A review and comparison of studies on office window behaviour using engineering and social science methods

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Abstract. With the urgent need of reducing building carbon emissions to ease climate change, it is necessary to have energy efficient buildings. An effective way of achieving this mission is adopting natural ventilation, which is commonly achieved by openable windows controlled by building occupants in most cases. In this kind of buildings, therefore, occupant window behaviour becomes significantly important on the building performance. To better understand this behaviour, researchers from both engineering domain and social science domain have contributed, but it seems like that they have different research aims, methods and findings. To promote transdisciplinary collaboration in this area, this study has carried out a thorough review of studies on window behaviour in office buildings. The review work collected 66 relevant studies, and analysed their aims, methods and main findings to figure out the differences between engineering studies and social science studies. The existing studies were mainly coming from renowned academic journals (91%) and academic conferences (9%). The comparison revealed significant differences between the two scientific domains, with some overlapping between them. To obtain deeper understanding on occupant window behaviour, critical discussions on how to better collaborate between these two domains in the future have been provided as well.

1 Introduction

1.1 Research background

Buildings contribute largely to global energy use, and this consumption is continuously increasing [1, 2]. On a global scale, the buildings and construction sector accounts for 36% of global energy use, leading to 37% energy-related CO_2 emissions [3]. Moreover, with the need to mitigate climate change as a matter of human activities, it is urgent to reduce the carbon emissions from buildings [4], and there is a high potential for reducing building energy consumption for achieving sustainability [5-7].

Occupant behaviour has received much attention among the factors affecting building energy consumption [8-10]. It is defined as the interaction between the building users and the building systems, such as opening/closing windows or blinds, turning on/off air conditioning or lights [11, 12]. This behaviour is also called adaptive behaviour, which has been evidenced as having significant impact on building consumption [13, 14].

To reduce building carbon emissions, natural ventilation (NV) has been considered as an effective method for better indoor air quality and lower building energy demand [15-17]. In most NV buildings, the control of indoor environment is mainly achieved by manual opening/closing windows from building occupants [18], so their window behaviour has a great impact on the performance of buildings [19]. For example, a study carried out by Scheuring and Weller [20] shows that natural ventilation requires 50% to 70% less energy than mechanical ventilation when cooling energy is required (in August). In 2016, a research by Tong et al [21] indicates that 8–78% of the cooling energy consumption can be potentially reduced by natural ventilation. However, when the building is heated or cooled using mechanical ventilation, window operations will cause extra energy loss [22-24].

To better understand this impact and maximize the performance of buildings, researchers have carried out many studies. Some studies tried to identify the drivers of window behaviour [25, 26], some tried to develop useful behavioural models for building performance simulation [27-29], some tried to change occupant window behaviour for better building performance [4], and some tried to develop and justify better research methods [30, 31].

Existing studies in this topic mainly contributed from researchers in engineering and social science domains. However, in this research area, one major aim is to inform better building design, so most studies were carried using engineering methods [32]. In recent years, however, a consensus has been widely established that occupant behaviours, including window operation, are complex and a comprehensive understanding of it needs contributions from various disciplines, especially social

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sciences [13, 33-35]. To guide the design of future research, an in-depth understanding on the studies carried out by both engineering method and social science method, including their aims, methods and main findings, becomes important and needed. This study, therefore, has carried out a systematic literature review on existing studies in terms of office window behaviour studies, and critically compared the review results between engineering-based studies and social science-based studies.

1.2 Methodology

This study has adopted a systematic literature review method to investigate the current research status for office window behaviour, focusing on the differences between engineering-based studies and social science-based studies. The major advantage of systematic literature review is that it gives transparent and clear protocols for researchers to search and evaluate the relevant existing studies in a specific research topic [36, 37]. Additionally, strictly-defined review rules can also help to maximize the acquisition of knowledge related to specific research questions and identify gaps in the research field [37, 38].

