A Key to Make Sustainable Buildings People Centric: User-environment Interactions

Citation for published version:
Goh, CS & Yang, KS 2022, A Key to Make Sustainable Buildings People Centric: User-environment Interactions. in *PAQS Congress 2022 Proceedings.* Singapore Institute of Surveyors and Valuers, pp. 97-105. <https://issuu.com/paqs2022/docs/congress_proceedings_-_paqs_2022/s/16796006>

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Early version, also known as pre-print

Published In:
PAQS Congress 2022 Proceedings

A Key to Make Sustainable Buildings People Centric: User-environment Interactions

Citation for published version:
Goh, CS & Yang, KS 2022, A Key to Make Sustainable Buildings People Centric: User-environment Interactions. in *PAQS Congress 2022 Proceedings.* Singapore Institute of Surveyors and Valuers, pp. 97-105. <https://issuu.com/paqs2022/docs/congress_proceedings_-_paqs_2022/s/16796006>

Published In:
PAQS Congress 2022 Proceedings

A Key to Make Sustainable Buildings People Centric: User-environment Interactions

Cheng Siew Goh (corresponding author), c.goh@hw.ac.uk
Heriot-Watt University Malaysia, Malaysia

Khai Sheng Yang, ky40@hw.ac.uk
Heriot-Watt University Malaysia, Malaysia

Abstract
Sustainable buildings are designed not only to reduce environmental impacts but also to promote health and wellbeing. A range of studies illustrated that user behaviours can significantly affect the performance of sustainable buildings in meeting the goals. Significant performance gaps are found if users fail to conform with the ways sustainable buildings are designed to. It is therefore critical to examine if the prevalent sustainable building solutions meet the evolving needs and expectations of people. This paper explored the relationships between users and environment in sustainable buildings and determine its user-environment interactions. A survey method was used to collect data from users of selected sustainable buildings. The results show that respondents generally agree sustainable building solutions can enable meaningful user-environment interactions and improve user satisfactions. User-environment interactions can be greatly promoted if users are provided an authority to adapt to changes in response to different building conditions and external factors. The findings however showed that there is a gap in existing sustainable building systems to capture the implications of users' behaviours on the building usage pattern in adaptation to its environment. The paper demonstrated the importance of examining user-environment interactions in sustainable buildings to advance the goals of sustainable development. With an improved understanding of user-environment interactions, a more people-centric approach can therefore be built into the development of sustainable buildings and unlock the next-level values of sustainable built environment.

Keywords
Sustainable buildings, people-centric, user-environment interactions. Up to five keywords, in lower case, alphabetical order, separated by commas, finishing with full-stop.

1 Introduction

The construction sector has been recognized as a main contributor to climate change and greenhouse gases emissions. According to United Nations (2019), approximately 28% of energy-related CO2 emissions are released from buildings. Following increased concerns over environmental issues and climate change, various sustainability initiatives has been launched regionally and globally. Net zero buildings and sustainable buildings are advocated as the building standards for new and existing building stocks to counteract the environmental impacts, thus driving sustainability transition into the construction industry. The benefits of sustainable buildings go beyond the environmental considerations. In addition to a reduction in energy consumption and carbon footprints, sustainable buildings also provide a better quality of living and promote health and wellbeing of people.

By incorporating sustainable design solutions that enhance the link of physical conditions of built environments with nature, sustainable buildings increase indoor environmental quality and improve occupants' health and well-being. Previous studies (Lee and Guerin, 2010; Liang et al., 2014) have demonstrated the values of sustainable buildings in ensuring a more pleasant indoor environment, assuring health and wellbeing of occupants, and increasing productivity and work efficiency. In a broader sense, sustainable buildings emphasise a holistic system approach of creating value chains along the life cycle by meeting the environmental challenges, assuring economic viability and developing the social capital.

