BRIDGING THE GAP IN GREEN BUILDING RESEARCH: THE ROLE OF POST OCCUPANCY EVALUATION

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Abstract. The building sector has contributed to reducing carbon emissions and energy consumption by implementing green buildings in the last decade. Green building performance evaluation studies can be evidence to the community about the advantages of implementing sustainability concepts in the building sector, such as through Post Occupancy Evaluation (POE). Several POE studies have been conducted to measure building performance. Nevertheless, only a few literature studies about POE specifically for Green Building. Thus, this study aims to conduct a review about POE in green buildings literature, to 1) identify the prominent institutions, countries, publishers, authors, and keywords of this topic; 2) identify the gaps in building types, and green building standards of this research topic; 3) identify green building standards, building types, countries, POE purposes, indicators, and analysis methods used of selected articles. This article's method uses bibliometric and scientometric analysis using VOSviewer, a database set from Scopus. The data uses 116 articles, 249 institutions, 27 countries, 48 sources, 326 authors, and 897 keywords related to POE studies in green buildings. The findings from this research will be useful for practitioners interested in improving the quality of green building standards.

Key words: green buildings, indoor environmental quality, occupancy survey, occupancy satisfaction.

1. Introduction

There are more than 42 green building assessments in the world that have been identified as being used in high-density cities, including Leadership in Energy and Environmental Design (LEED), Green Star, Building Research Establishment Environmental

Assessment Method (BREEAM), Green Building Index (GBI), German Sustainable Building Council (DGNB) rating system (Pan *et al.,* 2022). Several studies reveal the advantages of green building implementation (Addy *et al.,* 2022; Sarireh, 2021). In general, green buildings offer better environmental benefits in saving energy, water, materials, and land resources compared to traditional buildings (Zhou *et al.,* 2022). Green buildings also offer economic benefits throughout their entire life cycle (Dwaikat and Ali, 2018). The environmental and economic benefits are sufficient to cover the additional costs of building green construction (Zhao *et al.,* 2022). In addition, green buildings also offer a better healthy environment (Balaban and Puppim de Oliveira, 2017).

Despite these benefits, the design of green buildings does not automatically guarantee the well-being and comfort of its residents (Al horr *et al.,* 2016). Thus, surveys of the residents can be used to subjectively evaluate the performance of green buildings related to the Indoor Environment Quality (IEQ) criteria claimed, such as in LEED (Altomonte and Schiavon, 2013; Hua *et al.*, 2014; Wilder *et al.,* 2019; Vosoughkhosravi *et al.,* 2022), Green Mark (Cheung *et al.,* 2021), and also related to IEQ parameters that are not assessed at the time of conducting green building certification as in the Excellence in Design for Greater Efficiencies (EDGE) assessment standard (Agyekum *et al.,* 2023). The EDGE standards evaluate only quantifiable green building parameters such as energy savings, water savings, and embodied carbon in materials. The EDGE green building software covers several building types, including office, residential (houses, flats/apartments), hospitality (hotels, serviced apartments, resorts), retail (shopping malls, department store, supermarket, small food retail, and non-food big box retail), light industry, warehouse, healthcare facilities (including hospitals, nursing homes, clinics, dental hospitals), and education facilities (including pre-schools, schools, universities) (IFC, 2019, 2021). Therefore, EDGE does not assess the quality of indoor environment indicators.

The indicator of IEQ and its effect on the well-being and comfort of residents is an important area of study because there is a complexity of the relationship between the IEQ parameters of occupant comfort in green buildings (Al horr *et al.,* 2016). Nevertheless, the actual IEQ conditions of green buildings in some countries cannot be compared due to differences in design and implementation criteria at the operational stage as well as socioeconomic background (Laiche *et al,* 2021; Geng *et al,* 2019).

Topics commonly discussed in IEQ field study are sick building syndrome and well-being, Indoor Air Quality (IAQ), thermal comfort, acoustic comfort, and visual comfort (Wilder *et al.*, 2019; Al horr *et al.,* 2016). Meanwhile, the POE approach can be used to evaluate the performance of buildings during the operational period that have been occupied for at least several years (Li *et al.,* 2018) and to understand the effectiveness of building design (Ye *et al.,* 2022). Optimizing the POE approach requires long-term and continuity because the operational stage of the building uses the longest time in its entire life cycle. Therefore, it has great potential in energy saving and provides optimum IEQ (Jiang *et al.,* 2022). In general, the purpose of the POE is to evaluate design, technology, energy performance, user satisfaction, user behavior, IEQ, building facilities, develop POE methods and standards, and model validation (Li *et al.,* 2018).

Several studies have been conducted to evaluate the actual IEQ condition of green buildings that can affect the perception and satisfaction of residents (Liang *et al.,* 2014; Leder *et al.,* 2016; Cheung *et al.,* 2021). The factors to assess occupant satisfaction in buildings related to IEQ are air quality, lighting, noise, and thermal comfort, with additional parameters related to design and building management including health, aesthetics, furniture, cleanliness, productivity, needs, maintenance, environmental control, image, and easiness interaction with co-workers (Khoshbakht *et al.,* 2018; Laiche *et al.,* 2021).

Research in green buildings also uses surveys to subjectively assess the performance of buildings that are not related to IEQ in the assessment of green buildings, including aspects of satisfaction with office type, spatial layout, distance from windows, building size, gender, age, type of work, time spent in the office, and duration of working hours (Schiavon and Altomonte, 2014). Another non IEQ aspect was also conducted to find out demographic info, namely gender, age, duration of employees in the workspace and type of office space, although this data was only used by researchers as a description of the background of respondents in buildings that adopted green building concept (Agyekum *et al.,* 2023). In addition, the POE is also used to assess the performance of operating costs and spatial in green residential buildings (Olanrewaju and Chong, 2021).

Although there have been many studies on POE, not much literatures are systematically based on the specific typology of the research objectives (Li *et al.,* 2018). Until now, there has been no consensus on the subjective measurement of occupant satisfaction with green buildings (Li Y. *et al.,* 2022). In fact, for decades the design of green buildings has attracted the interest of developers in the construction sector (Geng *et al.,* 2019; Khoshbakht *et al.,* 2018). Meanwhile, IEQ and the adaptability of a livable environment have not been the main topics in the current ranking system, even though the IEQ issue emerged strongly during the Covid-19 pandemic and has become a priority (Ascione *et al.,* 2022).

To increase the positive trend of green building application, it is necessary to evaluate the studies to be carried out in this field, especially related to the POE in green building literature.

