems follows the same philosophy of human–machine interaction as is established in the wider engineering domain. For example, machine learning algorithms have effectively been used in Building Energy Management Systems (BEMS). Occupant behaviour is seen as a vital factor in reduction of the ecological footprint [77]. And finally, occupant behaviour must be taken into account for Life Cycle Assessment (LCA), especially for operational estimation [78].

Occupants adapt themselves for the building environment for the best possible fit of their comfort requirements and indoor environment conditions. However, occupant behaviour is affected by several contextual factors, such as socio-cultural background, demographics, personal limitations, lifestyles etc. Considering occupant behaviour is a key factor of energy consumption; a better understanding of it is needed for energy management that covers efficiency and conservation in buildings.

To conclude, buildings consume energy: this consumption, however, is driven by the needs of occupants. Occupants are the ones who consume energy, cause greenhouse gas (GHG) emissions and produce waste in buildings. Occupants have a direct effect on the heating, cooling, and ventilation of buildings. They are one of the most important reasons for the energy performance gap and have the biggest impact on consuming energy. That is why occupant behaviour is one of the hot topics related to energy conservation and efficiency in buildings.

2.4. Energy efficiency, conservation, and consumption

Energy saving measures work in different ways and therefore need to be selected on the basis of a good understanding of the workings of specific buildings [79]. Conserving energy, however, is not the same as reducing consumption or increasing efficiency, two terms that are frequently confused and poorly understood [80]. Energy efficiency and energy conservation are related terms, but each has a distinct meaning [81]. According to the Energy Information Administration (EIA) [81] energy efficiency relates to the use of technology to provide the same service with less energy, while conservation relates to any intervention that results in the use of less energy in relation to the total amount of energy used. Energy efficiency may be increased, and consumption can be reduced, through a better understanding of occupant behaviour in buildings. Another key point to remember is the need to define time intervals and metrics when calculating consumption. Depending on context, one may for instance decide to aggregate energy data as weekly, monthly, seasonal or annual, or to measure energy use per person, household, building volume or floor area. Consumption may be compared in relation to a specific target or goal of research. By way of example, reference can be made to the outcomes of research by Levy and Belaid [53]. They state that consumption intensity per person may vary according to the diversity of households. However, the age of households and their consumption may be totally different, whereas consumption per square meter remains relatively stable. One of the outcomes of their research was that larger households with more members consume more energy overall, although the individual energy usage of a member of such a household is decreased [53]. Thus, researchers must align their targets with their method of analysis. Meaningful outcomes require the use of meaningful performance measures and the correct use of statistics.

Varying habits, attitudes and lifestyles among individuals in a society render the definition of energy- based measures complicated and force researchers to inspect several issues related to interactions between these measures and human beings. To achieve energy targets, people should ask themselves to define their objectives for energy consumption in buildings. According to Filippin et al. [82] saving energy is more cost-effective than producing energy. Consuming less energy reduces GHG emissions, preserves resources and decreases users' energy costs. The research of Steinberger et al. [83], which was concerned with negawatt and energy saving in relation to reduced consumption, reveals that EU targets for the reduction of GHG emissions by 2050 are unachievable through technological improvements alone.

Pre-bound and rebound effects are also important tasks to deal with in considering energy efficiency related to occupant behaviour. Hens et al. [84] and Santin [85] define the rebound effect as added energy used after retrofitting, while Sunikka-Blank and Galvin [86] explain the pre-bound effect as using less energy than expected before any retrofitting. Both are believed to cause a gap between measured and performance consumptions due to the behaviour of occupants.

To conclude, it should not be forgotten that (i) energy efficiency might not decrease total consumption of energy but might positively affect energy conservation and that (ii) energy efficiency and conservation have positive effects on reducing energy consumption. However, these two factors might be subject to prebound and rebound effects related to occupant behaviour.

2.5. Importance of data for analysis of occupant behaviour

Data, whether quantitative or qualitative, is crucial to all analysis of occupant behaviour. Qualitative research gathers data about opinions, attitudes, perceptions and understandings of people and groups in different contexts, using interviews, focus groups, observation, case studies, etc., while quantitative research gathers data in terms of numbers, using surveys, statistics, modelling etc. [87]. Quantitative research provides the best means of testing hypotheses and quantifying relationships, whereas qualitative methods are appropriate for exploratory studies or for acquiring deeper levels of information [87].

It may be noted that recent research on occupant behaviour is highly focused on data collection and analysis. Hong et al. [48] define four areas in which data should be gathered: (i) occupant movement and presence, (ii) thermal comfort sensation and control, (iii) operation of windows, shades and blinds and (iv) operation of lighting and electrical equipment. One of the biggest obstacles with regard to data collection is the lack of standardized data-gathering, storage, and analysis protocols. Privacy issues also pose a problem [48]. Furthermore, occupancy data collection at the building scale is highly varied [54] and exact details of the underlying data-gathering and analysis often remain vague. With only a few exceptions, all reviewed research papers use data analysis combined with case/field study, surveys, questionnaires, interviews or monitoring. In recent research, excellent data analysis has been achieved using different statistical methods, mathematical formulations with capable computer systems and simulation tools. Consequently, quantitative research easily stands out amongst the many quantitative or mixed-mode efforts. However, Day and O'Brien [88] point out the importance of data gathering based on qualitative research for detailing hidden and important facts which quantitative research may overlook. Most of the research related to occupant behaviour is conducted during post occupancy stages.

Post Occupancy Evaluation (POE) is the evaluation of a building based on its performance with occupants [89,70]. According to a review by Li et al., [23] energy use is by far the most explored issue. POE can be applied to any type of building. To have statistically significant outcomes, however, demographics and the size of samples of occupants should be carefully chosen. Research based on POE has been produced by Vale and Vale [90] for domestic energy use and lifestyles, Korsavi et al. [91] for adaptive behaviours, and Gonzales-Caceres et al. [92] for evaluation in social housing.

Monitoring, whether for a single building or dwelling is one of the methods most often used in studies of occupant behaviour [54]. Records of energy consumption based on bills and meter readings may be listed as basic methods. More advanced approaches employ motion sensors, vision- based technology, Radio Frequency (RF) based technology, Passive Infrared Sensors (PIR), multi- sensor networks, CO_2 sensors, acoustic sensors, air pressure sensors, Device Free Localization (DFL), or virtual sensors [76,54]. The monitoring period is important for understanding monitoring results. Seasonal effects are often critical and monitoring for a full year may be needed to capture the full complexity of the observed quantities in sufficient detail [67]. Demographics should be taken into account when deciding on sample size. Time intervals for monitoring vary from 1, 5, 10, 15, 30 or 60 min to daily, weekly, seasonal and yearly intervals, depending on the specific purpose of the research. Research based on monitoring is to be found in Gilani and O'Brien [93] for *in situ* monitoring for offices and Abubakar et al. [94] for energy monitoring devices

Simulation can be defined as the digital representation of the behaviour of a building, process or a system. Challenging factors in building simulation are the representation of social constraints and dynamics, lack of stressors, and unfamiliarity with the environment [67]. A large number of simulation tools is available for the prediction of a building's energy consumption [56] and new tools are regularly introduced with highly different underlying models and opportunity of use. Melfi et al. [95] and Yan et al. [67] list temporal, spatial, and state resolutions for occupancy modelling as challenging factors, requiring knowledge of occupancy (activity type, identity and number of occupants with a specific state), spatial resolution (community, building, zone and room) with time intervals (seconds, minutes, hours, days and years). Yu et al. [49] assert that it is not possible to define all the effects of occupant behaviour and activities through simulation, due to the behavioural diversity and complexity of users. There are several methods and systems that attempt occupant modelling in the field. Some of these are based on Statistical-Linear Regression, Bayesian Probability, Logistic Regression, Support Vector Regression, *t*-test, the *U* test, the Pearson chi-square test, the KS test, Time Series, the Stochastic Standard Markov Model, the Markov Chain-Monte Carlo, the Hidden Markov Model, the Layered Hidden Markov Model, the Autoregressive Hidden Markov Model, the Dynamic Markov Time-Window Inference, Various Probability Distributions, the Machine Learning- Support Vector Machine, the Artificial Neural Network, the Decision Tree, Classification Methods, Polynomial Regression, Clustering, Bayesian Networks, Presence Sense and Optimization [48,76]. Building performance simulation is a low-cost and efficient alternative for analysing and optimising building designs and systems [12]. Research based on simulations can be accessed in Virote and Neves-Silva [64] (occupant behaviour assessment based on stochastic models); Yang and Becerik-Gerber [96] (a systematic review of simulation programs for coupling of occupancy information with HVAC energy simulations); and Feng et al. [59] (simulations of occupancy in buildings). Moreover, an occupant behaviour XML schema, obXML, has been developed for exchange of occupant information modelling and integration with building simulation tools [97,98]

Surveys are valuable for gaining knowledge of relationships among a group of variables [4] and are often used in social science. Different approaches can be discerned, such as transverse, longitudinal, and background surveys [68]. Validation is important for the avoidance of misinformation [67]. Research with large datasets based on surveying can be found in Acharya and Sadath [99] for surveys of more than 40,000 households conducted over a period of several years to investigate the relationship between energy poverty and economic development. Time User Surveys (TUS), which aim to identify, quantify and classify people, are also used for profiling occupants with large datasets and likewise the research of Barthelmes et al. [100].

Questionnaires provide a well-known method for gathering data for analysis and are often used in occupant behaviour studies. An important piece of information about in questionnaire research is the response rate. However, this information is often missing from occupant behaviour research. Questionnaires can be augmented by diaries and observation and focus groups. Research on the use of questionnaires in the field of occupancy has been provided by Carpino et al. [101].

To conclude, data is crucial for occupant behaviour research, whether quantitative or qualitative. Advanced methods are used to gather reliable data for the analysis of occupant behaviour. Extensive data sets are required to find trends within this challenging domain. However, no standards or protocols have so far been developed, which makes it difficult to compare data originating from different research projects.

2.6. Building types researched in previous studies

There is a close relation between building type, typical occupants, and occupant behaviour. However, research on occupant behaviour is not evenly split over all building types. Most research focuses on residential buildings, offices, educational buildings, and healthcare facilities [7]. These types represent different fractions of the overall building stock; residences form a major part of the total building stock and thus represent the most common building type [102]. It is worth keeping in mind that everyone is linked to some sort of residential building; a house can be considered as "*a machine to live in*" [103] for twenty-four hours, which entails a constant consumption of energy. Although people may not be present during the full twenty-four hours, many systems of the house will still be consuming energy in their absence. For instance, equipment such as refrigerators will run all day; other systems, such as heating, are likely to remain on during winter at a reduced setpoint to prevent freezing. In some countries cooling and air conditioning may also run during hours of non-occupation in summer. Systems such as home security apparatus, fire alarms and similar appliances also have to be kept on for twenty-four hours a day all year round, which requires a continuous energy supply.

Personal choices have a strong influence on energy use [104,105], and a house has more options for personalisation than socially shared spaces in other building types [27]. People may adjust themselves and change environmental conditions in their own homes on the basis of their personal preferences in ways that may not be possible in shared spaces. In contrast to other building types, the limited number of people who share a home can often be seen to constitute a homogenous group. However, a variety of personal differences may remain, leading to potential conflict among family members [106]. Residential units have been well studied by researchers who carry out case or field studies. However, an important problem with the research on occupants in residential settings is the issue of privacy [12] and data confidentiality. Sensor-based monitoring within a house might thus be challenging [107]. Moreover, outcomes of a survey may fail to reveal exact realities, due to seasonal effects, mood, boredom, a suspicious attitude towards surveys and concerns related to privacy. These constraints make data on occupants of residences difficult to gather and analyse. Another concern within residences is further classification of the building typologies. A resident can have the use of very different buildings that have widely differing attributes in terms of size, geometry, status, location, physical appearance, heating systems, energy performance, dwelling type etc. Although these buildings are all classified as residential buildings, major differences can make it very hard to compare outcomes for different residents. However, it is also important to note that most residents pay their own energy bills, which impacts their perception of building energy consumption [108].

The office is another building type that is frequently studied in occupant behaviour research. Compared to residences, offices have more shared spaces, contain more people and involve hierarchical management structures [109]. These occupants typically are a heterogeneous group, consisting of adults with different backgrounds. People generally spend one third of their day in offices [110]. Unlike residences, offices are mostly occupied during daytime and more active systems are used for HVAC. Certain appliances, mostly those related to Information and Communication Technologies (ICT), are standard features of an office. HVAC systems, their setpoints and other operational decisions are often centrally controlled and based on time schedules and automated settings via a BEMS, especially in large, modern office buildings. Yet data gathering in an office could be easier compared to that in most other building types. Unlike residences, the activity patterns of occupants in offices are relatively steady and relate mostly to working hours. This eases the definition of occupancy patterns, especially where data analysis is done in the context of simulation-based research. Since offices are assigned as working places, there may be benefits for researchers in using this work environment as a living laboratory, without distracting occupants' attention. Easy access to infrastructure for monitoring equipment may be another positive contribution to data gathering [93]. Where offices use BEMS, these systems may be accessed to see detailed setpoints and timings. Data can also be reviewed for longer times if the system contains a logging facility. On the other hand, whenever energy systems are more advanced, effects on occupants may arise which require a deeper understanding of occupant behaviour. Furthermore, since there will be different stakeholders using an office, there will be a variety of occupant profiles for comfort and satisfaction levels. Social interaction may impact the interaction with office HVAC control systems, such as thermostats or light switches, and this may cause some occupants to be less satisfied with comfort conditions [111]. According to Chen et al., [112] there are no universally applicable human-building interactions - "one size fits all"-, encompassing differences in culture, gender, etc., that effectively provide both comfort and energy savings in workplaces. However, office occupants may tend to consume less energy where they pay their own energy bills and are owner-occupiers.