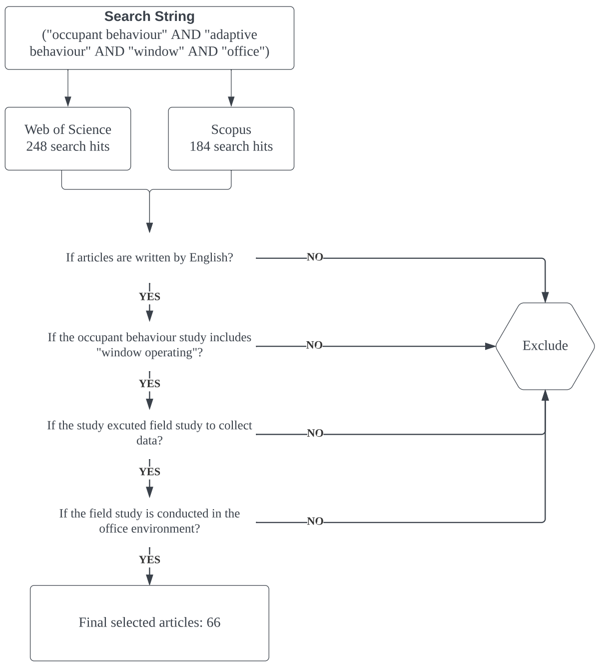

Fig. 1. Paper selection process in the systematic literature review

When searching existing literature, two major databases, i.e. Web of Science and Scopus, have been used in this study, as shown in Figure 1. The keywords were ‘occupant behaviour’, ‘adaptive behaviour’, ‘window’ and ‘office’. The search scope included published articles in academic journals, international/national conferences, and academic reports. The collected literatures were then filtered following the PRISMA Protocol [39], which is a widely adopted systematic review protocol describing the rationale, hypothesis and planned methods of the review work. After this filtration process, sixty-six publications were finally selected for further analysis, including sixty journal papers (91%), mainly from journals like Building and Environment, and Energy Research & Social Science; six conference papers (9%), such as Proceedings of BS2015: 14th International Conference of the International Building Performance Simulation and Proceedings of the international IBPSA conference.

As mentioned above, the aim of this study is to compare existing studies using engineering and social science methods in terms of office window behaviour. Therefore, the sixty-six publications were classified as engineering-based studies, social science-based studies and studies combining engineering and social science methods, based on the following criteria:

(1) Self-declaration of using social science methods, such as psychology, or engineering methods;

(2) Based on the fundamental differences between social science method (i.e. science of people or collections of people) and engineering method (i.e. the produced knowledge is only a means to be used for the purposes of designing technologies);

(3) Based on the authors’ research background (e.g. their institutional background and educational background).

Table 1 shows the classification results, with fifty-five (83%) used engineering method only, three (5%) used social science method only, and eight (12%) used both methods in their studies.

Table 1. Classification results for reviewed publications

Classification	Number	Percentage
Engineering-based studies	55	83%
Social Science-based studies	3	5%
Combing engineering and social science methods	8	12%
Total	66	100%

2 Results:

2.1 Studies using engineering method

From this review work, it was found that a majority (83%) existing studies on office window behaviour were carried out using the engineering method. This section, therefore, has analysed the main research aims, data collecting methods and findings, of engineering-based studies.

Table 2 has summarized the main aims of existing engineering-based studies. From the summary, most studies (32 of 55) tried to develop useful window behaviour models to support building performance simulation. Some studies (20 of 55) tried to better understand the driving factors of occupants’ window usage in office buildings. In these studies, some focused on environmental factors, e.g. outdoor temperature [26, 40] and wind speed [41], only, some focused on non-environmental factors, e.g. gender [42] and age [43], only, and some investigated both environmental and non-environmental factors [18, 44]. Additionally, one study aimed to verify the accuracy of a new data collection method, i.e. using cameras, to capture the state of windows [30]. Two other studies have collected window operational data, but their research aims are both not focusing on occupant behaviour, i.e. one's aim is to test the performance of a new window signalling system [4] and the other's aim is trying to connect occupants' adaptive behaviour and their neutral temperature [15].