This literature study aims to analyze bibliometric and scientometric data from POE on green building studies and look for common threads with observed parameters and analysis methods used. The scientometric approach has been used in various studies to visualize the structure of knowledge in their respective fields (Darko *et al.,* 2019; Jiang *et al.,* 2022).

Specifically, this study aims to 1) identify the prominent institutions, countries, sources, authors, and keywords of this topic; 2) identify the gaps in building types, and green building standards of this topic; 3) identify the most influence research articles and identify green building standards, building types, countries, the POE purposes, indicators, analysis methods used in the POE of green buildings researches.

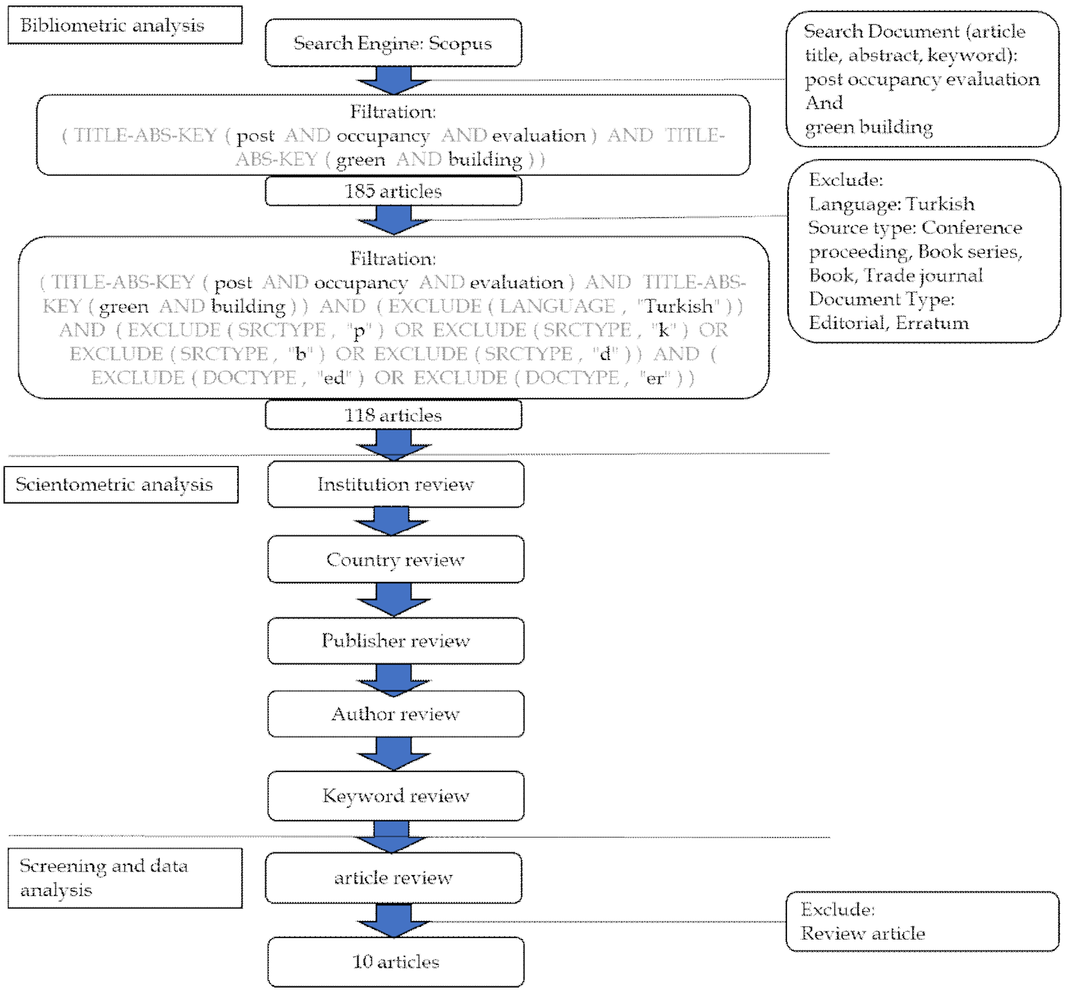

Fig. 1. Stages of literature review for analyzing the topic of POE in green building publications.

2. Materials and methods

This literature review aims to investigate POE on the indicators used in green building case studies. The research method uses science mapping with the first two steps the same way as Umeokafor *et al.* (2022), bibliometric analysis taken from the Scopus database, and scientometric analysis using VOSViewer software version 1.6.20. The scientometric approach has been used in various studies to visualize the structure of knowledge in their respective fields, including green buildings (Darko *et al.*, 2019), IEQ and indexing model (Roumi *et al.*, 2022), post-occupancy evaluation (Jiang *et al.*, 2022), and green construction (Luo *et al.*, 2022). The stages of the literature review can be seen in Fig. 1.

2.1. Bibliometric analysis

A bibliometric study uses an internet database to assess and gain insights into global research trends from a specific topic (Kamaruzzaman *et al.*, 2022). With large data collection from scientific publications and science mapping tools, it is possible to create clear visual representations of complex structures for statistical analysis and interactive data exploration (Pierpaoli and Ruello, 2018).
This article uses bibliographic data from the Scopus database. Compared to the Web of Science (WOS), Scopus has more journals covered (Chadegani *et al.*, 2013; Powell and Peterson, 2017) and Scopus is shown to have a higher author h-index (Powell and Peterson, 2017). By using Scopus, document search focused on

article title, abstract, and keyword, with search words (TITLE-ABS-KEY (post AND occupancy AND evaluation) AND TITLE-ABS-KEY (green AND building)), data is accessed as of March 10, 2024. The result shows 185. Furthermore, this research is limited to articles published in English, similar to previous research (Jin *et al.*, 2019), excluding editorial and errata to maintain a focus on the substantive research contribution within the dataset. Conference papers are not included in the sample because those are published in larger numbers than journal articles, however, those contain less meaningful or practical information and have a low citation count (Butler and Visser, 2006). Therefore, 116 documents were obtained from the Scopus database.

2.2. Scientometric analysis

VOSviewer software facilitates the generation of author maps through citation analysis, the creation of journal and organization maps via co-authorship analysis of documents (Umeokafor *et al.,* 2022), and the creation of keyword maps from co-occurrence (Van Eck and Waltman, 2010). This tool features an interface that support an in-depth analysis of bibliometric map, including zoom, scroll, and search functions, enabling detailed examination of the map. Particularly, VOSviewer's visualization capabilities are most effective for maps encompassing a relatively significant number of elements, ideally over 100 items (Van Eck and Waltman, 2010).