A third building type often used in occupant research is educational facilities, such as university buildings and schools. Having groups of the same age and with similar educational backgrounds enables researchers to analyse more homogenous groups. Profiling students and defining patterns may be easier because students are in the same age groups with regular activities related to learning. As with offices, education generally takes place during daytime and weekdays. Since education proceeds in terms and semesters, the energy consumption may have peak values at certain times, but not continuously over the year. Data gathering thus can only be undertaken for a certain period of time and privacy may still be of concern, as occupants may be underage. Different disciplines and corresponding traditions and cultures make it more challenging to evaluate and compare buildings on the same basis. Educational facilities may also have their own policies in terms of maximizing energy conservation, which is seldomly the case for other building typologies. Research by Tucker and Izadpanahi [113] found that sustainable school design plays an important role in shaping children's environmental attitudes and behaviour. Thus, educational buildings might also be evaluated for their active contribution to inspire new generations to conserve energy.

Different occupants may occupy different types of building during the day. A user may be a resident of a house for the evening, a worker in an office in morning and a student at a school in the afternoon. Although these different spaces are occupied by the same user, his/her actions may vary according to the comfort conditions in these spaces in different time intervals [114]. This is due to variation in social codes, behavioural patterns, attitudes, lifestyle and different social roles. Each type of occupant behaviour should be analysed in its own specific contexts.

To conclude, offices, residences, and educational buildings are the most common building types that are studied in occupant behaviour research. Defining occupant patterns in offices and schools is easier than in residences because of the regularity of activity. Although residences represent a higher energy consumption in buildings, privacy and accuracy are still major concerns in relation to data gathering.

2.7. The near future and challenges

The National Aeronautics and Space Administration (NASA) has revealed that the decade 2010–2019 was the hottest that it has ever recorded, while the National Oceanic and Atmospheric Administration (NOAA), which has a climate record dating back 140 years, has reported that 2016 was the hottest year, closely followed by 2019 [115]. At the same time, the world's limited non-renewable energy, water and material resources are being consumed by an increasing population with a growing demand for energy. Society will eventually exhaust these resources, and moreover cause further GHG emissions with a substantial amount of waste, thus further exacerbating climate change and global warming. Wang et al., [116], whose research related to statistics from the IEA and the World Bank, reported that energy use and CO_2 emissions per capita rose significantly between the years 1960 and 2010 [117,118]. Climate change and global warming are at the top of the United Nations'(UN) agenda. Each day, further studies reflect the impact of climate change [119] which may amplify diseases [120], energy and water shortages and energy and fuel shortages [119] around the world. The UN, in an attempt to counter these trends, has introduced 17 urgent sustainable development goals, including affordable and clean energy, sustainable communities and cities, climate action and life on land [121].

The Energy Performance Building Directive (EPBD) recast [122] was introduced by the EU in 2010 and drives objectives of Nearly Zero Energy Buildings (NZEB) and cost optimization. Society needs to act immediately and cannot wait until the years 2030 or 2050 to achieve such targets. At a generic level, the EU 2020 has aimed to meet the following targets: (i) 20% cut in GHG emissions (from 1990 levels) (ii) 20% of EU energy generation from renewables (iii) 20% improvement in energy efficiency [123]. The outcomes by the end of the year will yield insights into the feasibility of the 2030 targets of (i) a minimum of 40% cuts in GHG emissions (from 1990 levels) (ii) at least a 32% share for renewable energy (iii) a proposed minimum 32.5% improvement in energy efficiency [265]. However the targets for the 2050 goal to curb the global temperature increase to well below 2 °C and efforts to keep it to 1.5 °C. have already failed, according to the global warming report of the Intergovernmental Panel on Climate Change (IPCC) [124].

Economic growth particularly affects energy consumption. According to the EIA, overall energy consumption in the US has almost tripled over the last 70 years [125]. For the reasons mentioned above, energy awareness campaigns are a worthwhile investment [61] in order to improve building energy performance and to bridge the gap between predicted and actual energy consumption in buildings [126].

It should be kept in mind that a "*one size fits all*" approach does not apply to different building types and across varying cultural cases. Occupant awareness and level of knowledge should also be kept in mind. Due to complexity of the physical, physiological, and psychological factors of humans, modelling occupants in simulations remains challenging [67]. Topics based on long term behavioural effects, such as adaptive behaviour and evolving occupant profiles and patterns, need long term monitoring or extended survey periods, which is demanding. Structuring datasets remains a challenging topic for researchers, as there are no agreed standards or policies. Issues of sampling size, frequencies and monitoring protocols for measurement equipment and calibration are still subject to contention, which makes it impossible to compare cross-culturally gathered data.

To conclude, due to the complexity of humans, it is not easy to estimate, model or calculate the behaviour of building occupants. Furthermore, the lack of standards and protocols for data gathering with accuracy of data are challenging areas in the field of building occupant research. Global warming and climate change are existent realities. Buildings are one of the highest consumers of energy, producing waste and GHG emissions and on an urban scale may be listed as one of the hot topics on the political agenda.

3. Ongoing efforts

The previous sections have reviewed the interaction between occupant behaviour and building energy consumption. The following section presents a detailed analysis of publications in seven leading academic journals in the time frame 2018–2019. All articles are published in English and indexed in Scopus, namely Building and Environment, Building Research & Information, Energy and Buildings, Energy Research & Social Science, Energy Policy, Journal of Building Engineering, and Renewable & Sustainable Energy Reviews. This section aims to capture the cutting edge of research in this area, and to direct needs for future work.

The papers are organized on the basis of the topics of the research and their study type. Furthermore, building types are also considered where research methodologies are used. Location of the research is also categorized with country and hemisphere information (Table 1). The table reflects the current status of research related to occupant behaviour, helping the reader to understand the main efforts and revealing topics that may have been underestimated or overlooked. The methodologies of current research are analysed to allow correlation between the method and the research topic.

3.1. Current Status/Topics of Research

The research presented in the selected papers is mostly focused on technical aspects rather than socio-economic issues. In the papers from 2018 and 2019, most of the work studies residential buildings, with some addressing offices. Energy is the dominant research topic in the domain, followed by thermal comfort. Other recurring subjects are window operation, retrofit & renovation, lighting, fuel poverty, and energy models (simulation). Some other research topics not listed above but present in the dataset are vulnerability [119], technical performance of buildings with occupants [53], the rebound effect [253], energy management [254], occupant drivers [255], user experience in low energy homes [256], NZEB [257], the energy performance gap [30], and energy metrics [82]. Effects of the impact of childhood and early adulthood on energy consumption [258], and analysing gender dynamics in slum rehabilitation housing [259] may be noted among rarely seen research topics in the field. Apart from the research papers, some of the review paper topics other than those listed above are occupancy detection [189], domestic hot water consumption [25], the human dimension in energy use [13], life cycle assessment [78], low carbon energy measures [260], and research techniques [22]. Research mostly centres on singular buildings or a small group of buildings in an urban context. There is a limited number of papers related to research about rural areas [261], districts [262], and the urban scale [151].

Most of the papers use data gathering techniques, such as monitoring and surveys. Large datasets are reported by van den Brom et al. [204], Levy and Belaid [53], Acharya and Sadath [99], and Damari and Kissinger [142]. However, no evidence has been found on the standardization of data gathering, protocols and sampling, which makes it hard to conduct comparative analysis across these projects.

3.2. Locations of Research

The papers studied report on findings from 158 different locations in 36 different countries. 147 of the locations are in the northern hemisphere, while only 11 are in the southern hemisphere. Since 88% of the global population lives in the northern hemisphere, this strong focus of research on the northern hemisphere is logical (Fig. 3). The work mostly stems from research in the USA, UK, China, the Netherlands, France, and Germany. Note that these are all developed and strongly industrialised countries where the average income is higher than the global average. While energy is a major challenge for developing countries, there seems to be little work that explores how occupant behaviour research might contribute to an understanding of the energy needs and problems of those countries.

3.3. Classification of research and keywords used

A deeper review of the keywords listed in the papers shows that 47% of them relate to technical issues, 28% to socio cultural aspects, 13% to construction issues and 12% deal with financial issues. Not surprisingly, the most widely used keyword is occupant behaviour, followed by thermal comfort, energy efficiency, building energy, residential building, and office building (Fig. 4). Energy performance, machine learning and energy consumption may be listed as the closest followers. Energy, thermal, building and occupant are the most referred main terms. A total number of 1009 keywords was used for the papers. Lifestyle, demographics, low income and NZEB are amongst the rarely used keywords.

4. Discussion of Research in papers reviewed

This paper explores the state of the art of research on the interaction between occupant behaviour and energy efficiency in buildings. The investigation focuses on papers from two years, 2018 and 2019, published in seven internationally indexed (SSCI, SCI, SCI-E) journals. This focus is important when assessing the outcomes.

Several papers on occupant behaviour have contributed in-depth reviews of the technical, constructional, financial and socio-economic effects of occupant behaviour on energy consumption in buildings. Most research is focused on technical aspects, such as adjusting windows, doors, blinds/sunshades, lighting adjustments, and the control of HVAC systems (both manually and automated), rather than on socio-economic issues. The mostly commonly researched building types are residences and offices, followed by educational facilities.

Quantitative and qualitative data is the basis of all research reported in the literature. Several methodologies have been used, with interviews, observation, case studies, surveys, monitoring and simulation tools frequently appearing to compute details and to explore ‘what-if’ scenarios for further analysis. Lack of a standard for data gathering and lack of protocols for data analysis make it difficult to compare outcomes. Modelling the energy consumption of occupants is another challenge in the field. For the most part, occupant attitudes and preferences have a significant impact on the use of energy resources [7]. It can be noticed that a general trend in research related to technical issues is centred around analysis of the operational habits of occupants. Occupant behaviour research usually requires a combination of social science and physical science [22]. The full complexity of human activity cannot easily be represented by patterns or profiles. One challenge is that humans are not always rational decision makers and that they do not always have fixed attitudes. Furthermore, occupants may change behavioural patterns during the daytime. At other times, a building user may behave differently and may not adapt comfort conditions in some spaces on the basis of external issues, such as social codes. Contrary to behavioural models, which mostly focus on a single action or activity generated by one or more environmental variables, recent studies are supporting approaches which consider complicated behaviour, different

Table 1
Classification of reviewed papers.

Topic of the research	Study Type	Building Type	Methodologies Used	Country	Hemisphere	Reference
Activity Estimation	Research	Residence, School	Monitoring, Simulation, Data Analysis	Denmark	North	[127]
Adaptive Behaviour	Review	Building	Literature Review			[91]
	Research	Residence	Survey, Data Analysis	Denmark	North	[128]
Air Condition	Research	Office	Monitoring, Simulation, Data Analysis	United States of America (USA), China	North	[129]
	Research	Residence	Survey, Monitoring, Simulation, Data Analysis	South Korea	North	[130]
	Research	Residence	Monitoring, Data Analysis	China,	North	[131]
	Research	Residence	Monitoring, Simulation, Data Analysis	China	North	[132]
Behavioural Effects & Interventions	Review	Residence	Literature Review			[133]
	Research	Residence	Data Analysis	UK	North	[134]
	Research	Residence, Office	Survey, Data Analysis	United Arab Emirates	North	[114]
	Research	Residence	Survey, Data Analysis	UK	North	[135]
	Research	Residence	Monitoring, Simulation, Data Analysis	UK	North	[136]
	Research	Office	Survey, Data Analysis	USA	North	[137]
Cooling	Research	Residence	Simulation, Data Analysis	USA	North	[138]
Demand Side Response	Review	Buildings	Literature Review			[139]
	Research	Buildings	Expert Interviews	UK	North	[140]
	Research	Residence	Field Study, Data Analysis	UK	North	[141]
Electricity Consumption	Research	Residence	Survey, Data Analysis	Israel	North	[142]
	Research	Residence	Panel Data, Data Analysis	Singapore	North	[143]
	Research	School	Monitoring, Data Analysis	France	North	[144]
Energy Consumption	Research	School, Day Care	Monitoring, Simulation, Data Analysis	Finland	North	[79]
	Research	Residence	Survey, Data Analysis	France	North	[145]
	Research	Residence	Monitoring, Simulation, Data Analysis	EU	North	[146]
	Review		Literature Review			[147]
Energy Demand	Research	Residence	Survey, Data Analysis	Kuwait,	North	[148]
	Research	Residence	Monitoring, Systematic Comparison, Data Analysis	New Zealand	South	[149]
	Research	Residence	Data Analysis	UK	North	[150]
	Review	Urban Building	Literature Review			[151]
Energy Efficiency (Retrofit)	Research	Residence	Data Analysis	The Netherlands	North	[152]
	Research	Residence	Monitoring, Simulation, Data Analysis	Germany	North	[153]
Energy Performance	Review	Building	Literature Review			[11]
	Research	Residence	Literature Review	The Netherlands	North	[154]
	Research	Office	Survey, Monitoring, Simulation, Data Analysis	Egypt	North	[155]
Energy PerformanceCertificate /Evaluation	Review	Residence	Literature Review, Data Analysis	UK	North	[156]
	Research	Residence	Survey, Data Analysis	Germany	North	[157]
	Research	Residence	Data Analysis	Japan	North	[158]
	Research	Residence	Monitoring, Data Analysis	Germany	North	[159]
Energy Poverty	Research	Residence	Survey	India	North	[99]
	Research	Residence	Data Analysis	Germany, China	North	[160]
Energy Use	Research	Commercial	Monitoring, Data Analysis	USA	North	[161]
	Research	Residence	Data Analysis	Greece	North	[162]
	Research	Residence	Survey, Data Analysis	Greece	North	[163]
	Research	Office	Monitoring, Data Analysis	USA	North	[164]
Fuel Poverty	Research	Residence	Simulation, Data Analysis	Chile	South	[165]
	Research	Residence	Data Analysis	France	North	[166]
	Research	Residence	Data Analysis	France	North	[167]
	Research	Residence	Simulation, Data Analysis, Sensitivity Analysis	Greece	North	[168]
	Research	Residence	Data Analysis	Scotland, UK	North	[169]
	Research	Residence	Survey, Data Analysis	UK	North	[170]
Heating	Review	Residence	Literature Review			[171]
	Review	Residence	Literature Review	EU	North	[24]
	Research	Residence	Data Analysis, Simulation	Switzerland	North	[172]
	Research	Residence	Survey, Data Analysis	Ireland	North	[173]
	Research	Residence	Survey, Data Analysis	UK	North	[174]
	Research	Residence	Interview, Survey	UK	North	[175]
Indoor Air / Environment Quality	Review	Residence	Literature Review			[176]
	Research	Residence	Monitoring, Data Analysis			[2]
	Research	Residence	Monitoring, Data Analysis	China	North	[177]
	Research	Residence	Survey	UK	North	[178]
	Research	Office	Survey, Interview, Data Analysis	USA	North	[179]
	Research	Residence	Monitoring, Validation	Australia	South	[180]
Lighting	Research	Office	Monitoring, Survey, Data Analysis	USA	North	[181]
	Research	Office	Monitoring, Survey, Data Analysis	Canada	North	[182]
	Research	Office	Monitoring, Survey, Data Analysis	China	North	[183]
	Research	Office	Survey, Data Analysis	USA	North	[184]
	Research	Office	Survey, Data Analysis	USA	North	[185]