Nevertheless, the quality and performance of sustainable buildings are not necessarily consistent. Increasing post-occupancy studies revealed lower performance in sustainable buildings than predicted. Newsham et al. (2009) revealed that around 28 - 35% of LEED buildings used more energy per floor area than their individually matched buildings in the 2003 Commercial Building Energy Consumption Survey database. On one hand, Goh also (2014) found some certified green buildings failed to deliver the desired sustainability goals during post occupancy stage, where wind turbine failed to harvest and generate wind energy as planned. On the other hand, Conniff (2017) also reported that refurbished green apartment buildings in Germany missed the predicted energy savings by 5 - 28%, while fifty leading-edge modern buildings in United Kingdom were reported to use up to 3.5 times more energy than the design had allowed for and produce approximate 3.8 times the predicted carbon emission.

The performance of sustainable buildings is strongly related to the management and operation strategies which require dynamic control and monitoring (Kern et al., 2016). An understanding of the roles of users in meeting the targets of sustainable buildings is called upon. Numerous research works have demonstrated that users' behaviours often play an important role in determining the effectiveness of building solutions (Kern et al., 2016; Macintosh and Steemers, 2005; Pisello, Piselli, and Cotana, 2015; Rebelo and Soares, 2022). A post-occupancy evaluation conducted by Macintosh and Steemers (2005) found that the building thermal efficiency solutions which optimises the balance of mechanical and natural ventilation have resulted in more energy use, due to the negligence of designers in considering the implications of users' behaviours and perceptions and the users' misunderstanding of building strategies. The effect of human attitudes on the efficacy of building system is also by acknowledged by Pisello *et al.* (2015) in which human behaviours overtake physical retrofits in the thermal energy efficacy. Rebelo and Soares (2022) also stressed that building characteristics are proven to be insufficient as determinants but user behaviours and socio-economic factors. Considerable performance gaps could be observed when users fail to conform with the ways sustainable buildings are designed to.

The significance of human factors as a function of the achievement of sustainable buildings is evidently illustrated. It is imperative to have a better understanding of user expectations, attitudes, perceptions, and behaviours by interrelating human factors with the physical performance of buildings (Rebelo and Soares 2022). However, human factors are not widely integrated into sustainable solutions of built environments. It is vital to move out of the "environmental thinking box" to assess the building sustainability. There is a clear need to understand user-environmental interactions to examine the capability of sustainable building solutions in meeting the evolving needs and expectations of people. To bridge the gaps, this paper explores the interrelationships between users and environment in sustainable buildings and examines user-environment interactions in affecting the building sustainability goals.

2 The Relationships Between Users and the Environment in Sustainable Buildings

Sustainable building solutions are designed based on the concept of active user participation for optimised building performance. The traditional consideration of regarding users as passive occupants fails to empower building users appropriate environmental control to support human activities and reduce energy consumptions in sustainable buildings. Users are expected to appreciate the values and functions of sustainable buildings, hence providing high commitments to achieve the goas of sustainable buildings.

To capture the relationships between users and the environment, understanding the users' perception and cognition is of importance. Gifford (2002) stated that building users often have their own environmental perceptions in which the data they received is reinterpreted based on how their knowledge is stored, transformed, organised, forgotten and recalled. Individuals and organisations have different concerns and expectations towards sustainable built environments and these specific concerns might affect their attitudes and behaviours during the building occupancy.

Identifying users' perceptions, cognition and expectations helps to improve the design and operation of sustainable building solutions. It takes into the account users' behaviours on the performance of sustainable buildings over the life cycle. The relationships between users and built environments change over time and there are diversified needs and expectations of users towards sustainable buildings. It is crucial to examine users' expectations, understanding and knowledge. According to Leaman and Bordass (2007), users would be more tolerant when sustainable buildings design (e.g. windows and thermostats) do not meet their expectations, since users fully appreciate the actual way of the systems or design work and their functionality. This is a manifestation of the importance of users' understanding and knowledge in contributing to optimized performance of sustainable buildings. Appropriate interventions incorporated in sustainable buildings can enhance user-environment interactions within the environments to align their initiatives to meeting the sustainability goals.