In exploring the interaction among the POE topics in green building research, the analysis of all articles reveals a quantitative interaction pattern. VOSviewer is useful in visualizing this network relationship by extracting citation data. The second phase of this methodology involves a bibliometric analysis using VOSviewer software to examine the contributions of institutions and countries, identify journals with high activity levels in publishing relevant articles, highlighting productive authors, observing frequently used keywords, and uncover research gaps, particularly concerning building types and green building standards within this topic.

2.3. Screening process and data analysis

This phase involves identifying the 10 most influential research articles on this topic specifically excluding review articles. The data and insight extracted from these selected works, which align with the thematic criteria, are subsequently subjected to a detailed analysis. This step is for achieving the third research objective: identify green building standards, building types, countries, the POE purposes, indicators, and methods used in conducting POE within green building research.

3. Results and discussions

The analysis conducted using VOSviewer's on POE in green buildings generated data from a comprehensive review: 116 articles were identified, involving 249 institutions and 326 authors across 27 countries, with contributions published in 48 different journals. This dataset, as summarized in Table 1, also encompassed a total of 897 keywords, illustrating the broad scope and diverse interest within the field of POE applied to green buildings.

Table 1. Main Info from VOSviewer analysis.

Analysis	Count	Type of Analysis
Documents	116	Citation
Institutions	249	Citation
Countries	27	Citation
Sources	48	Citation
Authors	326	Citation
Keywords	897	Co-occurrence, All keywords

Fig. 2 presents the publication trend in the POE of green building studies, highlighting an absence of research publications before 1999. Even though the use of the POE term was initially recorded in a 1975 study (Li *et al.,* 2018), the concept of green buildings emerged in the literature starting with a 1990 study (Darko *et al.,* 2019). Meanwhile, the first publication using "post-occupancy evaluation" term, related to the performance of green buildings was found in the abstract entitled "the green building challenge in the UK", through the journal Building Research & Information in 1999 (Curwell *et al.,* 1999).

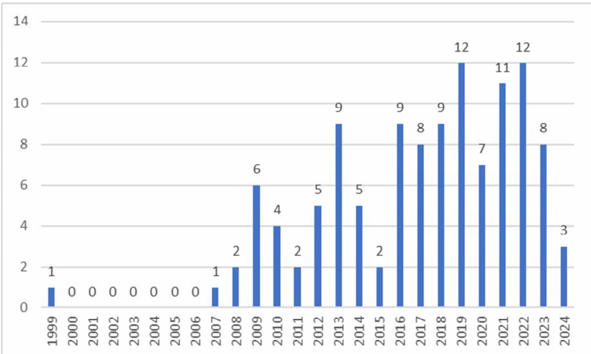

Fig. 2. The number of articles in the POE of green building journals from 1999 to 2024.

The graph (Fig. 2) indicates that the integration of POE within the green building research commenced in 1999, with a notable gap in publications of this topic from 2000 to 2006. Subsequenlty, there was an observable increase in publication from 2009, with six documents, peaking in 2019 and 2022, each with twelve documents. However, notable decrease was observed in 2011 and 2015, each with only two publications. As of the first semester of 2024, the time when this article was being prepared, three articles have already been published, suggesting an anticipation of further growth in publications by the end of the year. This trend underscores the evolving interest and emphasis on POE within the context of green building studies over the past decades.

3.1. Institution analysis

A co-authorship analysis of VOSviewer is used to identify the most productive institution in this topic, obtaining 249 institutions. By setting a minimum of 2 articles, Table 2 shows the top 9 institutions that produce the highest number of POE on green building articles.

Table 2. The most productive institution.

No	Institution	Articles	Citations	Country
1	Department of Building Science, Tsinghua University	4	374	China
2	Key Laboratory of Eco Planning & Green Building, Ministry of Education, Tsinghua University	3	263	China
3	Beijing key laboratory of IAQ evaluation and control, Tsinghua University	2	212	China
4	School of Civil Engineering and Transportation, South China University of Technology	2	69	China
5	State Key Laboratory of Subtropical Building Science, South China University of Technology	2	69	China
6	Australia-China Relations Institute, University of Technology Sydney	2	28	Australia
7	Energy Studies Institute, National University of Singapore	2	28	Singapore
8	China Merchant Shekou Holdings Northeast Corporation	2	24	China
9	School of Architecture & Fine Art, Dalian University of Technology	2	24	China

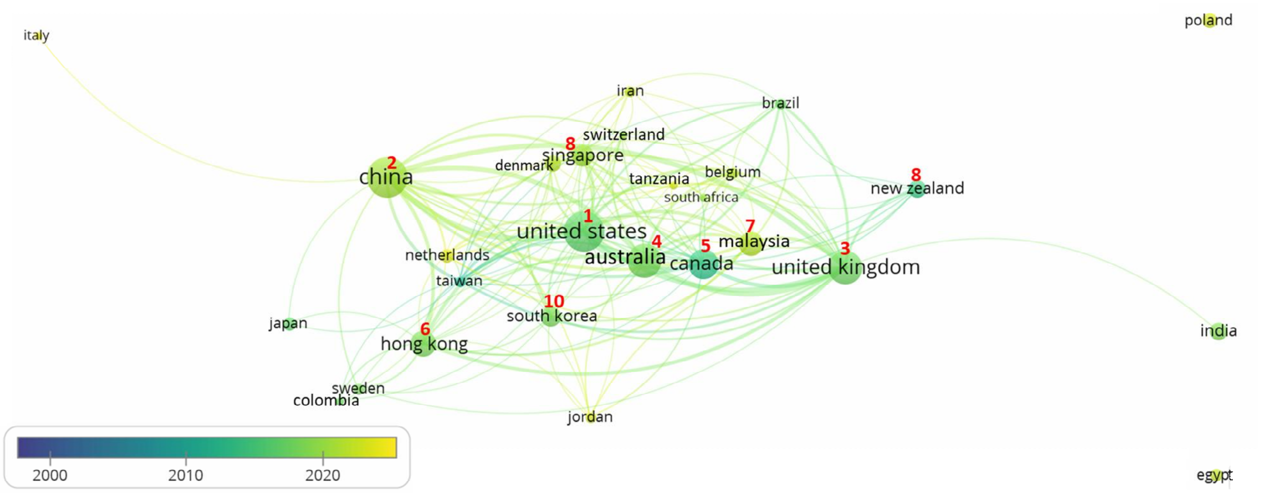

Fig. 3. Overlay visualization of countries map.