Table 2. Research aims of engineering-based studies

Research aims		Number (Percentage)
To develop/improve the window behaviour models		32 (58%)
To better understand the driving factors of window behaviour	Environmental factors	6 (11%)
	Non-environmental factors	5 (9%)
	Both	9 (16%)
To justify new data collection method		1 (2%)
Others		2 (4%)
Total		55 (100%)

About data collection methods, engineering-based studies focused on both window state (open/close or angle) and relevant environmental parameters. Table 3 has listed the methods that have been used to collect these data. For recording window state, most researchers selected data loggers/sensors (e.g., magnetic induction devices [6], microswitches [45] and camera [30]); some adopted questionnaires (e.g. longitudinal questionnaire at monthly or weekly intervals [46], daily log at daily intervals [47, 48] and one-time questionnaire [49]), and observations (by a person [42] or by a team of researchers [50]). Environmental factors included both indoor (i.e. temperature, relative humidity, CO_2, air velocity, PM2.5, illuminance) and outdoor (i.e. temperature, rainfall, wind speed, relative humidity, solar radiation, air quality, precipitation and PM2.5) parameters and in existing studies they were measured by relevant sensors, such as using thermistor to measure temperature [42] and anemometer to measure air velocity [40]. For non-environmental factors, engineering-based studies focused mainly on those easy to collect and quantify, such as age and gender(using one-time questionnaires [14]), time of day and seasons (using sensors [51]). These non-environmental factors provide personal characteristics and environmental context of actual office users to support window behaviour model development.

Table 3. Data collection methods of engineering-based studies

Data Acquisition		Number (Percentage)
Window behaviour (window states/angle)	Data logger/Sensor	42 (76%)
	Questionnaire	12 (22%)
	Observation	2 (4%)
Environmental parameters	Sensor (indoor)	51 (93%)
	Weather station/meteorological sensor (outdoor)	42 (76%)
Non-environmental factors	Questionnaire	15 (27%)
	Observation	1 (2%)
Total		55 (100%)

About research findings, the engineering-based studies have identified many environmental factors that drive occupant window behaviour, such as indoor and outdoor air temperatures [25, 52, 53], air quality [26, 44], outdoor wind speed [41, 48] and solar radiation [19]. Additionally, some non-environmental factors, which are easy to quantity, have been suggested to be influential as well, including time of day [19], seasons [42, 44, 54] and age [43]. Based on these factors, many useful window behaviour models have been developed for both office buildings [27, 28, 46], to improve the accuracy of building performance simulation [55-57]. For example, Gu et al. [6] have proposed a new computational algorithm using binary logic, and this model has improved the prediction accuracy of the window opening by 5.9%. Zhou et al. [58] adopted a random forest algorithm in the modelling of window behaviour, and the method gave a model accuracy of up to 70%.

According to the above analysis, engineering-based studies often have explicit practicality. A most popular direction is to identify behaviour patterns and establish useful behavioural models [28, 55, 59-64]. Using these models, researchers can predict the impact of occupant behaviour on building performance [65, 66]. Other topics include identifying the driving factors behind occupant behaviour [44, 67-70], changing occupant behaviour for building performance optimisation [71-73] and improving behavioural monitoring methods [74].

2.2 Studies using social science method

From this review work, only three studies, that are based on social science method only, were found, and their aims are listed in Table 4. In existing studies, the social science method was applied to subjectively understand the relationship between occupant behaviour and major non-environmental factors, such as social and cultural background [32, 75], personality traits [75, 76], perceived control [32] and psychological considerations [75], which are difficult to be considered in engineering-based studies.