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Table 1 (*continued*)

Topic of the research	Study Type	Building Type	Methodologies Used	Country	Hemisphere	Reference
	Research	Office	Survey	USA	North	[186]
	Research	Office	Simulation, Data Analysis	Canada	North	[107]
OCCUPANCY	Research	Office	Monitoring, Data Analysis	Italy	North	[187]
Pattern	Research	Residence	Survey, Data Analysis	Denmark	North	[100]
Profiles	Research	Office	Monitoring, Data Analysis	USA	North	[188]
Sensing	Review	Building	Literature Review			[189]
Detection	Review	Building	Literature Review			[15]
	Research	Residence	Monitoring, Data Analysis	Ireland	North	[190]
	Research	Residence	Monitoring, Data Analysis	Portugal	North	[191]
	Research	Residence	Simulation, Data Analysis	UK	North	[54]
Occupant Comfort	Research	Residence	Survey, Data Analysis	Denmark	North	[192]
	Research	Office	Survey, Data Analysis	Canada	North	[193]
Occupant Satisfaction	Research	Office	Survey, Data Analysis	China	North	[194]
	Research	Residence	Survey, Data Analysis	The Netherlands	North	[195]
Performance gap	Review	Building	Literature Review			[30]
	Research	Building	Interview, Data Analysis	Australia	South	[196]
	Research	Residence	Survey, Data Analysis	The Netherlands	North	[28]
Retrofit & Renovation	Research	Residence	Monitoring, Survey, Data Analysis	UK	North	[197]
	Research	Buildings	Monitoring, Simulation, Data Analysis	UEA	North	[198]
	Research	Residence	Simulation, Data Analysis	The Netherlands	North	[199]
	Research	Residence	Survey, Monitoring, Data Analysis	UK	North	[200]
	Research	Residence	Data Analysis	UK	North	[201]
	Research	Residence	Monitoring, Data Analysis	Argentina	South	[82]
	Research	Residence	Simulation, Data Analysis	Italy	North	[202]
	Research	Office	Survey, Data Analysis, Sensitivity Analysis	Middle East	North	[203]
	Research	Residence	Survey, Data Analysis	The Netherlands	North	[204]
	Research	Residence	Survey	EU	North	[205]
	Research	Residence	Data Analysis	USA	North	[206]
Simulations(Energy Models)	Review		Literature Review			[207]
	Review		Literature Review			[26]
	Research	Building	Simulation, Data Analysis			[208]
	Research	Office	Data Analysis	USA	North	[209]
	Research	Residence	Monitoring, Simulation, Data Analysis	China	North	[210]
	Research	Office	Simulation, Data Analysis	Hong Kong	North	[211]
	Research	Office	Monitoring, Simulation, Data Analysis	USA	North	[212]
	Research	Residence	Mock-up, Monitoring, Simulation, Data Analysis	UK	North	[213]
Smart Buildings / Houses	Research	Building	Experiment, Monitoring, Data Analysis			[214]
	Research	Residence	Field Study, Monitoring, Interview	UK	North	[215]
Thermal Comfort	Review		Literature Review			[34]
	Review		Literature Review			[216]
	Research	Office	Survey	USA	North	[217]
	Research	Residence	Monitoring, Survey, Data Analysis	Chile	South	[218]
	Research	Office	Monitoring, Data Analysis	USA	North	[219]
	Research	Office	Monitoring, Data Analysis	Poland	North	[220]
	Research	University Building	Survey, Monitoring, Simulation	South Korea	North	[221]
	Research	Dormitory	Monitoring, Simulation, Data Analysis	China	North	[222]
	Research	Residence	Monitoring, Logbook, Data Analysis	The Netherlands	North	[223]
	Research	Residence	Survey, Simulation, Data analysis	Greece	North	[224]
	Research	Residence	Monitoring, Survey	Japan	North	[225]
	Research	Residence, Office	Monitoring, Simulation, Data Analysis	USA	North	[226]
	Research	Office	Data Analysis, Simulation	USA	North	[227]
	Research	Residence	Monitoring, Survey, Data Analysis	China	North	[228]
	Research	School	Survey, Data Analysis	Australia	South	[229]
	Research	Residence	Interview, Survey, Data Analysis	Germany	North	[230]
	Research	Office	Survey, Monitoring	Brazil	South	[231]
	Research	Nursing	Monitoring, Survey, Data Analysis	Australia	South	[232]
	Research	Office	Survey, Monitoring	China	North	[233]
	Research	Office, Hospital	Survey, Monitoring	The Netherlands	North	[234]
	Research	Office	Data Analysis	USA	North	[235]
Uncertainty Analysis	Review		Literature Review			[236]
	Research	Office	Simulation, Data Analysis	France	North	[237]
Ventilation	Research	Residence	Monitoring, Simulation, Data Analysis	Portugal	North	[238]
	Research	Office	Monitoring	South Korea	North	[239]
	Research	Residence	Monitoring, Data Analysis	The Netherlands	North	[240]
	Research	Residence	Monitoring, Survey, Data Analysis	China	North	[241]
	Research	School	Survey	India	North	[242]
	Research	School	Monitoring, Simulation, Data Analysis	USA, India	North	[243]
Window	Research	Office	Monitoring, Simulation, Data Analysis	Austria	North	[244]
	Research	Office	MonitoringSurvey, Data Analysis	China	North	[245]
	Research	Office	Monitoring, Data Analysis	China	North	[246]
	Research	School	Monitoring, Survey, Data Analysis	Hungary	North	[247]

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Table 1 (*continued*)

Topic of the research	Study Type	Building Type	Methodologies Used	Country	Hemisphere	Reference
	Research	Residence	Monitoring, Data Analysis	China	North	[248]
	Research	Office	Monitoring, Simulation, Data Analysis	Germany	North	[249]
	Research	Residence	Simulation, Data Analysis	Germany	North	[250]
	Research	Office	Survey, Simulation, Data Analysis	China	North	[251]
	Research	Office	Survey, Monitoring, Data Analysis	UK	North	[252]

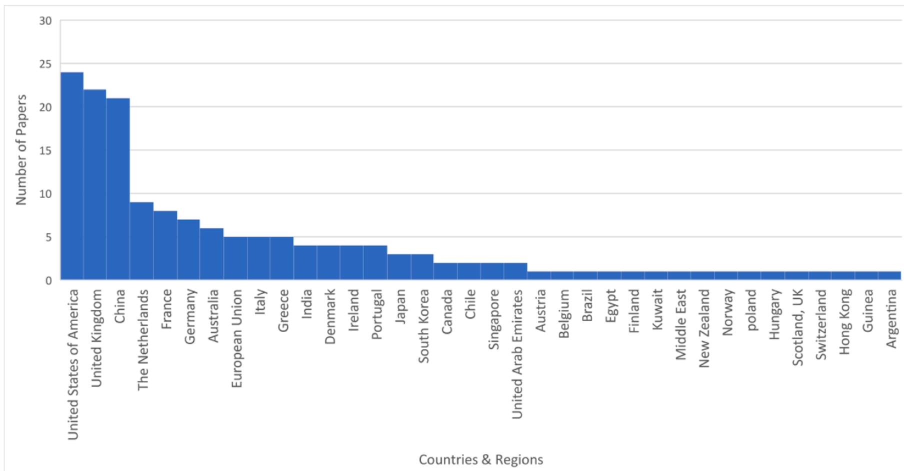

Fig. 3. Locations of the research based on reviewed papers.

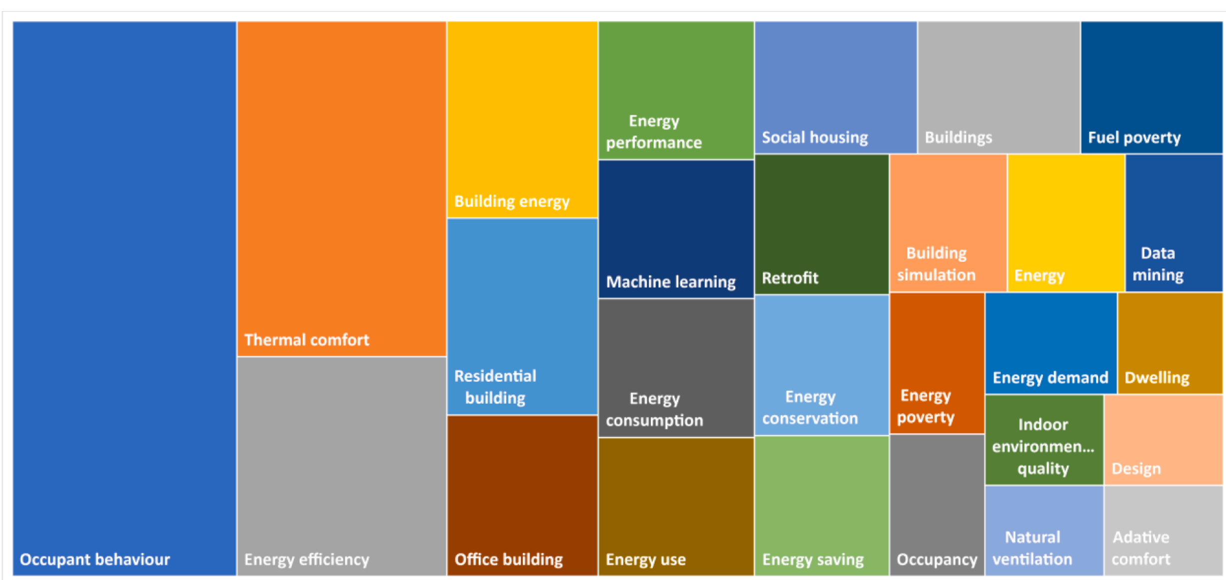

Fig. 4. Distribution of keywords used 4 times or more in reviewed papers.

lifestyles and the interaction between users [14]. Cole et al. [263] have commented that performance gaps stem less from the design and technology that is applied to buildings than from the disparity between assumed and actual occupant behaviour and the operation of controls and management. It can be observed that most building energy consumption models provide only short-term analyses and neglect to represent long-term profiles and predictions [147].

It may be a good time to change the perspective not only of the content -research topics and methodologies used for occupant behaviour- but also of the context. Total energy consumption of the built environment cannot be reported via analysis of singular buildings. Occupant behaviour within the building should be tracked, together with interactions with the neighbourhood, district, regions and cities. Fraysinnet et al. [151] claim that topics such as energy price, income, population density, urban morphology etc. are being ignored whenever a single building or a small group of buildings is analysed. Strategies to manage energy related to occupant behaviour should be developed within communities, while the differences between energy efficiency, energy conservation and energy consumption need to be borne in mind. Analyses of underdeveloped societies should also be undertaken; in such societies energy and fuel poverty may be the fundamental limitations. Humphries [264] points out that it is not possible to define a multifactor index of the indoor environment that would perfectly fit different cultures and countries of the world. Underdeveloped and developing countries need more research dedicated to the improvement of their capacity for energy conservation. Standardization of data gathering should be improved in order to make it possible to use data worldwide and to make it possible to comparatively analyse similar research topics in different locations, and to make big data available. Such standardization attempts, along with protocols, will form a basis for developing new parameters and measures where current ones fall short. Studies with an interdisciplinary approach are essential, since human activities can best be analysed through a wider collaboration of disciplines. Occupants with their differing social contexts and, specific social and psychological variables should be taken into account in the assessment of human-building interaction. A wide range of these variables should be considered, in terms of target behaviours (curtailment vs. efficient behaviours), demographics (e.g., income level), and building type (commercial vs. residential) [4].

Hong et al. [97] point out that optimal decisions and an overall improvement in human behaviour should be considered along with new technologies for energy efficiency in buildings. Statistical analysis of large samples of surveys while monitoring only single buildings or limited groups of people may not provide holistic approaches with worldwide applicability. Researchers should focus on immersive methodologies to understand occupants better and to cope with the performance gap.

5. Conclusion

Current research suggests that the effects of occupant behaviour on energy efficiency and conservation in buildings are mostly underestimated, oversimplified, misunderstood, or disregarded. However, typical data gathering efforts in the field face challenges regarding sample size and selection, and issues pertaining to the analysis methodologies implemented. A lack of standardised data gathering approaches is of concern.