The University of Tsinghua from China ranks in the top 3 institutions with the most publications and total citations, represented by the Department of Building Science (4 articles, 374 citations), the Key Laboratory of Eco Planning and Green building, the Ministry of Education (3 articles, 263 citations), and the Beijing Key Laboratory of IAQ Evaluation and Control (3 articles, 212 citations). Following by the South China University of Technology in 4th and 5th rank, occupied by School of Civil Engineering and Transportation, and the State Key Laboratory of Subtropical Building Science, each producing 2 articles with 69 citations.

Furthermore, ranked 6th to 9th for institution producing publications are the Australia-China Relations Institute at University of Technology Sydney, Australia (28 citations), Energy Studies Institute at the National University of Singapore (28 citations), China Merchant Shekou Holdings Northeast Corporation China (24 citations), and the School of Architecture and Fine Art from Dailan University of Tehcnology in China (24 citations).

3.2. Country analysis

Country analysis in bibliometric study aims to identify and visualize the geographical distribution of research output (Pierpaoli and Ruello, 2018). In terms of publication, Fig. 3 and Table 3 show 27 countries have contributed in the POE of green building studies. The top 10 contributing countries are, in order, the United States (US) leading, followed by China, England, Australia, Canada, Hong Kong, Malaysia, Singapore, New Zealand, and South Korea.

These results are nearly parallel to bibliometric study on the topic of IEQ for the period 1990 to 2018 conducted by Pierpaoli and Ruello (2018). Their study recorded the 10 most productive countries as, firstly, the US, followed by China, England, Canada, South Korea, Italy, France, Germany, Denmark, and Australia, indicates that European countries dominated IEQ publications for the period 1990 to 2018. Whereas POE topic publication on green building for the period 1999 to 2024 were dominantly by countries in Asia (10), such as China, Hong Kong, Malaysia, Singapore, South Korea, India, Japan, Taiwan, Jordan, and Iran, followed by countries in Europe (8), Africa (3), North America (2), South America (2), Oceania (2). Although the studies were conducted on different topics and time frames, both contributed to the context of the built environment studies, thereby indicating an increasing attention from Asian countries.

Table 3. The list of countries in terms of publications within the POE in green building studies.

	Country	Articles	% of 116	Continent
1	United States (US)	24	20.69%	North America
2	China	24	20.69%	Asia
3	United Kingdom (England)	17	14.66%	Europe
4	Australia	17	14.66%	Oceania
5	Canada	13	11.21%	North America
6	Hong Kong	10	8.62%	Asia
7	Malaysia	9	7.76%	Asia
8	Singapore	7	6.03%	Asia
9	New Zealand	6	5.17%	Oceania
10	South Korea	5	4.31%	Asia
11	India	5	4.31%	Asia
12	Denmark	4	3.45%	Europe
13	Japan	3	2.59%	Asia
14	Poland	3	2.59%	Europe
15	Netherland	3	2.59%	Europe
16	Brazil	2	1.72%	South America
17	Taiwan	2	1.72%	Asia
18	Belgium	2	1.72%	Europe
19	Jordan	2	1.72%	Asia
20	Sweden	2	1.72%	Europe
21	Iran	2	1.72%	Asia
22	Eqypt	2	1.72%	Africa
23	Colombia	1	0.86%	South America
24	Switzerland	1	0.86%	Europe
25	Tanzania	1	0.86%	Africa
26	South Africa	1	0.86%	Africa
27	Italy	1	0.86%	Europe

This finding reveals that in terms of publication on POE in green building, it has seen contributions from 27 countries, signaling a call to action for countries yet to engage in this area to start contributing and thereby enhance the body of research on this subject. This opens opportunities to other Asian countries, especially emerging countries, such as Indonesia, Vietnam, Thailand, the Philippines, Brunei Darussalam, Cambodia, and Laos, to contribute case studies from their respective countries to enrich scholarly work in this field.

3.3. Source analysis

Citation analysis from VOSviewer facilitated the visualization of network interactions highlighting the most active and impactful journals within the topic of the POE in green building studies. Out of a total of 48 journals analyzed, the largest set of connected journals comprised of 32 journals (Fig. 4).

In Fig. 4 illustrates that the size of each node represents the quantity of documents published by the journal, with larger nodes indicating a higher number of publications. This reveals that Building and Environment is the most active among the top ten active journals listed in Table 4, owing its highest number of publications (15.52% of total 116 publications). Followed by Building Research and Information, and Sustainability (Switzerland), each accounting for 8.62% of the total documents on this topic, the Journal of Green Building (6.90%), Energy and Buildings (6.03%), Facilities (4.31%), and Indoor and Built Environment (3.45%). The other three journals ranked at the bottom, each contributing 2.59%, are Buildings, Intelligent Buildings International, and the Journal of Building Engineering.

Table 4. The ten of most active journals.

No	Country	Articles	% of 116
1	Building and Environment	18	15.52%
2	Building Research and Information	10	8.62%
3	Sustainability (Switzerland)	10	8.62%
4	Journal of Green Building	8	6.90%
5	Energy and Buildings	7	6.03%
6	Facilities	5	4.31%
7	Indoor Air and Built Environment	4	3.45%
8	Buildings	3	2.59%
9	Intelligent Buildings International	3	2.59%
10	Journal of Building Engineering	3	2.59%