2.1 User-environment Interactions in Sustainable Buildings

Sustainable buildings integrate passive design strategies such as natural ventilation, natural sun light and thermal mass in the building systems to enhance the building occupants' comfort, while minimising environmental impacts. Any variations of the surrounding environment can directly influence the indoor environmental quality in sustainable buildings. An interactive building system is introduced to allow users to respond to changing conditions in the surroundings for meeting the required comfort and demands. Simple interventions can be done by giving access to users to manual controls of building systems, opening or closing of switches, adjustable curtains and windows, etc. Furthermore, users can also be empowered to be accounted for reducing water and energy consumption in sustainable buildings, with an integration of adjustable control in water and energy systems.

Sustainable solutions allow users to directly interact with the environment by using the control systems to adjust external environmental conditions based on their perceived needs. According to Cole *et al.* (2008), there is a conceptual shift to create a comfortable building environment by taking into consideration psychological, societal and users' behavioural perceptions. This shift allows designers of sustainable building to integrate more solutions allow direct user engagements and interactions. Brager and Dear (2000) described that natural ventilation of buildings should be more adaptive to suit different environmental conditions for users because naturally ventilated buildings have accounted to be more diverse in indoor temperatures compared to conventional air-conditioned buildings. Their findings suggest that advanced heat-balance models of thermal comfort should be proposed to allow a greater extent of user-environment interactions so that users can modify their behaviour and gradually adapt their expectation to match the environment.

One of the goals of sustainable buildings is to increase users' ability of resilience and adaptation to the climate change. Rather than emphasising on uniformity of building performance, a dynamic demand-control based building system is often necessitated in sustainable buildings. This shifts the way buildings used to perform by emhasising on dynamic interactions between users and environments. Varying behavioural aspects are considered in sustainable building design to allow users creating contextualized environmental conditions that suit to their needs.

Engaging and empowering users the control of space is important for their habitual occupation, physical safety and psychological wellbeing. User behaviours are shaped by designers as users are required to make some changes to adapt themselves to environments. If the building system drives a change in users' habitual actions or methods, users would feel intruded due to a loss of personal space or freedom. According to Motalebi (2006), the socialisation process makes individuals learn certain behaviours on the way they use specific spaces and react to stimuli of the environment. Hence, individuals usually behave based on their definition of the events, stimuli and spaces in accordance with the cultural value of their environment.

Improved sustainability performance can be achieved with proper architecture, interior design and space planning strategies by understanding environmental psychology of users. In order to identify sustainable building users' needs during the design phase. Behavioural social sciences in environmental design help to align sustainable building projects with current societal tendencies but also to predict future aspects of the sustainable design for future development. The users' behavioural aspects have to be taken into account along with the environmental consideration. According to Motalebi (2003), this information must be emphasised and transformed from the social scientific terminologies to the languages of design. Sustainable buildings should be designed in a way of creating an environment that can communicate with its users and reflect the users' needs. The bilateral relationship between users and the sustainable built environment is of importance as the physical environment often brings numerous effects to building users' who are constantly contacting it and influencing their behaviours.

The incorporation of Information and Communication Technology (ICT) in sustainable buildings helps to promote the relationship between users and the environment. ICT can act as a transformation tool of encourage societal aspects in sustainable buildings. ICT provide ease to users to control the physical environment by using remote control, monitoring devices and teleservices. This increases the conscious of building users to adopt more environmentally friendly behaviours and attitudes that cater for a wide range of user needs in operating sustainable buildings.

Interactive building solutions offer an opportunity for the users to control their environmental footprint and change their behaviours in responding to the environmental targets of sustainable buildings. An interactive display of up-to-date building achievements on energy consumption and carbon footprint would make the environmental efforts visible to users. Energy information and feedback in sustainable building solutions present an opportunity to building users to make necessary adjustments to the environment by changing their behaviours and attitudes in using the buildings. Building information systems, instructional signage and experiential building systems including smart real-time web-based feedback, kiosks, metres, etc allow building users to easily understand and take control of sustainable buildings performance. In Petersen et al. (2007)'s study, Oberlin College in Ohio has introduced an automated data monitoring system in their hall of residence to allow the building users to check on their energy and water usage. This real-time feedback has resulted in a reduction of electricity consumption by 55% as compared to the implementation of conventional metre readers. This has shown that interactive building solutions can involve users in a more active interaction with the environment by making necessary adjustments to the physical conditions for the environmental performance goals.