An in-depth review has highlighted the following challenges:

1) Studies of occupant behaviour are typically limited to single buildings or to a small group of buildings over short time intervals. There is limited research on occupants residing in interacting buildings. Occupant behaviour is still considered at the individual building-scale.
2) Data gathering about occupant behaviour does not follow well-established protocols or standards. Consequently, it is hard to compare data gathered in different research projects that have been conducted in different geographical locations. Therefore, it is hard to investigate and define cross-cultural and societal differences.
3) Research on occupant behaviour is heavily based on quantitative research located in the northern hemisphere and from developed countries with higher per capita income. Consequently, the effects of financial issues, such as fuel poverty and other socio-cultural factors, are generally disregarded or overlooked. Moreover, due to this geographical focus, occupant behaviour studies prioritise heating over cooling of buildings.
4) Most research does not employ holistic approaches. Typical research is focused on specific technical topics in a singular area of interest, such as window adjustment, lighting systems, heating systems or set point control. More attention should be paid to interdisciplinary research.
5) Specific areas, such as defining the backgrounds of comfort conditions and analysing lifestyles of occupants, may be listed as the less popular research topics concerning building occupant behaviour. Yet habits and attitudes differ across cultures, regions, climate, geography and local topography. Research therefore should pay more attention to lifestyles in order to understand profiles and patterns of occupants. Further human attributes should be explored within the context defined for occupancy, especially for the quantification of socio- cultural habits such as attitudes and lifestyles. New or composite metrics need to be developed to define such occupant traits.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] IEA, 2019, Global Energy and CO2 Status Report, https://webstore.iea.org/global-energy-co2-status-report-2018 (Last accessed December-2019).
[2] A. Szczurek, A. Dolega, M. Maciejewska, Profile of occupant activity impact on indoor air—method of its determination, Energy Build. 158 (2018) 1564–1575, https://doi.org/10.1016/j.enbuild.2017.11.052.
[3] L. Klein, J.-Y. Kwak, G. Kavulya, Farrokh Jazizadeh,Burçin Becerik Gerber, Pradeep Varakantham,, et al., Coordinating occupant behavior for building energy and comfort management using multi-agent systems, Autom. Constr. 22 (2012) 525–536, https://doi.org/10.1016/j.autcon.2011.11.012.
[4] Tianzhen Hong, Da. Yan, Simona D'Oca, Chien-fei Chen Ten questions concerning occupant behavior in buildings: The big picture, Build. Environ. 114 (2017) 518–530, https://doi.org/10.1016/j.buildenv.2016.12.006.
[5] Da. Yan, Tianzhen Hong, Bing Dong, Ardeshir Mahdavi, Simona D'Oca, Isabella Gaetani, Xiaohang Feng, IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings, Energy Build. 156 (2017) 258–270, https://doi.org/10.1016/j.enbuild.2017.09.084.
[6] Directive 2002/91/EC Of The European Parliament And Of The Council On The Energy Performance Of Buildings, 2002 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF (Last accessed September-2020).
[7] Pervez Hameed Shaikh, Nursyarizal Bin Mohd Nor, Perumal Nallagownden, Irraivan Elamvazuthi, Taib Ibrahim. A review on optimized control systems for building energy and comfort management of smart sustainable buildings. Renewable and Sustainable Energy Reviews, 2014; 34: 409-429. https://doi.org/10.1016/j.rser.2014.03.027.
[8] Kathryn B. Janda, Buildings don't use energy: people do, Architectural Science Review 54 (1) (2011) 15–22, https://doi.org/10.3763/asre.2009.0050.
[9] Mengda Jia, Ravi S. Srinivasan, Adeeba A. Raheem, From occupancy to occupant behavior: An analytical survey of data acquisition technologies, modeling methodologies and simulation coupling mechanisms for building energy efficiency, Renew. Sustain. Energy Rev. 68 (2017) 525–540, https://doi.org/10.1016/j.rser.2016.10.011.
[10] Yimin Zhu, Sanaz Saeidi, Tracey Rizzuto, Astrid Roetzel, Robert Kooima, Potential and challenges of immersive virtual environments for occupant energy behavior modeling and validation: A literature review, Journal of Building Engineering 19 (2018) 302–319, https://doi.org/10.1016/j.jobe.2018.05.017.
[11] Yan Zhang, Xuemei Bai, Franklin P. Mills, C.V. John, Pezzey Rethinking the role of occupant behavior in building energy performance: A review, Energy Build. 172 (2018) 279–294, https://doi.org/10.1016/j.enbuild.2018.05.017.
[12] Bruna Faitão Balvedi, Enedir Ghisi, Roberto Lamberts. A review of occupant behaviour in residential buildings. Energy and Buildings, 2018; 174: 495-505. https://doi.org/10.1016/j.enbuild.2018.06.049.
[13] Simona D'Oca, Tianzhen Hong, Jared Langevin, The human dimensions of energy use in buildings: A review, Renew. Sustain. Energy Rev. 81 (2018) 731–742, https://doi.org/10.1016/j.rser.2017.08.019.
[14] Francesca Stazi, Federica Naspi, Marco D'Orazio, A literature review on driving factors and contextual events influencing occupants' behaviours in buildings, Build. Environ. 118 (2017) 40–66, https://doi.org/10.1016/j.buildenv.2017.03.021.
[15] Sophie Naylor, Mark Gillott, Tom Lau, A review of occupant-centric building control strategies to reduce building energy use, Renew. Sustain. Energy Rev. 96 (2018) 1–10, https://doi.org/10.1016/j.rser.2018.07.019.
[16] Kadir Amasyalı, Nora M. El-Gohary, A review of data-driven building energy consumption prediction studies, Renew. Sustain. Energy Rev. 81 (2018) 1192–1205, https://doi.org/10.1016/j.rser.2017.04.095.
[17] Elham Delzendeh, Wu. Song, Angela Lee, Ying Zhou, The impact of occupants' behaviours on building energy analysis: A research review, Renew. Sustain. Energy Rev. 80 (2017) 1061–1071, https://doi.org/10.1016/j.rser.2017.05.264.
[18] Wooyoung Jung, Farrokh Jazizadeh, Human-in-the-loop HVAC operations: A quantitative review on occupancy, comfort, and energy-efficiency dimensions, Appl. Energy 239 (2019) 1471–1508, https://doi.org/10.1016/j.apenergy.2019.01.070.
[19] Christel de Bakker, Myriam Aries, Helianthe Kort, Alexander Rosemann, Occupancy-based lighting control in open-plan office spaces: A state-of-the-art

review, Build. Environ. 112 (2017) 308–321, https://doi.org/10.1016/j.buildenv.2016.11.042.
[20] Gaëlle Guyot, Max H. Sherman, Iain S. Walker, Smart ventilation energy and indoor air quality performance in residential buildings: A review, Energy Build. 165 (2018) 416–430, https://doi.org/10.1016/j.enbuild.2017.12.051.
[21] Ardalan Khosrowpour, Rishee K. Jain, John E. Taylor, Gabriel Peschiera, Jiayu Chen, Rimas Gulbinas, A review of occupant energy feedback research: Opportunities for methodological fusion at the intersection of experimentation, analytics, surveys and simulation, Appl. Energy 218 (2018) 304–316, https://doi.org/10.1016/j.apenergy.2018.02.148.
[22] Patrick XW Zou, Xu. Xiaoxiao, Jay Sanjayan, Jiayuan Wang, A mixed methods design for building occupants' energy behavior research, Energy Build. 166 (2018) 239–249, https://doi.org/10.1016/j.enbuild.2018.01.068.
[23] Peixian Li, Thomas M. Froese, Gail Brager, Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review, Build. Environ. 133 (2018) 187–202, https://doi.org/10.1016/j.buildenv.2018.02.024.
[24] Georgios Martinopoulos, Konstantinos T. Papakostas, Agis M. Papadopoulos, A comparative review of heating systems in EU countries, based on efficiency and fuel cost, Renew. Sustain. Energy Rev. 90 (2018) 687–699, https://doi.org/10.1016/j.rser.2018.03.060.
[25] E. Fuentes, L. Arce, J. Salom, A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis, Renew. Sustain. Energy Rev. 81 (2018) 1530–1547, https://doi.org/10.1016/j.rser.2017.05.229.
[26] Gabriel Happle, Jimeno A. Fonseca, Arno Schlueter, A review on occupant behavior in urban building energy models, Energy Build. 174 (2018) 276–292, https://doi.org/10.1016/j.enbuild.2018.06.030.
[27] Olivia Guerra Santin, Laure Itard, Henk Visscher, The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy Build. 41 (11) (2009) 1223–1232, https://doi.org/10.1016/j.enbuild.2009.07.002.
[28] Paula van den Brom, Arjen Meijer, Henk Visscher, Performance gaps in energy consumption: household groups and building characteristics, Building Research & Information 46 (1) (2018) 54–70, https://doi.org/10.1080/09613218.2017.1312897.
[29] Taehoon Hong, Choongwan Koo, Jimin Kim, Minhyun Lee, Kwangbok Jeong, A review on sustainable construction management strategies for monitoring, diagnosing, and retrofitting the building's dynamic energy performance: Focused on the operation and maintenance phase, Appl. Energy 155 (2015) 671–707, https://doi.org/10.1016/j.apenergy.2015.06.043.
[30] Patrick XW Zou, Xu. Xiaoxiao, Jay Sanjayan, Jiayuan Wang, Review of 10 years research on building energy performance gap: Life-cycle and stakeholder perspectives, Energy Build. 178 (2018) 165–181, https://doi.org/10.1016/j.enbuild.2018.08.040.
[31] Pieter de Wilde, The gap between predicted and measured energy performance of buildings: A framework for investigation, Autom. Constr. 41 (2014) 40–49, https://doi.org/10.1016/j.autcon.2014.02.009.
[32] Ardeshir Mahdavi, In the matter of simulation and buildings: some critical reflections, J. Build. Perform. Simul. 13 (1) (2020) 26–33, https://doi.org/10.1080/19401493.2019.1685598.
[33] Rui Yang, Lingfeng Wang, Development of multi-agent system for building energy and comfort management based on occupant behaviors, Energy Build. 56 (2013) 1–7, https://doi.org/10.1016/j.enbuild.2012.10.025.
[34] June Young Park, Zoltan Nagy, Comprehensive analysis of the relationship between thermal comfort and building control research-A data-driven literature review, Renew. Sustain. Energy Rev. 82 (2018) 2664–2679, https://doi.org/10.1016/j.rser.2017.09.102.
[35] Olivia Guerra-Santin, Laure Itard, Occupants' behaviour: determinants and effects on residential heating consumption, Building Research & Information 38 (3) (2010) 318–338, https://doi.org/10.1080/09613211003661074.
[36] Koen Steemers, Geun Young Yun, Household energy consumption: a study of the role of occupants, Building Research & Information 37 (5-6) (2009) 625–637, https://doi.org/10.1080/09613210903186661.
[37] Ting Yue, Ruyin Long, Hong Chen, Factors influencing energy-saving behavior of urban households in Jiangsu Province, Energy Policy 62 (2013) 665–675, https://doi.org/10.1016/j.enpol.2013.07.051.
[38] E. John, Fernandez Resource consumption of new urban construction in China, J. Ind. Ecol. 11 (2) (2007) 99–115, https://doi.org/10.1162/jie.2007.1199.
[39] Talakonukula Ramesh, K.K. Ravi Prakash, Shukla., Life cycle energy analysis of buildings: An overview, Energy Build. 42 (10) (2010) 1592–1600, https://doi.org/10.1016/j.enbuild.2010.05.007.
[40] IEA, https://www.iea.org/topics/energyefficiency/buildings/ (Last accessed December-2019).
[41] M.A. Fergus Nicol, Humphreys., Thermal comfort as part of a self-regulating system, Building Research and Practice 1 (3) (1973) 174–179, https://doi.org/10.1080/09613217308550237.
[42] J.A. Clarke, Building energy simulation: the state-of-the-art, Solar & Wind Technology 6 (4) (1989) 345–355, https://doi.org/10.1016/0741-983X(89)90053-2.
[43] Nick Baker, Mark Standeven, A behavioural approach to thermal comfort assessment, International Journal of Solar Energy 19 (1-3) (1997) 21–35, https://doi.org/10.1080/01425919708914329.
[44] Fergus Nicol, Adaptive thermal comfort standards in the hot–humid tropics, Energy Build. 36 (7) (2004) 628–637, https://doi.org/10.1016/j.enbuild.2004.01.016.
[45] Ardeshir Mahdavi, Satish Kumar, Implications of indoor climate control for comfort, energy and environment, Energy Build. 24 (3) (1996) 167–177.
[46] IEA, Annex 53-Total energy Use in Buildings: Analysis and Evaluation Methods, Project Summary Report, 2016.
[47] IEA, Annex,, 66-Definition and Simulation of Occupant Behaviour in Buildings, Final report (2018).
[48] Tianzhen Hong, Sarah C. Taylor-Lange, Simona D'Oca, Da. Yan, P. Stefano, Corgnati Advances in research and applications of energy-related occupant behavior in buildings, Energy Build. 116 (2016) 694–702, https://doi.org/10.1016/j.enbuild.2015.11.052.
[49] Zhun Yu, Benjamin C.M. Fung, Fariborz Haghighat, Hiroshi Yoshino, Edward Morofsky. A systematic procedure to study the influence of occupant behavior on building energy consumption. Energy and Buildings, 2011;43(6): 1409-1417. https://doi.org/10.1016/j.enbuild.2011.02.002.
[50] Gülsu Ulukavak Harputlugil, Timuçin Harputlugil, Matthieu Pedergnana, Esra Sarıoğlu, A novel approach for renovation of current social housing stock based on energy consumption in Turkey: Significance of occupant behaviour, Architectural Science Review 62 (4) (2019) 323–337, https://doi.org/10.1080/00038628.2019.1615862.
[51] Herman Carstens, Xiaohua Xia, Sarma Yadavalli, Measurement uncertainty in energy monitoring: Present state of the art, Renew. Sustain. Energy Rev. 82 (2018) 2791–2805, https://doi.org/10.1016/j.rser.2017.10.006.
[52] Olivia Guerra Santin, Behavioural patterns and user profiles related to energy consumption for heating, Energy Build. 43 (10) (2011) 2662–2672, https://doi.org/10.1016/j.enbuild.2011.06.024.
[53] Jean-Pierre Lévy, Fateh Belaïd, The determinants of domestic energy consumption in France: Energy modes, habitat, households and life cycles, Renew. Sustain. Energy Rev. 81 (2018) 2104–2114, https://doi.org/10.1016/j.rser.2017.06.022.
[54] Victoria Aragon, Stephanie Gauthier, Peter Warren, Patrick A.B. James, Ben Anderson, Developing English domestic occupancy profiles, Building Research & Information 47 (4) (2019) 375–393, https://doi.org/10.1080/09613218.2017.1399719.
[55] Oxford Learners Online Dictionary https://www.oxfordlearnersdictionaries.com/definition/english/occupant?q=occupant (Last accessed December-2019).
[56] J. Page, D. Robinson, N. Morel, J.L. Scartezzini, A generalised stochastic model for the simulation of occupant presence, Energy Build. 40 (2) (2008) 83–98, https://doi.org/10.1016/j.enbuild.2007.01.018.
[57] P. Hoes, J.L.M. Hensen, M.G.L.C. Loomans, B. de Vries, D. Bourgeois, D., User behavior in whole building simulation, Energy Build. 41 (3) (2009) 295–302, https://doi.org/10.1016/j.enbuild.2008.09.008.
[58] M. Fergus Nicol, Humphreys., Understanding the adaptive approach to thermal comfort, ASHRAE transactions 104 (1998) 991–1004.
[59] Xiaohang Feng, Da. Yan, Tianzhen Hong, Simulation of occupancy in buildings, Energy Build. 87 (2015) 348–359, https://doi.org/10.1016/j.enbuild.2014.11.067.
[60] Henry Feriadi, Nyuk Hien Wong, Thermal comfort for naturally ventilated houses in Indonesia, Energy Build. 36 (7) (2004) 614–626, https://doi.org/10.1016/j.enbuild.2004.01.011.
[61] O.T. Masoso, Louis Johannes Grobler, The dark side of occupants' behaviour on building energy use, Energy Build. 42 (2) (2010) 173–177, https://doi.org/10.1016/j.enbuild.2009.08.009.
[62] Jinlong Ouyang, Kazunori Hokao, Energy-saving potential by improving occupants' behavior in urban residential sector in Hangzhou City, **China.** Energy and Buildings 41 (7) (2009) 711–720, https://doi.org/10.1016/j.enbuild.2009.02.003.
[63] O. Guerra-Santin, S. Boess, T. Konstantinou, N. Romero Herrera, T. Klein, S. Silvester, Designing for residents: Building monitoring and co-creation in social housing renovation in the Netherlands, Energy Res. Social Sci. 32 (2017) 164–179, https://doi.org/10.1016/j.erss.2017.03.009.
[64] João Virote, Rui Neves-Silva, Stochastic models for building energy prediction based on occupant behavior assessment, Energy Build. 53 (2012) 183–193, https://doi.org/10.1016/j.enbuild.2012.06.001.
[65] Valentina Fabi, Rune Vinther Andersen, Stefano Corgnati, Bjarne W. Olesen, Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models, Build. Environ. 58 (2012) 188–198, https://doi.org/10.1016/j.buildenv.2012.07.009.
[66] Gram-Hanssen Kirsten, Efficient technologies or user behaviour, which is the more important when reducing households' energy consumption? Energ. Effi. 6 (3) (2013) 447–457, https://doi.org/10.1007/s12053-012-9184-4.
[67] Da Yan, William O'Brien, Tianzhen Hong, Xiaohang Feng, H. Burak Gunay, Farhang Tahmasebi, Ardeshir Mahdavi. Occupant behavior modeling for building performance simulation: Current state and future challenges. Energy and Buildings, 2015;107: 264-278. https://doi.org/10.1016/j.enbuild.2015.08.032.
[68] H.B. Rijal, P. Tuohy, M.A. Humphreys, J.F. Nicol, A. Samuel, J. Clarke, Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings, Energy Build. 39 (7) (2007) 823–836, https://doi.org/10.1016/j.enbuild.2007.02.003.
[69] Tuan Anh Nguyen, Marco Aiello, Energy intelligent buildings based on user activity: A survey, Energy Build. 56 (2013) 244–257, https://doi.org/10.1016/j.enbuild.2012.09.005.
[70] Z.M. Gill, M.J. Tierney, I.M. Pegg, N. Allan, Low-energy dwellings: the contribution of behaviours to actual performance, Building Research & Information 38 (5) (2010) 491–508, https://doi.org/10.1080/09613218.2010.505371.