Table 4. Research aims of social science-based studies

Research Aim	Number (Percentage)
To better understand the driving factors of window behaviour – only non-environmental factors (i.e., social and culture background, perceived control, personality traits and psychological consideration)	3 (100%)
Total	3 (100%)

About data collection methods, window behavioural data have been collected by different methods, as listed in Table 5. It reflects that most studies adopted the methods popularly adopted in social science, such as interviews [32], questionnaires [75] and observations [32]. Although sensors have been adopted to collect behavioural data, only one study has used this method, and its main aim was to collect enough data to do quantitative analysis. The same as engineering-based studies, environmental parameters were popularly collected by sensors and non-environmental parameters were popularly collected by questionnaires. However, the main target information were users' social psychology [75] or their personality traits on behaviour patterns [75, 76]. Additionally, semi-structured interviews have been adopted as well to collect information about building users' perception of control elements [32].

Table 5. Data collection methods of social science-based studies

Data Collecting Methods		Number (Percentage)
Window behaviour	Questionnaire	1 (33%)
	Observation + interview	1 (33%)
	Sensor	1 (33%)
Environmental parameters	Sensor and weather station	1 (33%)
Non-environmental factors	Questionnaire	2 (66%)
	Daily log	1 (33%)
	Interview	1 (33%)

Total	3 (100%)

The findings from social science-based studies can be summarized as:

(1) personal factors, such as personal preference and personality traits, have significant impact on occupant window behaviour [75, 76];

(2) occupants' social and cultural background can affect occupants' behavioural decisions on window usage [32, 75];

(3) both perception of control elements and group dynamics are influential factors for occupants' window behaviours [75].

In summary, studies on window behaviour using social science method are devoted to exploring the influential factors beyond physical factors, which has significant implications to justifying the results from engineering-based studies.

2.3 Comparison between engineering-based and social science-based studies

From this review work, it was found that the window behaviour studies using engineering and social science methods are quite different in terms of their research aim, method and findings. For engineering-based studies, a majority (i.e. 58%) were aiming to develop/improve occupant behavioural models or building performance prediction, and 27% of studies aimed to understand the impact of environmental factors on window operation better. These aims are consistent with the nature of engineering [77, 78]. Unlike engineering research, which mainly focuses on physical environmental factors, social science-based research pays more attention to non-environmental factors, mainly personality traits [76], socio-cultural background [32, 75], and group dynamics (willingness to share control) [75], which were not commonly investigated in engineering-based studies.

In terms of data collection methods, engineering-based studies tend to collect behavioural data (i.e. window state) in real buildings mainly using electronic sensors [6, 25, 79]. Some researchers have also used daily logs [47], observation [42] and cameras [30]. For social science-based studies, the preferred methods include questionnaire survey [75], interview [32] and observation [32] to collect data about the drivers/influential factors of occupants' window operation.

Regarding research findings, engineering-based studies mainly revealed close correlation between window behaviour and relevant environmental factors, such as indoor and outdoor air temperatures [53], indoor air quality [26], outdoor wind speed [48], and solar radiation [19]. Using these influential factors, useful window behaviour models were developed to support building performance simulation [6, 58]. From social science-based studies, the impact from non-environmental factors, such as personality traits [76], group dynamics [75], social and cultural background [32], on window behaviour has been well justified. Additionally, using semi-structured interviews also helped to better understand the social interactions between occupants in multi-occupational space [32].

2.4 Combining engineering and social science methods

Due to the well-acknowledged complexity of occupant behaviour in buildings [13, 34], some researchers have tried to combine both engineering and social science methods, in order to get a more comprehensive understanding on occupant behaviour [13, 33-35]. This part will provide insights into the following two issues through an in-depth analysis of the selected studies:

(1) research direction or research aim of studies combining engineering and social science;

(2) the role of engineering and social science in the research.

In the sixty-six publications collected in this review work, eight studies (12%) have used both methods, and the contributions from both of them have been summarized in Table 6.