3 Methodology

This section presents the methodology of a survey study that includes 1) the survey design and 2) the process of data collection and results interprtations. Because the study aims to investigate the user perceptions and their interatons in sustainable buildings, the study invited users of two selected sustainable buildings to participate in the survey. Both buildings are certifed green buildings by Green Buildng Index, Malaysia.

3.1 Questionnaire design

A survey was developed to collect data from users of selected sustainable buildings. There were two sections in the survey. Section 1 was structured to gather the demographic information of respondents including their background and experience in respective sustainable buildings. Section 2 solicited data to determine the extent to which users-environment interactions are captured in sustainable buildings. A five-point Likert scale was used to investigate the level of agreement of users to the described scenario or statements, where the lowest scale indicated strong disagreement and the highest scale show strong agreement.

3.2 Data collection

Because of practicality, free of access and universal accessibility, a web-based questionnaire, Google Form was chosen. Data collection took about 4 weeks in the period from February to March 2022. The survey was distributed to 100 respondents using emails and 41 responses were received. This gives to the response rate of 41% which is considered satisfactory for a sample more than 45 respondents. According to ASHRAE (2013), the response rate must be higher than 35% for samples of more than 45 respondents.

4 Findings and Discussion

Frequency distribution analysis was used to identify the user-environment interactions in sustainable buildings and to determine a rank order based on the mean values of the scores. The typical duration of occupying sustainable buildings was investigated. The durations could have an impact, directly and indirectly, on the user perceptions, attitudes and behaviours in sustainable buildings.

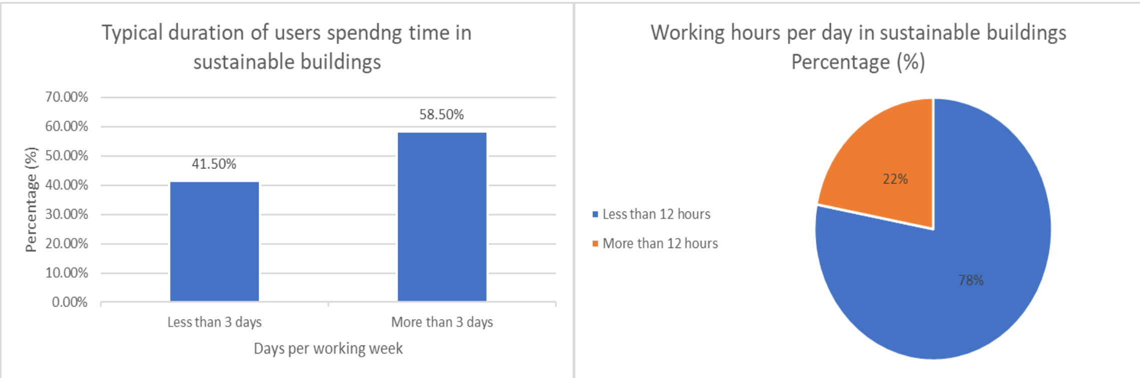

Figure 1. Typical duration of users spending time in sustainable buildings in terms of day per working week and hours per day.

More than half of the respondents (58.5%) spent more than 3 days in a week while around 41.50% respondents spent less than 3 days. The results indicated that there is change of user' usage pattern in sustainable buildings following the COVID-19 pandemic outbreak. Data was collected in during the recovery period of COVID-19 and some organisations may not resume to 100% physical work condition as it was before the pandemic. Majority respondents. (78%) spent less than 12 hours in sustainable buildings in a day.