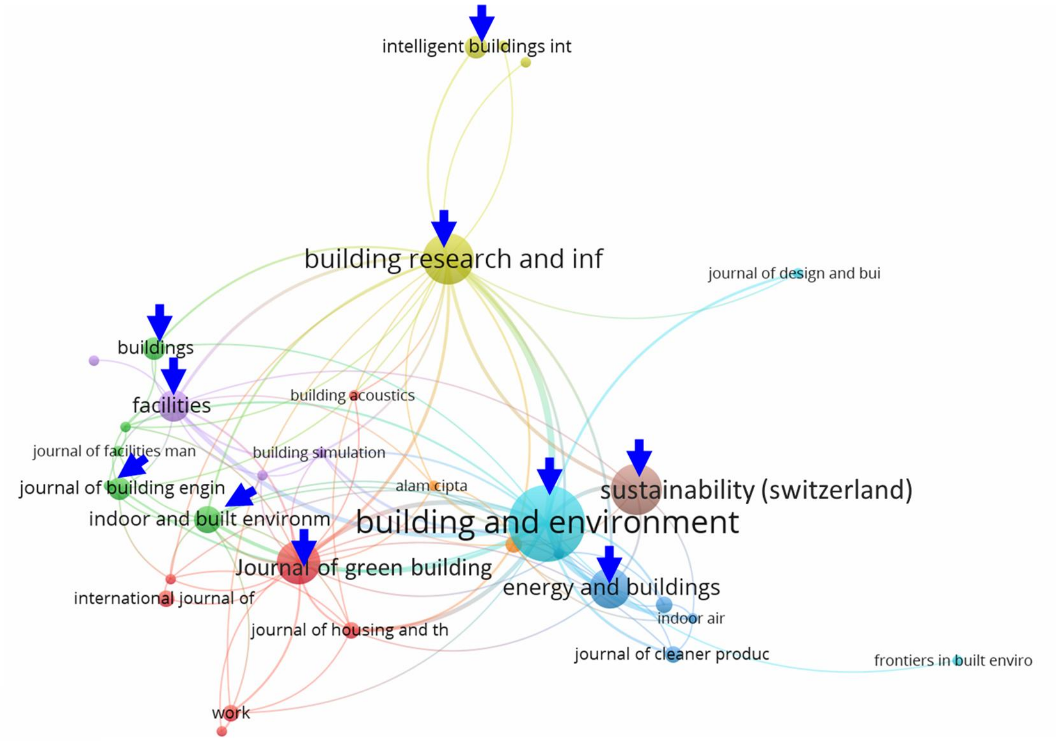

Fig. 4. The ten of most active journals within the network of 32 interconnected journals.

3.4. Author analysis

The quantity of publications by authors can provide insight to investigate new ideas in a particular field (Roumi *et al.*, 2022). Citation analysis from VOSviewer reveals a total of 326 authors have involved within the topic of the POE in green building studies.

Table 5. The most active and productive authors of the articles on POE in green building.

No.	Authors	Articles	Contribution score
1	Lin, Borong	4	0,88
2	Zhu, Yingxin	4	0,49
3	Cole, Raymond J.	4	1,89
4	Baird, George	3	1,81
5	Gou, Zhonghua	3	1,54
6	Hedge, Alan	3	1,47
7	Newsham, Guy R.	3	1,08
8	Schiavon, Stefano	3	0,96
9	Wang, Zhe	3	0,61
10	Mancini, Sandra	3	0,46
11	Lau, Stephem Siu-Yu	3	0,57
12	Tham, Kwok Wai	3	0,28

Table 5 shows that among twelve most productive authors, Borong Lin, Yingxin Zhu, Raymond J. Cole, contributed the highest number of articles, with four each, while nine other authors in Table 5 each produced three articles on this topic. Conversely, when considering the most prominent contributions, Raymond J. Cole, George Baird, and Zhonghua Gou were identified as the top three contributors.

The method for assessing an author's impact on POE studies in the context of green building research employs a strategic approach, originally introduced by Howard *et al.* (1987). This approach has been widely adopted across various research domains, including IEQ analysis (Roumi *et al.*, 2022; Zhang and Yuan, 2019; Yuan and Shen, 2011). This method quantitatively evaluates each author's contribution to a collaborative piece, ensuring a precise and equitable recognition of their input to the collective work.

$$S = (1.5^{n-i})/(\Sigma_{i=1}^{n} 1.5^{i-1})$$

where S represents score of the author contribution, n is the total number of authors, and i is the position number of the authors by order.

In the context of author contributions across multiple articles, the allocation of scores based on authorship order provides an insightful method to quantify an individual's contribution to research. For instance, consider the scoring mechanism where the first receives a score of 0.47, the second author is awarded 0.32, and the third author receive 0.21, as seen in Table 6. This scoring system was exemplified through the contributions of Zhonghua Gou across three different publications.

Zhonghua Gou's contributions were distinguished in three separate articles, each varying in order and consequently in the score attributed. Specifically, in the collaboration leading to the publication by Gou *et al.* (2013), which involved a total of two authors, Gou, being the first author, earned score of 0.46. Furthermore, Gou maintained the position of first author in other two articles (Gou *et al.,* 2012a, 2012b), both of which were composed by three authors. For each of these articles, Gou was attributed the first-author score of 0.47.

Table 6. Author's contribution score.

No. of Authors (*n*)	Author's order (*i*)					
	1	2	3	4	5	6
1	1					
2	0.60	0.40				
3	0.47	0.32	0.21			
4	0.42	0.28	0.18	0.12		
5	0.38	0.26	0.17	0.11	0.08	
6	0.37	0.25	0.16	0.10	0.07	0.05

Summing these scores provides a view of Gou's total contribution across these works, amounting to a score of 1.54. This scoring framework not only quantifies individual contributions in a multi-author setting but also highlights the impact of authorship order on the recognition of an individual's contributions in scholarly publication.

3.5. Keyword analysis

The outcomes of the keyword extraction can identify a cluster of interconnected subjects (Shin *et al.*, 2023). Furthermore, highlighting the most frequently mentioned keywords in articles helps to clarify the primary subjects, facilitating an understanding of the research themes that are most prominently addressed (Yuan and Shen, 2011; Jin *et al.,* 2019). The previous study highlighted three primary themes of POE that are commonly used were monitoring energy usage during building operation, IEQ, and occupants' perception evaluation (Jiang *et al.,* 2022).

This research applied the VOSviewer tools for co-occurrence analysis, employing the "all keywords" option, to examine keywords from publications of POE within the context of green buildings, resulted in a total of 897 keywords. By setting 2 occurrences at the minimum of the keyword, a network visualization map can be seen in Fig. 5. The size of the nodes points out the frequency of keyword, and the curve between the nodes indicates its co-occurrence in the same publication (Yu *et al.,* 2020). The node's color indicates the cluster to which the keyword belongs. Therefore, the frequent keywords are post-occupancy evaluation, green buildings, office buildings, architectural design, and energy efficiency. Environmental performance, carbon emission, health, rating, and life cycle are rare.

Subsequently, terms related to building types and green building standards were selected to calculate the number of terms found and divided by the total all keywords for each respective cluster (see Table 7). This aims to observe the evolving research areas related to the typology of the subject buildings and the green building standard applied within the topic of POE in green buildings.