[71] Sonja S. van Dam, Conny A. Bakker, J.D.M. Van Hal, Home energy monitors: impact over the medium-term, Building Research & Information 38 (5) (2010) 458–469, https://doi.org/10.1080/09613218.2010.494832.
[72] Brohus, H., Heiselberg, P., Simonsen, A., & Sørensen, K. C. Uncertainty of energy consumption assessment of domestic buildings. In Proceedings of the Eleventh International IBPSA Conference, 2009 Glasgow, Scotland.
[73] Tracey Crosbie, Keith Baker, Energy-efficiency interventions in housing: learning from the inhabitants, Building Research & Information 38 (1) (2010) 70–79, https://doi.org/10.1080/09613210903279326.
[74] EEA Technical Report No:5/2013 Achieving energy efficiency through behaviour change: what does it take? https://www.eea.europa.eu/publications/achieving-energy-efficiency-through-behaviour/achieving-energy-efficiency-through-behaviour/viewfile#pdfjs.action=download (Last accessed December-2019).
[75] IEA, Energy Efficiency Market Report 2016 https://webstore.iea.org/download/direct/325?fileName=mediumtermenergyefficiency2016.pdf (Last accessed December-2019).
[76] Shide Salimi, Amin Hammad, Critical review and research roadmap of office building energy management based on occupancy monitoring, Energy Build. 182 (2019) 214–241, https://doi.org/10.1016/j.enbuild.2018.10.007.
[77] Allison Woodruff, Jay Hasbrouck, Sally Augustin, A bright green perspective on sustainable choices. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2008.
[78] Charles Thibodeau, Alain Bataille, Marion Sié, Building rehabilitation life cycle assessment methodology–state of the art, Renew. Sustain. Energy Rev. 103 (2019) 408–422, https://doi.org/10.1016/j.rser.2018.12.037.
[79] Annu Ruusala, Anssi Laukkarinen, Ju.ha. Vinha, Energy consumption of Finnish schools and daycare centers and the correlation to regulatory building permit values, Energy Policy 119 (2018) 183–195, https://doi.org/10.1016/j.enpol.2018.04.029.
[80] Brenda Boardman, Achieving energy efficiency through product policy: the UK experience, Environ. Sci. Policy 7 (3) (2004) 165–176, https://doi.org/10.1016/j.envsci.2004.03.002.
[81] EIA web page -https://www.eia.gov/energyexplained/use-of-energy/efficiency-and-conservation.php (Last accessed December-2019).
[82] Celina Filippín, Silvana Flores Larsen, Florencia Ricard, Improvement of energy performance metrics for the retrofit of the built environment. Adaptation to climate change and mitigation of energy poverty, Energy Build. 165 (2018) 399–415, https://doi.org/10.1016/j.enbuild.2017.12.050.
[83] Julia K. Steinberger, Johan van Niel, Dominique Bourg, Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy, Energy Policy 37 (1) (2009) 361–370, https://doi.org/10.1016/j.enpol.2008.08.030.
[84] Hugo Hens, Wout Parijs, Mieke Deurinck, Energy consumption for heating and rebound effects, Energy Build. 42 (1) (2010) 105–110, https://doi.org/10.1016/j.enbuild.2009.07.017.
[85] O. Guerra-Santin, Occupant behaviour in energy efficient dwellings: evidence of a rebound effect, J. Hous. Built Environ. 28 (2) (2013) 311–327, https://doi.org/10.1007/s10901-012-9297-2.
[86] Minna Sunikka-Blank, Ray Galvin, Introducing the prebound effect: the gap between performance and actual energy consumption, Building Research & Information 40 (3) (2012) 260–273, https://doi.org/10.1080/09613218.2012.690952.
[87] Benjamin K. Sovacool, Jonn Axsen, Steve Sorrell, Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design, Energy Res. Social Sci. 45 (2018) 12–42, https://doi.org/10.1016/j.erss.2018.07.007.
[88] Julia K. Day, William O'Brien, Oh behave! Survey stories and lessons learned from building occupants in high-performance buildings, Energy Res. Social Sci. 31 (2017) 11–20, https://doi.org/10.1016/j.erss.2017.05.037.
[89] F.F. Council, & National Research Council. Learning from our buildings: A state-of-the-practice summary of post-occupancy evaluation, National Academies Press. 145 (2002).
[90] Brenda Vale, Robert Vale, Domestic energy use, lifestyles and POE: past lessons for current problems, Building Research & Information 38 (5) (2010) 578–588, https://doi.org/10.1080/09613218.2010.481438.
[91] Sepideh Sadat Korsavi, Azadeh Montazami, James Brusey, Developing a design framework to facilitate adaptive behaviours, Energy Build. 179 (2018) 360–373, https://doi.org/10.1016/j.enbuild.2018.09.011.
[92] Alex Gonzalez-Caceres, Ariel Bobadilla, Jan Karlshøj, Implementing post-occupancy evaluation in social housing complemented with BIM: A case study in Chile, Build. Environ. 158 (2019) 260–280, https://doi.org/10.1016/j.buildenv.2019.05.019.
[93] Sara Gilani, William O'Brien, Review of current methods, opportunities, and challenges for in-situ monitoring to support occupant modelling in office spaces, J. Build. Perform. Simul. 10 (5–6) (2017) 444–470, https://doi.org/10.1080/19401493.2016.1255258.
[94] I. Abubakar, S.N. Khalid, M.W. Mustafa, H. Shareef, M. Mustapha, Application of load monitoring in appliances' energy management–A review, Renew. Sustain. Energy Rev. 67 (2017) 235–245, https://doi.org/10.1016/j.rser.2016.09.064.
[95] R. Melfi, B. Rosenblum, B. Nordman, K. Christensen, Measuring building occupancy using existing network infrastructure., International Green Computing Conference and Workshops, Orlando, FL 2011 (2011) 1–8, https://doi.org/10.1109/IGCC.2011.6008560.
[96] Zheng Yang, Burcin Becerik-Gerber, Coupling occupancy information with HVAC energy simulation: A systematic review of simulation programs, IEEE Press, 2014.
[97] Tianzhen Hong, Simona D'Oca, William J.N.Turner, Sarah C. Taylor-Lange. An ontology to represent energy-related occupant behavior in buildings. Part I: Introduction to the DNAs framework. Building and Environment, 92, 764-777. https://doi.org/10.1016/j.buildenv.2015.02.019.
[98] Tianzhen Hong, Simona D'Oca, Sarah C. Taylor-Lange, William J.N.Turner, Yixing Chen, Stefano p. Corgnati. An ontology to represent energy-related occupant behavior in buildings. Part II: Implementation of the DNAS framework using an XML schema. Building and Environment, 94, 196-205. https://doi.org/10.1016/j.buildenv.2015.08.006.
[99] Rajesh H. Acharya, Anver C. Sadath, Energy poverty and economic development: Household-level evidence from India, Energy Build. 183 (2019) 785–791, https://doi.org/10.1016/j.enbuild.2018.11.047.
[100] Verena M. Barthelmes, Rongling Li, Rune K. Andersen, William Bahnfleth, Stefano P. Corgnati, Carsten Rode, Profiling occupant behaviour in Danish dwellings using time use survey data, Energy Build. 177 (2018) 329–340, https://doi.org/10.1016/j.enbuild.2018.07.044.
[101] Cristina Carpino, Dafni Mora, Marilena De Simone, On the use of questionnaire in residential buildings. A review of collected data, methodologies and objectives, Energy Build. 186 (2019) 297–318, https://doi.org/10.1016/j.enbuild.2018.12.021.
[102] EU Buildings Database https://ec.europa.eu/energy/en/eu-buildings-database (Last accessed December-2019).
[103] Le Corbusier, Towards a new Architecture, Martino Fino Books (2014).
[104] Jiayu Chen, John E. Taylor, Hsi-Hsien Wei, Modeling building occupant network energy consumption decision-making: The interplay between network structure and conservation, Energy Build. 47 (2012) 515–524, https://doi.org/10.1016/j.enbuild.2011.12.026.
[105] Hunt Allcott, Sendhil Mullainathan, Behavior and Energy Policy, Science 327 (2010) 1204–1205, https://doi.org/10.1126/science.1180775.
[106] Benjamin K. Sovacool, Mari Martiskainen, Jody Osborn, Amal Anaam, M.Lipson. From thermal comfort to conflict: the contested control and usage of domestic smart heating in the United Kingdom. Energy Research & Social Science, 69, 101566. https://doi.org/10.1016/j.erss.2020.101566.
[107] Sara Gilani, H. William O'Brien, Burak Gunay, Simulating occupants' impact on building energy performance at different spatial scales, Build. Environ. 132 (2018) 327–337, https://doi.org/10.1016/j.buildenv.2018.01.040.
[108] H. Burak Gunay, William O'Brien, Ian Beausoleil-Morrison, Andrea Perna, On the behavioral effects of residential electricity submetering in a heating season, Build. Environ. 81 (2014) 396–403, https://doi.org/10.1016/j.buildenv.2014.07.020.
[109] Sam C. Staddon, Cycil Chandrika, Murray Goulden, A. Caroline Leygue, Spence., **Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence.** Energy Research & Social, Science 17 (2016) 30–51, https://doi.org/10.1016/j.erss.2016.03.027.
[110] Panagiota Antoniadou, Agis M. Papadopoulos, Occupants' thermal comfort: State of the art and the prospects of personalized assessment in office buildings, Energy Build. 153 (2017) 136–149, https://doi.org/10.1016/j.enbuild.2017.08.001.
[111] H. William O'Brien, Burak Gunay, The contextual factors contributing to occupants' adaptive comfort behaviors in offices–A review and proposed modeling framework, Build. Environ. 77 (2014) 77–87, https://doi.org/10.1016/j.buildenv.2014.03.024.
[112] Chien-fei Chen, et al., Culture, conformity, and carbon? A multi-country analysis of heating and cooling practices in office buildings, Energy Res. Social Sci. 61 (2020), 101344, https://doi.org/10.1016/j.erss.2019.101344.
[113] Richard Tucker, Parisa Izadpanahi, Live green, think green: Sustainable school architecture and children's environmental attitudes and behaviors, Journal of Environmental Psychology 51 (2017) 209–216, https://doi.org/10.1016/j.jenvp.2017.04.003.
[114] Min Lin, Elie Azar, Mixing work and leisure? Energy conservation actions and spillovers between building occupants at work and at home in the UAE, Energy Res. Social Sci. 47 (2019) 215–223, https://doi.org/10.1016/j.erss.2018.10.004.
[115] NOAA Website https://www.noaa.gov/news/2019-was-2nd-hottest-year-on-record-for-earth-say-noaa-nasa (Last Accessed September-2020).
[116] N. Wang, P.E. Phelan, C. Harris, J. Langevin, B. Nelson, K. Sawyer, Past visions, current trends, and future context: A review of building energy, carbon, and sustainability, Renew. Sustain. Energy Rev. 82 (2018) 976–993, https://doi.org/10.1016/j.rser.2017.04.114.
[117] Energy Use Data https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE?end=2010&start=1960 (Last accessed December-2019).
[118] CO2 Emissions by energy source, world 1990-2017 https://www.iea.org/data-and-statistics/?country=WORLD&fuel=CO2+emissions (Last accessed December-2019).
[119] C. Sanchez-Guevara, M.N. Peiró, J. Taylor, A. Mavrogianni, J.N. González, Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London, Energy Build. 190 (2019) 132–143, https://doi.org/10.1016/j.enbuild.2019.02.024.
[120] William J. Fisk, Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures, Build. Environ. 86 (2015) 70–80, https://doi.org/10.1016/j.buildenv.2014.12.024.
[121] UN Sustainable Development Goals https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (Last accessed December-2019).
[122] Directive 2010/31/EU Of The European Parliament And Of The Council On The Energy Performance Of Buildings (recast), 2010 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:en:PDF (Last accessed September-2020).