Figure 2 presents the extent of agreement of user-environment interactions provided in sustainable buildings. From the results, majority respondents (88%) agree or strongly agree that sustainable building solutions enable meaningful user-environment interactions and improve user satisfactions. As illustrated in Table 1, it obtained a mean value of 4.07 with the standard deviation of 0.755. User-environment interactions can generally be promoted in sustainable buildings since users are given opportunities to adapt to changes in response to different building conditions and external factors.

Sustainable buildings can allow users interact with the physical environment by giving them the control over lighting, ventilation and thermal comfort systems. Control over lighting systems was rated highly with an average score of 4.15, followed by ventilation systems (3.88) and thermal comfort systems (3.85). Over 80% users agreed that the presence of appropriate lighting control in sustainable buildings enable them to align the physical environment to their lighting needs. As compared to the lighting control, ventilation and thermal comfort systems do not gain wide agreements among users in which 73% and 68% agreed to have adequate control to interact with the building ventilation and thermal comfort systems. The findings can be linked to the adoption of centralized air conditioning systems in sustainable buildings for energy efficiency purposes. The centralized air conditioning system has removed some controls from end-user interfaces, thus resulting in lower user engagement. Embarking on the adaptive comfort theory, the thermal comfort level varies from one person to another. The changeable parameters with no fixed comfort levels could set more challenges in identifying preferred level of thermal comfort.

There is a lower level of agreement that sustainable buildings provide clear instructions to users to operate and manage the buildings, with a mean value of 3.76. Around 61% respondents agreed that sustainable buildings promote user experience without triggering forced adaptive responses. A blend of automatic and manual systems in sustainable buildings scored a mean value of 3.76 with a standard deviation of 0.94. The findings suggested that there could be a gap in existing sustainable building systems to capture the implications of users' behaviours on the building usage pattern in adaptation to its environment. Only 56% respondents agreed sustainable buildings capture and display usage data to promote environmental behaviour. Up-to-date building performance may not be captured and communicated effectively to users as it was rated the lowest with a mean score of 3.63.

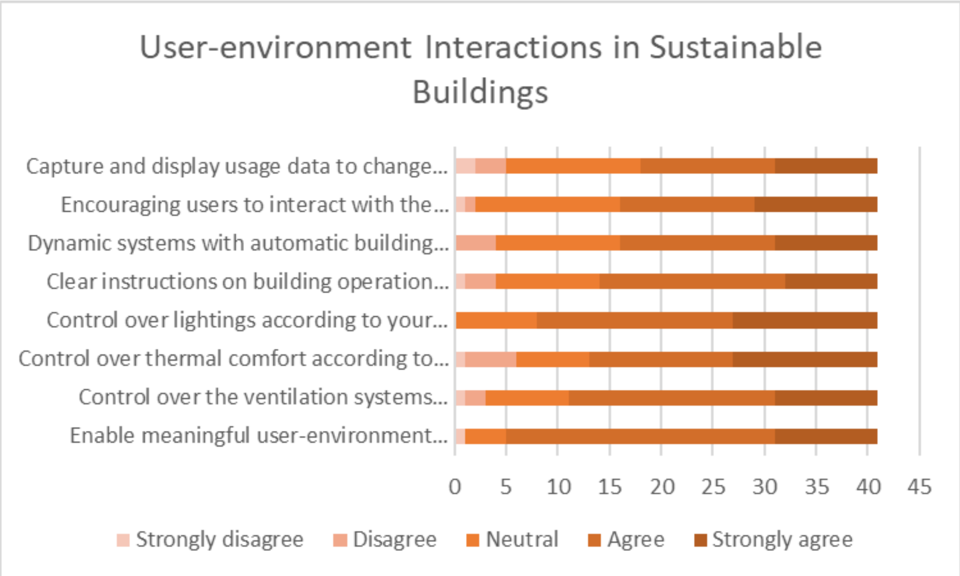

Figure 2. User-environement interactions perceived by users in sustainable buildings

Table 1. Mean values and standard deviations of user-environmental interactions in sustainable buildings

	Mean	Standard Deviation
Enable meaningful user-environment interactions	4.07	0.755
Control over ventilation systems according to needs	3.88	0.927
Control over thermal comfort according to needs	3.85	1.108
Control over lightings according to needs	4.15	0.727