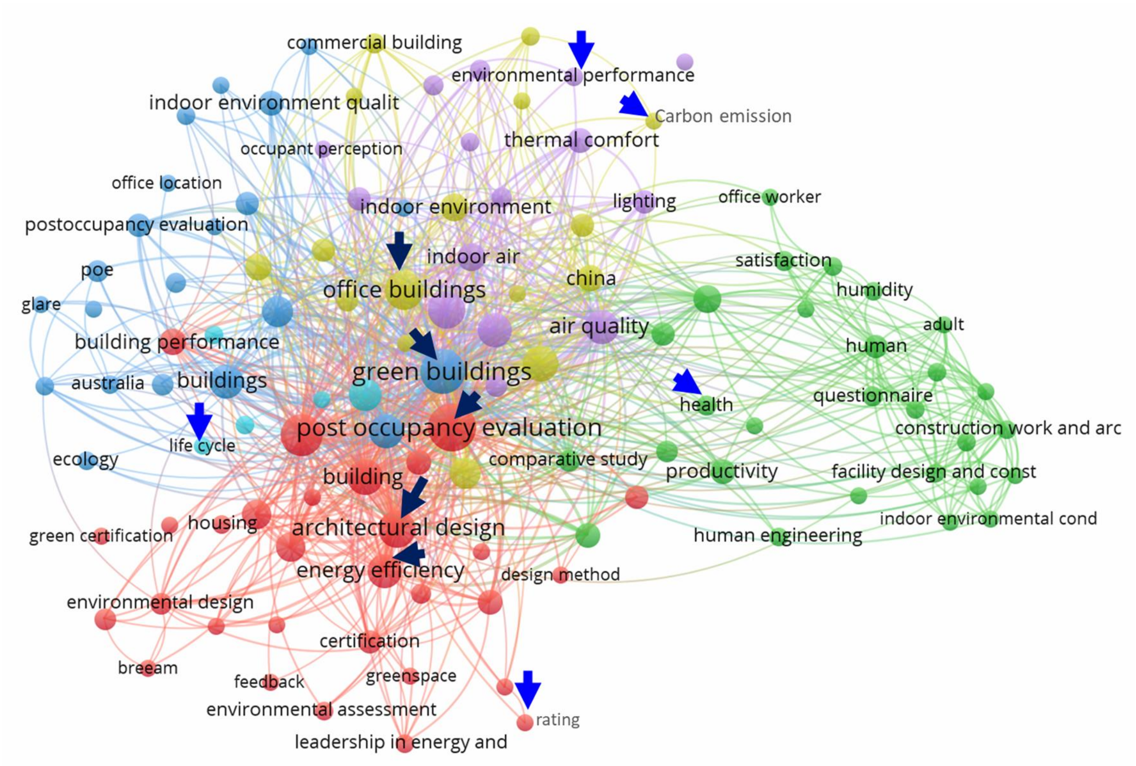

Fig. 5. Network visualization of all keywords based on co-occurrence analysis.

From the keyword filtering results, Table 7 shows that the contribution of researchers related to the most explored building types are offices (Mao *et al.,* 2024; Pistore *et al.,* 2023; Marchwiński, 2023; Khoshbakht *et al.,* 2022; Su *et al,* 2022a, 2022b; Nkini *et al,* 2022; Lei *et al.,* 2022; Grover and Brar, 2022; Rahanjam and Ilbeigi, 2021; Laiche *et al.,* 2021; Newsham *et al.,* 2009), followed by residential buildings (Wu and Ying, 2024; Al Mughairi *et al.,* 2023; Rastogi and Paul, 2023; Khoo *et al.,* 2022; Dabaieh and Serageldin, 2020; Liu *et al.,* 2019a, 2019b; Lee and Shepley, 2018; Adekunle and Nikolopoulou, 2016; Xue *et al.,* 2016; Behar, 2014) and education facilities includes campuses (Yong *et al.,* 2022; Wilder *et al.,* 2019; Moore and Iyer-Raniga, 2019; Baja *et al.,* 2019; Cianfrani *et al.,* 2018; Dorsey and Hedge, 2017; Bonde and Ramirez, 2015; Hedge *et al.,* 2014; Hedge and Dorsey, 2013), schools (Kim 2023; Cole and Hamilton, 2020; Newton *et al.,* 2018; Peters, 2018; Radwan and Issa, 2017; Best and Purdey, 2012), and public library (Tseng, 2008). Subsequent types include nursing homes (Yu *et al.,* 2017; Cutler and Kane, 2009) and convention center (Mondor *et al.,* 2013). These finding indicates that building types such as hospital, retail, hospitality, warehouse, and light industry have been less developed in this area of research.

In POE research on green buildings, the green building standards in Table 7, include LEED (Li H. *et al*, 2022; Mansour and Elrawy, 2022; Wilder *et al.,* 2019; Altomonte *et al.*, 2019; Baja *et al.,* 2019; Liu *et al,* 2018, Dorsey and Hedge, 2017; Hedge and Dorsey, 2013), China Green Building Label (China GBL) (Mao *et al.,* 2024; Liu *et al,* 2018; *Gou et al.,* 2012a), Passive House (Dabaieh and Serageldin, 2020), BREEAM (Liu *et al,* 2018), Green Mark (Cheung *et al.,* 2021; Lee *et al.,* 2020, 2019; Bozovic-Stamenovic *et al.,* 2016), Green Star (Hirning *et al.,* 2013), Green Building Index (Esfandiari *et al.,* 2021; Yaman *et al.*, 2021), Minergie (Pastore and Andersen, 2019).

Minergie is a Swiss green building standard that focus on energy efficiency to reduce the environmental impact of buildings and promoting sustainable construction practices (Beyeler *et al.*, 2009).

Table 7. Terms related to specific cluster.

Selected cluster	Terms (number of terms found)	Count	% of 897
Building type	office (22), residential (21), education facilities (15), nursing home (2), convention center (2)	62	7%
Green building standard	LEED (5), China green building label (2), passive house (2), green mark (2), BREEAM (1), green star (1), green building index (1), minergie (1)	15	2%

These results also show opportunities for researchers to contribute to POE studies related with other green building standards, such as EDGE, DGNB, and green building standards from Southeast Asia countries such as Thai's Rating of Energy and Environmental Sustainability (TREES) (Lohmeng *et al.,* 2017), Greenship from Indonesia (GBCI, 2024), Lotus from Vietnam (VGBC, 2024), and Berde from the Philippine (PhilGBC, 2024).

The selection of building type and green building standard, based on the keyword analysis aims to inspire researchers by highlighting areas within the POE in sustainable building that are still underexplored. This approach offers a novelty to enrich the discourse on POE within green building studies.

3.6. Prominent and selected articles

From an initial set of 116 articles, a focused review identified 10 that have the most impactful in the POE of green building research articles (Table 8). These articles were selected based on the highest normalized citation counts, a technique previously employed in construction research (Jin *et al.,* 2019). The normalized citations for a document are calculated by dividing the document citation count by the total citation count of all documents published in the same year. The normalization process accounts for the varying opportunities documents have to accumulate citations over time, thereby ensuring a fair comparison among documents in different publication years (Van Eck and Waltman, 2023).