[123] EU 2020 Targets. https://ec.europa.eu/clima/policies/strategies/2020_en (Last accessed December-2019).

[124] IPCC, Special Report on the impacts of global warming of 1.5°C, https://www.ipcc.ch/sr15/ (last accessed January,2020).

[125] EIA, report for use of energy https://www.eia.gov/energyexplained/use-of-energy/ (last accessed January,2020).

[126] Pei Liu, Borong Lin, Wu. Xiaoying, Hao Zhou, Bridging energy performance gaps of green office buildings via more targeted operations management: A system dynamics approach, J. Environ. Manage. 238 (2019) 64–71, https://doi.org/10.1016/j.jenvman.2019.02.111.

[127] Sebastian Wolf, Jan Kloppenborg Moller, Magnus Alexander Bitsch, John Krogstie, Henrik Madsen **A Markov-Switching model for building occupant activity estimation**, Energy Build. 183 (2019) 672–683, https://doi.org/10.1016/j.enbuild.2018.11.041.

[128] A.R. Hansen, K. Gram-Hanssen, H.N. Knudsen, How building design and technologies influence heat-related habits, Building Research & Information 46 (1) (2018) 83–98, https://doi.org/10.1080/09613218.2017.1335477.

[129] Xin Zhou, Da. Yan, Jingjing An, Tianzhen Hong, Xing Shi, Xing Jin, Comparative study of air-conditioning energy use of four office buildings in China and USA, Energy Build. 169 (2018) 344–352, https://doi.org/10.1016/j.enbuild.2018.03.073.

[130] Sun-Hye Mun, Younghoon Kwak, Jung-Ho Huh, A case-centered behavior analysis and operation prediction of AC use in residential buildings, Energy Build. 188 (2019) 137–148, https://doi.org/10.1016/j.enbuild.2019.02.012.

[131] Jingjing An, Da. Yan, Tianzhen Hong, Clustering and statistical analyses of air-conditioning intensity and use patterns in residential buildings, Energy Build. 174 (2018) 214–227, https://doi.org/10.1016/j.enbuild.2018.06.035.

[132] Jian Yao, Modelling and simulating occupant behaviour on air conditioning in residential buildings, Energy Build. 175 (2018) 1–10, https://doi.org/10.1016/j.enbuild.2018.07.013.

[133] Obiajulu Iweka, Shuli Liu, Ashish Shukla, Da. Yan, Energy and behaviour at home: a review of intervention methods and practices, Energy Res. Social Sci. 57 (2019), 101238, https://doi.org/10.1016/j.erss.2019.101238.

[134] Gianluca Trotta, Factors affecting energy-saving behaviours and energy efficiency investments in British households, Energy Policy 114 (2018) 529–539, https://doi.org/10.1016/j.enpol.2017.12.042.

[135] Christine Boomsma, Rory V. Jones, Sabine Pahl, Alba Fuertes, Do psychological factors relate to energy saving behaviours in inefficient and damp homes? A study among English social housing residents, Energy Res. Social Sci. 47 (2019) 146–155, https://doi.org/10.1016/j.erss.2018.09.007.

[136] Nicholas Bardsley, Milena Büchs, Patrick James, Anastosios Papafragkou, Thomas Rushby, Clare Saunders, Graham Smith, Rebecca Wallbridge, Nicholas Woodman, Domestic thermal upgrades, community action and energy saving: A three-year experimental study of prosperous households, Energy Policy 127 (2019) 475–485, https://doi.org/10.1016/j.enpol.2018.11.036.

[137] Da. Li, Xu. Xiaojing, Chien-fei Chen, Carol Menassa, Understanding energy-saving behaviors in the American workplace: A unified theory of motivation, opportunity, and ability, Energy Res. Social Sci. 51 (2019) 198–209, https://doi.org/10.1016/j.erss.2019.01.020.

[138] Jeffrey Munk, Jon Winkler, Effect of occupant behavior on peak cooling and dehumidification loads in typical and high-efficiency homes, Energy Build. 184 (2019) 122–140, https://doi.org/10.1016/j.enbuild.2018.10.044.

[139] Yongbao Chen, Xu. Peng, Gu. Jiefan, Ferdinand Schmidt, Weilin Li, Measures to improve energy demand flexibility in buildings for demand response (DR): A review, Energy Build. 177 (2018) 125–139, https://doi.org/10.1016/j.enbuild.2018.08.003.

[140] Murray Goulden, Alexa Spence, Jamie Wardman, Caroline Leygue, Differentiating 'the user'in DSR: Developing demand side response in advanced economies, Energy Policy 122 (2018) 176–185, https://doi.org/10.1016/j.enpol.2018.07.013.

[141] Trevor Sweetnam, Catalina Spataru, Mark Barrett, Edwin Carter, Domestic demand-side response on district heating networks, Building Research & Information 47 (4) (2019) 330–343, https://doi.org/10.1080/09613218.2018.1426314.

[142] Yuval Damari, Meidad Kissinger, An integrated analysis of households' electricity consumption in Israel, Energy Policy 119 (2018) 51–58, https://doi.org/10.1016/j.enpol.2018.04.010.

[143] Tian Sheng Allan Loi, Jia Le Ng, Analysing households' responsiveness towards socio-economic determinants of residential electricity consumption in Singapore, Energy Policy 112 (2018) 415–426, https://doi.org/10.1016/j.enpol.2017.09.052.

[144] Mathieu Bourdeau, Xiaofeng Guo, Elyes Nefzaoui, Buildings energy consumption generation gap: A post-occupancy assessment in a case study of three higher education buildings, Energy Build. 159 (2018) 600–611, https://doi.org/10.1016/j.enbuild.2017.11.062.

[145] Olivier Damette, Philippe Delacote, Gaye Del Lo, Households energy consumption and transition toward cleaner energy sources, Energy Policy 113 (2018) 751–764, https://doi.org/10.1016/j.enpol.2017.10.060.

[146] Stavroula Karatasou, Marina Laskari, Mat Santamouris, Determinants of high electricity use and high energy consumption for space and water heating in European social housing: Socio-demographic and building characteristics, Energy Build. 170 (2018) 107–114, https://doi.org/10.1016/j.enbuild.2018.04.019.

[147] Yixuan Wei, Xingxing Zhang, Yong Shi, Liang Xia, Song Pan, Wu. Jinshun, Mengjie Han, Xiaoyun Zhao, A review of data-driven approaches for prediction and classification of building energy consumption, Renew. Sustain. Energy Rev. 82 (2018) 1027–1047, https://doi.org/10.1016/j.rser.2017.09.108.

[148] Badria Jaffar, Tadj Oreszczyn, Rokia Raslan, Alex Summerfield, Understanding energy demand in Kuwaiti villas: Findings from a quantitative household survey, Energy Build. 165 (2018) 379–389, https://doi.org/10.1016/j.enbuild.2018.01.055.

[149] Kiti Suomalainen, David Eyers, Rebecca Ford, Janet Stephenson, Ben Anderson, Michael Jack, Detailed comparison of energy-related time-use diaries and monitored residential electricity demand, Energy Build. 183 (2019) 418–427, https://doi.org/10.1016/j.enbuild.2018.11.002.

[150] Aimie Hope, Thomas Roberts, Ian Walker, Consumer engagement in low-carbon home energy in the United Kingdom: Implications for future energy system decentralization, Energy Res. Social Sci. 44 (2018) 362–370, https://doi.org/10.1016/j.erss.2018.05.032.

[151] Loic Frayssinet, Lucie Merlier, Frederic Kuznik, Jean-Luc Hubert, Maya Milliez, Jean-Jacques Roux, Modeling the heating and cooling energy demand of urban buildings at city scale, Renew. Sustain. Energy Rev. 81 (2018) 2318–2327, https://doi.org/10.1016/j.rser.2017.06.040.

[152] Shima Ebrahimigharehbaghi, Queena K. Qian, M. Frits, Henk J. Meijer, Visscher., Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? Energy Policy 129 (2019) 546–561, https://doi.org/10.1016/j.enpol.2019.02.046.

[153] Ines Weber, Anna Wolff, Energy efficiency retrofits in the residential sector–analysing tenants' cost burden in a German field study, Energy Policy 122 (2018) 680–688, https://doi.org/10.1016/j.enpol.2018.08.007.

[154] P. Boerenfijn, J.K. Kazak, L. Schellen, J. Van Hoof, A multi-case study of innovations in energy performance of social housing for older adults in the Netherlands, Energy Build. 158 (2018) 1762–1769, https://doi.org/10.1016/j.enbuild.2017.10.101.

[155] Aly M. Elharidi, Paul G. Tuohy, Mohamed A. Teamah, The energy and indoor environmental performance of Egyptian offices: Parameter analysis and future policy, Energy Build. 158 (2018) 431–452, https://doi.org/10.1016/j.enbuild.2017.10.035.

[156] A. Hardy, D. Glew, An analysis of errors in the Energy Performance certificate database, Energy Policy 129 (2019) 1168–1178, https://doi.org/10.1016/j.enpol.2019.03.022.

[157] Melanie Franke, Claudia Nadler, Energy efficiency in the German residential housing market: Its influence on tenants and owners, Energy Policy 128 (2019) 879–890, https://doi.org/10.1016/j.enpol.2019.01.052.

[158] M. Ashouri, F. Haghighat, B.C. Fung, H. Yoshino, Development of a ranking procedure for energy performance evaluation of buildings based on occupant behavior, Energy Build. 183 (2019) 659–671, https://doi.org/10.1016/j.enbuild.2018.11.050.

[159] Florian Heesen, Reinhard Madlener, Consumer behavior in energy-efficient homes: The limited merits of energy performance ratings as benchmarks, Energy Build. 172 (2018) 405–413, https://doi.org/10.1016/j.enbuild.2018.04.039.

[160] N. Bonatz, R. Guo, W. Wu, L. Liu, A comparative study of the interlinkages between energy poverty and low carbon development in China and Germany by developing an energy poverty index, Energy Build. 183 (2019) 817–831, https://doi.org/10.1016/j.enbuild.2018.09.042.

[161] Hamed Nabizadeh Rafsanjani, Changbum R. Ahn, Jiayu Chen, Linking building energy consumption with occupants' energy-consuming behaviors in commercial buildings: Non-intrusive occupant load monitoring (NIOLM), Energy Build. 172 (2018) 317–327, https://doi.org/10.1016/j.enbuild.2018.05.007.

[162] A.G. Gaglia, E.N. Dialynas, A.A. Argiriou, E. Kostopoulou, D. Tsiamitros, D. Stimoniaris, K.M. Laskos, Energy performance of European residential buildings: Energy use, technical and environmental characteristics of the Greek residential sector–energy conservation and CO_2 reduction, Energy Build. 183 (2019) 86–104, https://doi.org/10.1016/j.enbuild.2018.10.042.

[163] C. Vogiatzi, G. Gemenetzi, L. Massou, S. Poulopoulos, S. Papaefthimiou, E. Zervas, Energy use and saving in residential sector and occupant behavior: A case study in Athens, Energy Build. 181 (2018) 1–9, https://doi.org/10.1016/j.enbuild.2018.09.039.

[164] Hamed Nabizadeh Rafsanjani, Changbum Ryan Ahn, Kent M. Eskridge, Understanding the recurring patterns of occupants' energy-use behaviors at entry and departure events in office buildings, Build. Environ. 136 (2018) 77–87, https://doi.org/10.1016/j.buildenv.2018.03.037.

[165] A. Pérez-Fargallo, C. Rubio-Bellido, J.A. Pulido-Arcas, F.J. Guevara-García, Fuel Poverty Potential Risk Index in the context of climate change in Chile, Energy Policy 113 (2018) 157–170, https://doi.org/10.1016/j.enpol.2017.10.054.