Clear instructions on building operation and management	3.76	0.969
Dynamic systems with automatic building systems and an appropriate level of demand control	3.76	0.943
Encouraging users to interact with the environment without forced adaptative mechanisms	3.83	0.972
Capture and display usage data to change environmental behaviour	3.63	1.09

Differences in human factors need to be acknowledged in sustainable buildings needs to be acknowledged in the very early stage of building life cycle. Capturing the users' interactions and perceptions with the physical environments can be made via people centric approaches. A people-centric approach is a holistic method that emphasise the understanding of human factors and their interactions with building systems to maximise human wellbeing and overall system performance in sustainable buildings. Taking people-centric approach, it optimises the ability of sustainable built environment to harmonise with surrounding environments through sensory design for improved user-environment interactions. In response to a dynamically changing environment, users tend to maintain the surrounding environments in a homeostatic condition to provide a good level of comfort, wellbeing and health.

5 Conclusions

The paper demonstrated the importance of examining user-environment interactions in sustainable buildings to advance the goals of sustainable development. With an improved understanding of user-environment interactions, a more people-centric approach can therefore be built into the development of sustainable buildings and unlock the next-level values of sustainable built environment.

6 Acknowledgement

The work is supported by School of Geoscience, Engineering, Infrastructure and Society (EGIS), Heriot-Watt University Malaysia under the EmGRS 2021/2022 Project "Optimising the Performance of Sustainable Buildings via Human-centric Design".

7 References

ASHRAE. 2013. *ANSI/ASHRAE Standard 55-2013, Thermal environmental conditions for human occupancy*. American Society of Heating. Refrigerating and Air-Conditioning Engineers, Inc.

Cole, R. J., Robinson, J., Brown, Z., & O'shea, M., 2013. Re-contextualizing the notion of comfort. In *Comfort in a Lower Carbon Society* (pp. 25-38). Routledge.

Gifford, R., 2007. Environmental Psychology: Principles and practice. Allyn and Bacon, Boston.

Goh, C. S., 2014. Development of a capability maturity model for sustainable construction. *HKU Theses Online (HKUTO)*.

Kern, A. P., Antoniolli, C. B., Wander, P. R., Mancio, M., & González, M. A. S., 2016. Energy and water consumption during the post-occupancy phase and the users' perception of a commercial building certified by Leadership in Energy and Environmental Design (LEED). *Journal of Cleaner Production*, *133*, 826-834.

Leaman, A., & Bordass, B., 2007. Are users more tolerant of 'green'buildings?. *Building Research & Information*, *35*(6), 662-673.

Lee, Y. S., and Guerin, D. A., 2010. Indoor environmental quality differences between office types in LEED-certified buildings in the US. *Building and Environment*, *45*(5), 1104-1112.

Liang, H. H., Chen, C. P., Hwang, R. L., Shih, W. M., Lo, S. C., and Liao, H. Y., 2014. Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan. *Building and Environment*, *72*, 232-242.

Macintosh, A. and Steemers, K., 2005. Ventilation strategies for urban housing: Lessons from a PoE case study, *Building Research and Information*, 33(1), pp. 17-31. doi: 10.1080/0961321042000322771.

Motalebi, G. H., 2003. Environmental Psychology, a new knowledge for architecture and urban design. *Journal of fine arts. University of Tehran publication*, (10), 65.

Newsham, G. R., Mancini, S., & Birt, B. J., 2009. Do LEED-certified buildings save energy? Yes, but…. *Energy and Buildings*, Vol *41* Issue 8, pp 897-905.

Pisello A.L., Piselli, C. and Cotana, F., 2015. Influence of human behavior on cool roof effect for summer cooling, *Building and Environment*, 88(2015), pp. 116-128. doi: 10.1016/j.buildenv.2014.09.025.

Rebelo, F., & Soares, M. (Eds.)., 2022. *Advances in ergonomics in design, usability & special populations: Part II*. AHFE International (USA).