Table 8. The 10 most influential articles in POE of green building research.

No	Source	Norm. citation	Total citation
1	Al Mughairi *et al.*, 2023	4.00	7
2	Su *et al.*, 2022a	3.86	18
3	Liang *et al.*, 2014	3.51	175
4	Altomonte and Schiavon, 2013	3.34	220
5	Cheung *et al.*, 2021	3.23	37
6	Hirning *et al.*, 2017	3.17	50
7	Leder *et al.*, 2016	3.11	115
8	Newsham *et al.*, 2009	3.05	453
9	Deuble and de Dear, 2012	2.94	205
10	Brown *et al.*, 2010	2.53	76

Given the selection criteria aimed at identifying POE objectives, indicators, and research analysis methods, the 10 selected articles were strictly research articles. Consequently, the review article comparing the actual operational performance of green building in China and the United States with regard to energy usage, IEQ, and occupant satisfaction by Geng *et al.* (2019) despite having 191 citation score and the highest normalized citation score of 4.07, was excluded and replaced by the study of Brown *et al.* (2010), which has a normalized citation score of 2.53. This adjustment was made to ensure the selection reflects the focus on specific research frameworks and findings.

Based on the data presented in Table 8, the article by Al Mughairi *et al.* (2023), despite having a citation count of 7, achieves the highest influence in this topic with a normalization number of 4.00. For instance, the article by Newsham *et al.* (2009), occupies the 8th position, even though it has the highest number of citations at 453. The reason its high citation count is attributable to the year of publication. Nevertheless, a normalization figure of 3.05 effectively adjusts the article's citation contribution relative to the average publication, providing a more accurate measure of its influence.

In Table 8, the top 10 influential articles on the topic of POE in green buildings are listed based on their citation normalization order. The foremost five ranks are led by the article titled "post-occupancy evaluation for enhancing building performance and automation deployment" by Al Mughairi *et al.* (2023), which holds normalization value of 4 and a total of 7 citations, ranking first. This is followed by the work of Su *et al.* (2022a), with a normalization of 3.86 and a total citation total count of 18. The third place is secured by Liang *et al.* (2014), with a normalized citation of 3.51 and extensive citation total of 175. Altomonte and Schiavon (2013) come next, with a normalized citation score of 3.34 and a total citation count of 220. Lastly, the article by Cheung *et al.* (2021) holds the fifth rank, with a normalized citation of 3.23 and 37 total citations.

Table 9 presents the green building standards most widely used in research using the POE method, with the LEED of the US leading the way (Altomonte and Schiavon, 2013; Hirning *et al.,* 2017; Leder *et al.* 2016; Newsham *et al.,* 2009; Brown *et al.,* 2010). This is followed by the Green Mark of Singapore (Cheung *et al.,* 2021; Hirning *et al.,* 2017), the GBI of Malaysia (Hirning *et al.,* 2017), the China GBL (Su *et al*., 2022a), and the EEWH of Taiwan (Liang *et al.,* 2014). The EEWH rating system of Taiwan, developed and implemented since 1999, stands as the fourth green building evaluation system in the world (Chuang *et al.,* 2011).

Within the scope of this topic, notable studies by Al Mughairi *et al.* (2023) and Deuble de Dear (2012) stand out for their exploration of the building performance without employing standardized green building frameworks. Al Mughairi *et al.* (2023) did not use a green building certified projects due to the absence of a green certification program in Oman. Instead, their research involved a comprehensive review of the literature, incorporating 83 references, to develop recommendations for a building code and a strategic roadmap for the deployment of Building Automation (BAS) in Oman.

The study by Deuble and de Dear (2012) in Table 9, shows no specific green building standard applied means this study analyzed two buildings that had implemented green concepts through different approaches. The initial building adopted a combination of passive and active design elements, including operable windows, shading devices, and a Building Management System (BMS) that interface with both indoor and outdoor temperature sensors. This integration was designed to activate cooling systems when indoor temperatures exceeded 25°C. This Mixed-Mode (MM) building demonstrated significantly reduced electricity consumption profile compared to conventional air-conditioned buildings.

The second building prioritized natural ventilation, employing individual window air conditioning units for only 10% of its occupants. This design choice let the naturally ventilated building to consume less electricity by 61 kWh / m^2 / year than the MM building Deuble and de Dear (2012).

Table 9. Selected cluster in most influential articles of POE in green building research.

	Source	GB standard	Building type	Project location
1	Al Mughairi *et al.*, 2023	No green building (GB) standard	Homes	Oman
2	Su *et al.*, 2022a	One-star China GBL	Exhibition hall	China
3	Liang *et al.*, 2014	EEWH	Offices	Taiwan
4	Altomonte and Schiavon, 2013	LEED	Offices	US, Canada, Australia, Finland, Italy
5	Cheung *et al.*, 2021	Green Mark	Offices	Singapore
6	Hirning *et al.*, 2017	LEED, Green Mark, GBI	Offices	Malaysia
7	Leder *et al.*, 2016	LEED	Offices	Canada, US
8	Newsham *et al.*, 2009	LEED	Commercial and institutional buildings	US
9	Deuble and de Dear, 2012	No green building standard	Academic office buildings	Australia
10	Brown *et al.*, 2010	LEED	Offices	Canada

These studies illustrate the diverse methodologies and approaches that be adopted in the absence of formalized green building standards, offering insight into the potential of innovative design and technology in enhancing building performance and sustainability.

Regarding the geographical distribution of the case studies within the field of green building research, there is a notable predominance of studies originating from developed countries such as the US (Altomonte and Schiavon, 2013; Leder *et al.*, 2016; Newsham *et al.*, 2009), Canada (Altomonte and Schiavon, 2013; Leder *et al.*, 2016; Brown *et al.*, 2010), Australia (Altomonte and Schiavon, 2013; Deuble and de Dear, 2012), Singapore (Cheung *et al.*, 2021), Taiwan (Liang *et al.*, 2014), Finland and Italy (Altomonte and Schiavon, 2013). In contrast, contributions from developing countries are represented by Oman (Al Mughairi *et al.*, 2023), China (Su *et al.*, 2022a), and Malaysia (Hirning *et al.*, 2017). This trend aligns with findings from Darko and Chan (2016) who observed that developed countries, notably the US and Singapore, have been leading in promoting green building research, with emerging contribution from developing country such as China. In addition, these findings similar with the research on the topic of occupant satisfaction, which shows that the majority of studies are still limited to developed countries such as the US, the UK, and Australia (Li *et al.*, 2022).