[166] Audrey Berry, The distributional effects of a carbon tax and its impact on fuel poverty: A microsimulation study in the French context, Energy Policy 124 (2019) 81–94, https://doi.org/10.1016/j.enpol.2018.09.021.

[167] Fateh Belaïd, Exposure and risk to fuel poverty in France: Examining the extent of the fuel precariousness and its salient determinants, Energy Policy 114 (2018) 189–200, https://doi.org/10.1016/j.enpol.2017.12.005.

[168] Lefkothea Papada, Dimitris Kaliampakos, A Stochastic Model for energy poverty analysis, Energy Policy 116 (2018) 153–164, https://doi.org/10.1016/j.enpol.2018.02.004.

[169] Ade Kearns, Elise Whitley, Angela Curl, Occupant behaviour as a fourth driver of fuel poverty (aka warmth & energy deprivation), Energy Policy 129 (2019) 1143–1155, https://doi.org/10.1016/j.enpol.2019.03.023.

[170] J. Morris, A. Genovese, An empirical investigation into students' experience of fuel poverty, Energy Policy 120 (2018) 228–237, https://doi.org/10.1016/j.enpol.2018.05.032.

[171] K.J. Lomas, S. Oliveira, P. Warren, V.J. Haines, T. Chatterton, A. Beizaee, E. Prestwood, B. Gething, Do domestic heating controls save energy? A review of

the evidence, Renew. Sustain. Energy Rev. 93 (2018) 52–75, https://doi.org/10.1016/j.rser.2018.05.002.
[172] Kai Nino Streicher, Pierryves Padey, David Parra, Meinrad C. Bürer, Stefan Schneider, Martin K. Patel, Analysis of space heating demand in the Swiss residential building stock: Element-based bottom-up model of archetype buildings, Energy Build. 184 (2019) 300–322, https://doi.org/10.1016/j.enbuild.2018.12.011.
[173] J. Curtis, D. McCoy, C. Aravena, Heating system upgrades: The role of knowledge, socio-demographics, building attributes and energy infrastructure, Energy Policy 120 (2018) 183–196, https://doi.org/10.1016/j.enpol.2018.05.036.
[174] A. Bruce-Konuah, R.V. Jones, A. Fuertes, L. Messi, A. Giretti, The role of thermostatic radiator valves for the control of space heating in UK social-rented households, Energy Build. 173 (2018) 206–220, https://doi.org/10.1016/j.enbuild.2018.05.023.
[175] Luciana M. Miu, Christoph M. Mazur, Koen H. van Dam, Romain S.C. Lambert, Adam Hawkes, Nilay Shah, **Going smart, staying confused: Perceptions and use of smart thermostats in British homes.** Energy Research & Social, Science 57 (2019), 101228, https://doi.org/10.1016/j.erss.2019.101228.
[176] Alexandra Schieweck, Erik Uhde, Tunga Salthammer, Lea C. Salthammer, Lidia Morawska, Mandana Mazaheri, Prashant Kumar, Smart homes and the control of indoor air quality, Renew. Sustain. Energy Rev. 94 (2018) 705–718, https://doi.org/10.1016/j.rser.2018.05.057.
[177] Junjie Liu, Xilei Dai, Xiangdong Li, Susu Jia, Jingjing Pei, Yuexia Sun, Dayi Lai Xiong Shen, Hejiang Sun, Haiguo Yin, Kailiang Huang, Hongwei Tan, Yao Gao, Yiwen Jian **Indoor air quality and occupants' ventilation habits in China: seasonal measurement and long-term monitoring**, Build. Environ. 142 (2018) 119–129, https://doi.org/10.1016/j.buildenv.2018.06.002.
[178] Cheng Zeng, Shuli Liu, Ashish Shukla, Benqiang Yang, Identifying the occupant's satisfaction and awareness for the performance of Eco houses in the United Kingdom, Journal of Building Engineering 18 (2018) 281–291, https://doi.org/10.1016/j.jobe.2018.03.023.
[179] A. Jamrozik, C. Ramos, J. Zhao, J. Bernau, N. Clements, T.V. Wolf, B. Bauer, A novel methodology to realistically monitor office occupant reactions and environmental conditions using a living lab, Build. Environ. 130 (2018) 190–199, https://doi.org/10.1016/j.buildenv.2017.12.024.
[180] Andrew Carre, Terence Williamson, Design and validation of a low cost indoor environment quality data logger, Energy Build. 158 (2018) 1751–1761, https://doi.org/10.1016/j.enbuild.2017.11.051.
[181] Amy A Kim, Shuoqi Wang, Lindsay J. McCunn, **Building value proposition for interactive lighting systems in the workplace: Combining energy and occupant perspectives.** Journal of Building, Engineering 24 (2019), 100752, https://doi.org/10.1016/j.jobe.2019.100752.
[182] Sara Gilani, William O'Brien, A preliminary study of occupants' use of manual lighting controls in private offices: A case study, Energy Build. 159 (2018) 572–586, https://doi.org/10.1016/j.enbuild.2017.11.055.
[183] Da. Yan, X. Feng, Y. Jin, C. Wang, The evaluation of stochastic occupant behavior models from an application-oriented perspective: Using the lighting behavior model as a case study, Energy Build. 176 (2018) 151–162, https://doi.org/10.1016/j.enbuild.2018.07.037.
[184] J.Y. Park, T. Dougherty, H. Fritz, Z. Nagy, LightLearn: An adaptive and occupant centered controller for lighting based on reinforcement learning, Build. Environ. 147 (2019) 397–414, https://doi.org/10.1016/j.buildenv.2018.10.028.
[185] J.K. Day, B. Futrell, R. Cox, S.N. Ruiz, Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies, Build. Environ. 154 (2019) 107–121, https://doi.org/10.1016/j.buildenv.2019.02.037.
[186] Lindsay J. McCunn, Amy Kim, James Feracor, Reflections on a retrofit: Organizational commitment, perceived productivity and controllability in a building lighting project in the United States, Energy Res. Social Sci. 38 (2018) 154–164, https://doi.org/10.1016/j.erss.2018.02.002.
[187] D. Mora, G. Fajilla, M.C. Austin, M. De Simone, Occupancy patterns obtained by heuristic approaches: Cluster analysis and logical flowcharts. A case study in a university office, Energy Build. 186 (2019) 147–168, https://doi.org/10.1016/j.enbuild.2019.01.023.
[188] A.K. Mikkilineni, J. Dong, T. Kuruganti, D. Fugate, A novel occupancy detection solution using low-power IR-FPA based wireless occupancy sensor, Energy Build. 192 (2019) 63–74, https://doi.org/10.1016/j.enbuild.2019.03.022.
[189] H. Saha, A.R. Florita, G.P. Henze, S. Sarkar, Occupancy sensing in buildings: A review of data analytics approaches, Energy Build. 188–189 (2019) 278–285, https://doi.org/10.1016/j.enbuild.2019.02.030.
[190] R. Razavi, A. Gharipour, M. Fleury, I.J. Akpan, Occupancy detection of residential buildings using smart meter data: A large-scale study, Energy Build. 183 (2019) 195–208, https://doi.org/10.1016/j.enbuild.2018.11.025.
[191] P.F. Pereira, N.M. Ramos, R.M. Almeida, M.L. Simões, Methodology for detection of occupant actions in residential buildings using indoor environment monitoring systems, Build. Environ. 146 (2018) 107–118, https://doi.org/10.1016/j.buildenv.2018.09.047.
[192] Anders Rhiger Hansen, Line Valdorff Madsen, Henrik N. Knudsen, Kirsten Gram-Hassen Gender, age, and educational differences in the importance of homely comfort in Denmark. Energy Research & Social Science 54 (2019): 157-165. https://doi.org/10.1016/j.erss.2019.04.004.
[193] William O'Brien, Marcel Schweiker, Julia K. Day, Get the picture? Lessons learned from a smartphone-based post-occupancy evaluation, Energy Res. Social Sci. 56 (2019), 101224, https://doi.org/10.1016/j.erss.2019.101224.
[194] Y. Liu, Z. Wang, B. Lin, J. Hong, Y. Zhu, Occupant satisfaction in Three-Star-certified office buildings based on comparative study using LEED and BREEAM, Build. Environ. 132 (2018) 1–10, https://doi.org/10.1016/j.buildenv.2018.01.011.
[195] Marco A. Ortiz, Philomena M. Bluyssen, Proof-of-concept of a questionnaire to understand occupants' comfort and energy behaviours: First results on home occupant archetypes, Build. Environ. 134 (2018) 47–58, https://doi.org/10.1016/j.buildenv.2018.02.030.
[196] Patrick XW Zou, Dipika Wagle, Morshed Alam, Strategies for minimizing building energy performance gaps between the design intend and the reality, Energy Build. 191 (2019) 31–41, https://doi.org/10.1016/j.enbuild.2019.03.013.
[197] Carlos Calderón, Macarena Rodriguez Beltrán, Effects of fabric retrofit insulation in a UK high-rise social housing building on temperature take-back, Energy Build. 173 (2018) 470–488, https://doi.org/10.1016/j.enbuild.2018.05.046.
[198] Juan David Barbosa, Elie Azar, Modeling and implementing human-based energy retrofits in a green building in desert climate, Energy Build. 173 (2018) 71–80, https://doi.org/10.1016/j.enbuild.2018.05.024.
[199] R. Escandón, S. Silvester, T. Konstantinou, Evaluating the environmental adaptability of a nearly zero energy retrofitting strategy designed for Dutch housing stock to a Mediterranean climate, Energy Build. 169 (2018) 366–378, https://doi.org/10.1016/j.enbuild.2018.03.079.
[200] Sahar Zahiri, Heba Elsharkawy, Towards energy-efficient retrofit of council housing in London: Assessing the impact of occupancy and energy-use patterns on building performance, Energy Build. 174 (2018) 672–681, https://doi.org/10.1016/j.enbuild.2018.07.010.
[201] Gianluca Trotta, The determinants of energy efficient retrofit investments in the English residential sector, Energy Policy 120 (2018) 175–182, https://doi.org/10.1016/j.enpol.2018.05.024.
[202] A. Santangelo, D. Yan, X. Feng, S. Tondelli, Renovation strategies for the Italian public housing stock: Applying building energy simulation and occupant behaviour modelling to support decision-making process, Energy Build. 167 (2018) 269–280, https://doi.org/10.1016/j.enbuild.2018.02.028.
[203] Mohamad Awada, Issam Srour, A genetic algorithm based framework to model the relationship between building renovation decisions and occupants' satisfaction with indoor environmental quality, Build. Environ. 146 (2018) 247–257, https://doi.org/10.1016/j.buildenv.2018.10.001.
[204] P. van den Brom, A. Meijer, H. Visscher, Actual energy saving effects of thermal renovations in dwellings—longitudinal data analysis including building and occupant characteristics, Energy Build. 182 (2019) 251–263, https://doi.org/10.1016/j.enbuild.2018.10.025.
[205] Stella Tsoka, Katerina Tsikaloudaki, Theodoros Theodosiou, Antoine Dugue, Rethinking user based innovation: Assessing public and professional perceptions of energy efficient building facades in Greece, Italy and Spain, Energy Res. Social Sci. 38 (2018) 165–177, https://doi.org/10.1016/j.erss.2018.02.009.
[206] Amirhosein Jafari, Vanessa Valentin, Selection of optimization objectives for decision-making in building energy retrofits, Build. Environ. 130 (2018) 94–103, https://doi.org/10.1016/j.buildenv.2017.12.027.
[207] O.M. Popoola, Computational intelligence modelling based on variables interlinked with behavioral tendencies for energy usage profile–A necessity, Renew. Sustain. Energy Rev. 82 (2018) 60–72, https://doi.org/10.1016/j.rser.2017.09.020.
[208] Madiha Latif, Ali Nasir, Decentralized stochastic control for building energy and comfort management, Journal of Building Engineering 24 (2019), 100739, https://doi.org/10.1016/j.jobe.2019.100739.
[209] Hengfang Deng, David Fannon, Matthew J. Eckelman, Predictive modeling for US commercial building energy use: A comparison of existing statistical and machine learning algorithms using CBECS microdata, Energy Build. 163 (2018) 34–43, https://doi.org/10.1016/j.enbuild.2017.12.031.
[210] W. Li, Z. Tian, Y. Lu, F. Fu, Stepwise calibration for residential building thermal performance model using hourly heat consumption data, Energy Build. 181 (2018) 10–25, https://doi.org/10.1016/j.enbuild.2018.10.001.
[211] Wei Wang, Jiayu Chen, Tianzhen Hong, Modeling occupancy distribution in large spaces with multi-feature classification algorithm, Build. Environ. 137 (2018) 108–117, https://doi.org/10.1016/j.buildenv.2018.04.002.
[212] Zhaoxuan Li, Bing Dong, Short term predictions of occupancy in commercial buildings—Performance analysis for stochastic models and machine learning approaches, Energy Build. 158 (2018) 268–281, https://doi.org/10.1016/j.enbuild.2017.09.052.
[213] Yingchun Ji, Angela Lee, Will Swan, Building dynamic thermal model calibration using the Energy House facility at Salford, Energy Build. 191 (2019) 224–234, https://doi.org/10.1016/j.enbuild.2019.03.001.
[214] H. Zou, Y. Zhou, J. Yang, C.J. Spanos, Towards occupant activity driven smart buildings via WiFi-enabled IoT devices and deep learning, Energy Build. 177 (2018) 12–22, https://doi.org/10.1016/j.enbuild.2018.08.010.
[215] Tom Hargreaves, Charlie Wilson, Richard Hauxwell-Baldwin, Learning to live in a smart home, Building Research & Information 46 (1) (2018) 127–139, https://doi.org/10.1080/09613218.2017.1286882.
[216] Joyce Kim, Stefano Schiavon, Gail Brager, Personal comfort models–A new paradigm in thermal comfort for occupant-centric environmental control, Build. Environ. 132 (2018) 114–124, https://doi.org/10.1016/j.buildenv.2018.01.023.
[217] Joyce Kim, Fred Bauman, Paul Raftery, Edward Arens, Hui Zhang, Gabe Fierro, Michael Andersen, David Culler, Occupant comfort and behavior: High-resolution data from a 6-month field study of personal comfort systems with 37 real office workers, Build. Environ. 148 (2019) 348–360, https://doi.org/10.1016/j.buildenv.2018.11.012.
[218] A. Pérez-Fargallo, J.A. Pulido-Arcas, C. Rubio-Bellido, M. Trebilcock, B. Piderit, S. Attia, Development of a new adaptive comfort model for low income housing in