Table 6. The contributions of engineering and social science in research

Combination	
Engineering	**Social Science**
1.Develop/improve window behaviour modelling [80, 81]	1. Collect window behaviour related qualitative information to better understand the reasons behind window operation [5]
2.Quantitatively analysis of the factors studied (especially non-environmental factors) on window behaviour [5, 82]	2. To better explain the research results of engineering side [31, 83]
3. Collect continuous high-precision environmental parameters for quantitative analysis and modelling [5, 83, 84]	3. Guide the development and execution of subsequent quantitative research [84]
4. Collect window state (open/close or angle) for quantitative analysis and modelling [80, 81, 84]	

From Table 6, it could be found that the engineering part of the study was mainly to improve/develop window behaviour models by incorporating non-environmental factors such as number of people [81], occupants' subjective factors [1] and psychological considerations [80]. For this purpose, the studies require dynamic collection of many environmental parameters, e.g. temperature [5], air velocity [83] and relative humidity [82], as well as real-time window state [80, 81]. These data were used to quantitatively analyse the influence of potential factors on window-opening behaviour and were used to improve and develop window-opening behaviour models. Regarding the social science part, they focused on further exploring the influential factors by digging out the mechanisms and reasons behind them. Therefore, the social science part did not use sensors to record the state of the window, but instead using questionnaires [5, 83] and interviews (open-ended questions) [31, 84] to investigate the reasons behind the behaviour, such as personal values [84], perceived control [1], social cultural background [83] and other complex factors (hard-to-quantify). Additionally, the rich qualitative information collected by social science method can also be used to better explain the results from the engineering method [31] or guide the development of subsequent quantitative research tools to provide rich qualitative context (e.g., occupants' thermal preferences, control options, personal values) [84].

From the review work summarized in Table 6, another phenomenon that has been observed was that although researchers have already tried to combine engineering and social science methods, the contributions from each method are still relatively independent. The engineering section is usually only responsible for data processing and human behaviour modelling. In contrast, the social science section usually explores the mechanisms and reasons behind the window operating patterns or provides better explanations for the behaviour patterns found in engineering research. Therefore, the advantages of performing multidisciplinary studies cannot be fully reflected. The interdisciplinary framework proposed from IEA Annex66 [13] provides a solution. This framework aims to integrate social science insights into the study of occupant behaviour and provide innovative knowledge for stakeholders [85]. The framework, which combines the Drivers-Needs-Actions-Systems (DNAS) framework [86] with Social Cognitive theory [87] and Theory of Planned Behaviour [88], examines office environments and occupant behaviour primarily through an investigation based on building physics and social psychology [89]. In Brazil, Bavaresco et al. [1] implemented this framework into office occupant behaviour research to empirically assess the impact of multi-domain drivers on occupant behaviour (i.e., window use, blinds/shades, HVAC, and lighting use). Further studies may need to combine questionnaire application (subjective information) with indoor monitoring (objective data). Studies to more closely combine the data collected by the two research methods are still needed to be explored in future studies.

3 Conclusion

With the fundamental need to reduce the carbon impact of buildings to ease climate change, saving building energy consumption is urgent and essential, which is crucial to sustainable development. Among the factors affecting building energy consumption, occupants' behaviour, especially window operation, has captured great attention of researchers, as this behaviour will not only significantly affect the thermal performance of naturally ventilated buildings, but also their energy consumption level. Therefore, a better understanding about how occupants use their windows becomes critical for designing and operating buildings.

This paper has introduced results from a thorough review work on occupants' window behaviour in office buildings, focusing on the differences between studies adopted engineering methods and social sciences methods, in terms of their research aims, data collection methods, and research findings. In general, most existing studies on office window behaviour adopted engineering methods, although a broad consensus has been established that occupant behaviour is complex and requires the involvement of social science. To summarize, existing engineering-based studies mainly aimed to improve/develop window behaviour models to improve the accuracy of building performance simulation. The small number of social science-based studies aimed to explore the mechanisms and reasons behind the influence of various driving factors on occupants' window operation. There are some studies that have tried to combine engineering and social science methods to gain deeper understanding on occupants' window behaviour, but the link between the data collected by both methods was not well established. Therefore, future studies should consider closer cooperation between the engineering part and the social science part, based on an assumption that the complexity of occupant behaviour needs contribution from social science to gaining a better understanding and contribution from engineering to quantifying occupant behaviour to support building design and operation. This would be more important for multi-occupancy rooms, such as open offices, due to the potential interactions between room occupants.

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