the central-south of Chile, Energy Build. 178 (2018) 94–106, https://doi.org/10.1016/j.enbuild.2018.08.030.
[219] J. Kim, Y. Zhou, S. Schiavon, P. Raftery, G. Brager, Personal comfort models: predicting individuals' thermal preference using occupant heating and cooling behavior and machine learning, Build. Environ. 129 (2018) 96–106, https://doi.org/10.1016/j.buildenv.2017.12.011.
[220] Andrzej Szczurek, Monika Maciejewska, Mariusz Uchroński, Determination of thermal preferences based on event analysis, Energy Build. 166 (2018) 210–219, https://doi.org/10.1016/j.enbuild.2018.02.014.
[221] Geun Young Yun, Influences of perceived control on thermal comfort and energy use in buildings, Energy Build. 158 (2018) 822–830, https://doi.org/10.1016/j.enbuild.2017.10.044.
[222] Z. Wu, N. Li, J. Peng, H. Cui, P. Liu, H. Li, X. Li, Using an ensemble machine learning methodology-Bagging to predict occupants' thermal comfort in buildings, Energy Build. 173 (2018) 117–127, https://doi.org/10.1016/j.enbuild.2018.05.031.
[223] Anastasios Ioannou, Laure Itard, Tushar Agarwal, In-situ real time measurements of thermal comfort and comparison with the adaptive comfort theory in Dutch residential dwellings, Energy Build. 170 (2018) 229–241, https://doi.org/10.1016/j.enbuild.2018.04.006.
[224] I. Petidis, M. Aryblia, T. Daras, T. Tsoutsos, Energy saving and thermal comfort interventions based on occupants' needs: A students' residence building case, Energy Build. 174 (2018) 347–364, https://doi.org/10.1016/j.enbuild.2018.05.057.
[225] R. Kc, H.B. Rijal, M. Shukuya, K. Yoshida, An in-situ study on occupants' behaviors for adaptive thermal comfort in a Japanese HEMS condominium, Journal of Building Engineering 19 (2018) 402–411, https://doi.org/10.1016/j.jobe.2018.05.013.
[226] Zhipeng Deng, Qingyan Chen, Artificial neural network models using thermal sensations and occupants' behavior for predicting thermal comfort, Energy Build. 174 (2018) 587–602, https://doi.org/10.1016/j.enbuild.2018.06.060.
[227] Ashrant Aryal, Burcin Becerik-Gerber, Energy consequences of Comfort-driven temperature setpoints in office buildings, Energy Build. 177 (2018) 33–46, https://doi.org/10.1016/j.enbuild.2018.08.013.
[228] C. Xu, S. Li, X. Zhang, S. Shao, Thermal comfort and thermal adaptive behaviours in traditional dwellings: A case study in Nanjing, **China.** Building and Environment 142 (2018) 153–170, https://doi.org/10.1016/j.buildenv.2018.06.006.
[229] Jungsoo Kim, Richard de Dear, Thermal comfort expectations and adaptive behavioural characteristics of primary and secondary school students, Build. Environ. 127 (2018) 13–22, https://doi.org/10.1016/j.buildenv.2017.10.031.
[230] Veronica Galassi, Reinhard Madlener, Shall I open the window? Policy implications of thermal-comfort adjustment practices in residential buildings, Energy Policy 119 (2018) 518–527, https://doi.org/10.1016/j.enpol.2018.03.015.
[231] R.F. Rupp, J. Kim, R. de Dear, E. Ghisi, Associations of occupant demographics, thermal history and obesity variables with their thermal comfort in air-conditioned and mixed-mode ventilation office buildings, Build. Environ. 135 (2018) 1–9, https://doi.org/10.1016/j.buildenv.2018.02.049.
[232] Federico Tartarini, Paul Cooper, Richard Fleming, Thermal perceptions, preferences and adaptive behaviours of occupants of nursing homes, Build. Environ. 132 (2018) 57–69, https://doi.org/10.1016/j.buildenv.2018.01.018.
[233] C. Sun, R. Zhang, S. Sharples, Y. Han, H. Zhang, A longitudinal study of summertime occupant behaviour and thermal comfort in office buildings in northern China, Build. Environ. 143 (2018) 404–420, https://doi.org/10.1016/j.buildenv.2018.07.004.
[234] M.G.L.C. Loomans, A.K. Mishra, M.T.H. Derks, J.J. Kraakman, H.S.M. Kort, Occupant response to transitions across indoor thermal environments in two different workspaces, Build. Environ. 144 (2018) 402–411, https://doi.org/10.1016/j.buildenv.2018.08.049.
[235] S. Lee, P. Karava, A. Tzempelikos, I. Bilionis, Inference of thermal preference profiles for personalized thermal environments with actual building occupants, Build. Environ. 148 (2019) 714–729, https://doi.org/10.1016/j.buildenv.2018.10.027.
[236] Wei Tian, Yeonsook Heo, Pieter de Wilde, Zhanyong Li, Da Yan, Cheol Soo Park, Xiaohong Feng, Godfried Augenbroe. A review of uncertainty analysis in building energy assessment. Renewable and Sustainable Energy Reviews, 2018; 93: 285-301. https://doi.org/10.1016/j.rser.2018.05.029.
[237] W. Belazi, S.E. Ouldboukhitine, A. Chateauneuf, A. Bouchair, Uncertainty analysis of occupant behavior and building envelope materials in office building performance simulation, Journal of Building Engineering 19 (2018) 434–448, https://doi.org/10.1016/j.jobe.2018.06.005.
[238] J.F. Belmonte, R. Barbosa, M.G. Almeida, CO_2 concentrations in a multifamily building in Porto, Portugal: Occupants' exposure and differential performance of mechanical ventilation control strategies, Journal of Building Engineering 23 (2019) 114–126, https://doi.org/10.1016/j.jobe.2019.01.008.
[239] Hakpyeong Kim, Taehoon Hong, Jimin Kim, Automatic ventilation control algorithm considering the indoor environmental quality factors and occupant ventilation behavior using a logistic regression model, Build. Environ. 153 (2019) 46–59, https://doi.org/10.1016/j.buildenv.2019.02.032.
[240] X. Ren, C. Zhang, Y. Zhao, G. Boxem, W. Zeiler, T. Li, A data mining-based method for revealing occupant behavior patterns in using mechanical ventilation systems of Dutch dwellings, Energy Build. 193 (2019) 99–110, https://doi.org/10.1016/j.enbuild.2019.03.047.
[241] D. Lai, Y. Qi, J. Liu, X. Dai, L. Zhao, S. Wei, Ventilation behavior in residential buildings with mechanical ventilation systems across different climate zones in China, Build. Environ. 143 (2018) 679–690, https://doi.org/10.1016/j.buildenv.2018.08.006.
[242] S. Kumar, M.K. Singh, A. Mathur, J. Mathur, S. Mathur, Evaluation of comfort preferences and insights into behavioural adaptation of students in naturally ventilated classrooms in a tropical country, **India.** Building and Environment 143 (2018) 532–547, https://doi.org/10.1016/j.buildenv.2018.07.035.
[243] Jared Landsman, Gail Brager, Mona Doctor-Pingel, Performance, prediction, optimization, and user behavior of night ventilation, Energy Build. 166 (2018) 60–72, https://doi.org/10.1016/j.enbuild.2018.01.026.
[244] Farhang Tahmasebi, Ardeshir Mahdavi, On the utility of occupants' behavioural diversity information for building performance simulation: An exploratory case study, Energy Build. 176 (2018) 380–389, https://doi.org/10.1016/j.enbuild.2018.07.042.
[245] X. Zhou, T. Liu, X. Shi, X. Jin, Case study of window operating behavior patterns in an open-plan office in the summer, Energy Build. 165 (2018) 15–24, https://doi.org/10.1016/j.enbuild.2018.01.037.
[246] Song Pan, Yingzi Xiong, Yiye Han, Xingxing Zhang, Liang Xia, Shen Wei, Wu. Jinshun, Mengjie Han, A study on influential factors of occupant window-opening behavior in an office building in China, Build. Environ. 133 (2018) 41–50, https://doi.org/10.1016/j.buildenv.2018.02.008.
[247] Z.D. Belafi, F. Naspi, M. Arnesano, A. Reith, G.M. Revel, Investigation on window opening and closing behavior in schools through measurements and surveys: A case study in Budapest, Build. Environ. 143 (2018) 523–531, https://doi.org/10.1016/j.buildenv.2018.07.022.
[248] D. Lai, S. Jia, Y. Qi, J. Liu, Window-opening behavior in Chinese residential buildings across different climate zones, Build. Environ. 142 (2018) 234–243, https://doi.org/10.1016/j.buildenv.2018.06.030.
[249] R. Markovic, E. Grintal, D. Wölki, J. Frisch, C. van Treeck, Window opening model using deep learning methods, Build. Environ. 145 (2018) 319–329, https://doi.org/10.1016/j.buildenv.2018.09.024.
[250] Davide Calì, Mark Thomas Wesseling, Dirk Müller, WinProGen,, A Markov-Chain-based stochastic window status profile generator for the simulation of realistic energy performance in buildings, Build. Environ. 136 (2018) 240–258, https://doi.org/10.1016/j.buildenv.2018.03.048.
[251] Cheng Sun, Ran Zhang, Steve Sharples, Yunsong Han, Hongrui Zhang, Thermal comfort, occupant control behaviour and performance gap–A study of office buildings in north-east China using data mining, Build. Environ. 149 (2019) 305–321, https://doi.org/10.1016/j.buildenv.2018.12.036.
[252] L. Bourikas E. Costanza S. Gauthier P.A.B. James J. Kittley-Davies C. Ornaghi A. Rogers E. Saadatian Y. Huang Camera-based window-opening estimation in a naturally ventilated office Building Research & Information 46 2 2018 148 163 10.1080/09613218.2016.1245951.
[253] Fateh Belaïd, Salome Bakaloglou, David Roubaud, Direct rebound effect of residential gas demand: Empirical evidence from France, Energy Policy 115 (2018) 23–31, https://doi.org/10.1016/j.enpol.2017.12.040.
[254] C. Papatsimpa, J.P.M.G. Linnartz, Propagating sensor uncertainty to better infer office occupancy in smart building control, Energy Build. 179 (2018) 73–82, https://doi.org/10.1016/j.enbuild.2018.08.039.
[255] Pedro F. Pereira, Nuno MM Ramos, Occupant behaviour motivations in the residential context–An investigation of variation patterns and seasonality effect, Build. Environ. 148 (2019) 535–546, https://doi.org/10.1016/j.buildenv.2018.10.053.
[256] Graeme Sherriff, Trivess Moore, Stephen Berry, Aimee Ambrose, Barry Goodchild, Angela Maye-Banbury, Coping with extremes, creating comfort: User experiences of 'low-energy'homes in Australia, Energy Res. Social Sci. 51 (2019) 44–54, https://doi.org/10.1016/j.erss.2018.12.008.
[257] Nicolien van der Grijp, Frans van der Woerd, Bruno Gaiddon, Reto Hummelshøj, Mia Larsson, Olufolahan Osunmuyiwa, Rudy Rooth, Demonstration projects of Nearly Zero Energy Buildings: Lessons from end-user experiences in Amsterdam, Helsingborg, and Lyon, Energy Res. Social Sci. 49 (2019) 10–15, https://doi.org/10.1016/j.erss.2018.10.006.
[258] Anders Rhiger Hansen, 'Sticky'energy practices: the impact of childhood and early adulthood experience on later energy consumption practices, Energy Res. Social Sci. 46 (2018) 125–139, https://doi.org/10.1016/j.erss.2018.06.013.
[259] Minna Sunikka-Blank, Ronita Bardhan, Anika Nasra Haque, Gender, domestic energy and design of inclusive low-income habitats: A case of slum rehabilitation housing in Mumbai, **India.** Energy Research & Social Science 49 (2019) 53–67, https://doi.org/10.1016/j.erss.2018.10.020.
[260] J. Lizana, R. Chacartegui, A. Barrios-Padura, C. Ortiz, Advanced low-carbon energy measures based on thermal energy storage in buildings: A review, Renew. Sustain. Energy Rev. 82 (2018) 3705–3749, https://doi.org/10.1016/j.rser.2017.10.093.
[261] Nina Shao, Liangdong Ma, Jili Zhang, Study on the rural residence heating temperature based on the residents behavior pattern in South Liaoning province, Energy Build. 174 (2018) 179–189, https://doi.org/10.1016/j.enbuild.2018.06.023.
[262] P. Zhu, D. Yan, H. Sun, J. An, Y. Huang, Building Blocks Energy Estimation (BBEE): A method for building energy estimation on district level, Energy Build. 185 (2019) 137–147, https://doi.org/10.1016/j.enbuild.2018.12.031.

[263] Raymond J. Cole, John Robinson, Zosia Brown & Meg O'shea Re-contextualizing the notion of comfort, Building Research & Information 36 (4) (2008) 323–336, https://doi.org/10.1080/09613210802076328.
[264] Michael A. Humphreys, Quantifying occupant comfort: are combined indices of the indoor environment practicable? Building Research & Information 33 (4) (2005) 317–325, https://doi.org/10.1080/09613210500161950.
[265] EU 2030 climate & energy framework, https://ec.europa.eu/clima/policies/strategies/2030_en (Last accessed October-2020).