In terms of POE within green building studies, the building type most frequently analyzed is the office space (Liang *et al.*, 2014; Altomonte and Schiavon, 2013; Cheung *et al.*, 2021; Hirning *et al.*, 2017; Leder *et al.*, 2016; Deuble and de Dear, 2012; Brown *et al.*, 2010). This emphasis on office buildings likely reflects their prevalence in the commercial sector and have a potential for sustainability improvement. Additionally, exhibition hall consisting of space for exhibition, performance, and office (Su *et al.*, 2022a), highlighting an impact of energy consumption profile in a multifunctional spaces. Residential homes have also been a focus, as seen in the study by Al Mughairi *et al.* (2023), indicating a growing interest in applying POE methods to assess the performance of green living spaces. Moreover, commercial building, including a diverse range of subtypes such as offices, non supermarket retail spaces, multi-use res, hotel / resort, higher education have been evaluated in terms of their energy use againts LEED certification level (Newsham *et al.*, 2009).

Based on Table 9, this study indicates that the US and Canada are the most frequent locations for projects utilizing POE to promote green building practices. Furthermore, the building type most commonly associated with the application of POE in green building studies is offices. This finding suggests an opportunity for researchers to explore case studies on the use of POE in green buildings within developing countries, with a particular focus on deepening the understanding of building types such as hospitalities, healthcare facilities, education facilities, retail, and warehouse. The expansion of POE studies to include these diverse building types not only broadens the scope of green building research but also address the unique sustainability challenge and opportunities presented by each typology.

Table 10 shows the 10 most influential articles related to the POE in green buildings research, indicating one of the roles of POE is to assess building energy performance. This assessment involves physical measurements of electricity consumption, as highlighted in studies by Su *et al.* (2022a) and Newsham *et al.* (2009). Moreover, Su *et al.* (2022a) extended the application of POE to assess IEQ compliance during the Covid-19 pandemic in a one-star certified green building in Dalian, China, incorporating measurements of temperature, humidity, CO2, and PM2.5. This research explored the correlation between energy consumption and environmental factors before and after lockdown using Pearson correlation analysis. Meanwhile, the study by Newsham *et al.* (2009) used regression analysis to predict percentage of electricity savings-based energy credits, although the results were not statistically significant.

The objectives of the POE extend beyond energy performance to include the evaluation of user satisfaction, which is achieved through a hybrid approach of physical measurements and subjective assessment using questionnaires (Liang *et al.,* 2014; Hirning *et al*., 2017; Leder *et al.,* 2016; Deuble and de Dear, 2012). Liang *et al.* (2014) used Pearson correlation to conclude a strong relationship between the satisfaction perceptions of individual acoustic, thermal, and air quality indicators and the overall IEQ, whereas the relationship between lighting satisfaction and overall IEQ was found to be weak. Physical measurements and user surveys in that study were conducted to compare the performance of buildings and user satisfaction levels between green buildings and conventional buildings.

Hirning *et al.* (2017) also conducted a comparative study on green and non-green buildings by measuring glare levels and user dissatisfaction, where their findings were used to predict a glare probability model using regression analysis. Similarly, Leder *et al.* (2016) utilized detailed survey data collection and physical environmental measurements at individual workspaces. The analysis involved stepwise multiple regression to examine relationships between physical conditions and occupant comfort and well-being outcomes. The conclusion of their study highlighted that while physical office environment aspects such as workstation size and office type significantly affected employee satisfaction, improvements in IEQ typically associated with green buildings also tented to increase overall satisfaction.

In the study by Deuble and de Dear (2012), the main method of analysis employed was the use of structures questionnaires combined with the recording of objective environmental data like temperature. The questionnaires included POE and the NEP scale. These instruments were used to assess occupant satisfaction and environmental attitudes, and to analyze the relationship between these variables and the physical characteristics of green buildings.

In Table 10 shows research which carried out subjective measurements using several types of analysis methods such as descriptive statistics (Al Mughairi *et al.,* 2023; Brown *et al.,* 2010), Spearman's rank correlation (Altomonte and Schiavon, 2013), and regression (Cheung *et al.,* 2021). The utilization of POE in the study conducted by Al Mughairi *et al.* (2023) was aimed at evaluating and measuring occupants' perceptions of building performance, as well as exploring the readiness level to enhance IEQ and implement home automation. With the addition of a literature review analysis, the results of this study were part of a broader initiative to promote green building practices in Oman. While in Brown *et al.* (2010) study, the primary method of analysis involves POE conducted before and after the company's move to a new green headquarters building, which the conclusions suggest that integrating green building with workplace design from the outset can yield significant improvements in occupant comfort, health, and productivity.

Subjective measurements using POE with questionnaires were also conducted by Altomonte and Schiavon (2013) and Cheung *et al.* (2021). Both studies aim to assess occupant satisfaction with the indoor environment in commercial buildings, but focus on different aspects. The aim study of Altomonte and Schiavon (2013) was to compare satisfaction in LEED certified and non-LEED certified buildings, emphasizing the influence of green building features (building, workspace, IEQ) on occupant satisfaction by using Spearman correlation analysis. The method was used because it uses a dataset of ranks of values of the satisfaction vote (Gairaa *et al*., 2022).

Unlike Altomonte and Schiavon study, the focus of Cheung *et al.* (2021) is more specific, examining occupant satisfaction in Green Mark certified buildings in Singapore by applying a regression model to understand specific IEQ factors affecting satisfaction in a tropical country. This study also suggests modifications to satisfaction benchmarks based on local conditions and occupants' perceptions.

Overall, this variation application of POE, encompassing both objective and subjective dimensions, underscores the methodology's versatility in generating insights into the performance of green buildings. Through such variation evaluations, POE plays a role in advancing the understanding of green building practices and enhancing occupant well-being in the built environment.

According to Li *et al.* (2018), the objectives of POE are divided into two classifications, direct and indirect objectives. Research on green buildings as shown in Table 10 indicates that the directive objectives of POE are to evaluate energy performance (Su *et al*., 2022a; Newsham *et al*., 2009), IEQ evaluation (Su *et al*., 2022a; Liang *et al*., 2014), occupant evaluation (Liang *et al*., 2014, Altomonte and Schiavon, 2013; Cheung *et al*., 2021; Leder *et al*., 2016), and design evaluation (Brown *et al.,* 2010). Indirectly, the objectives of POE include providing future recommendations for green building design (Al Mughairi *et al*., 2023), model validation (Hirning *et al*., 2017), and developing POE questionnaires (Deuble and de Dear, 2012). Thus, the most dominant objective of POE in the top ten green building studies is to evaluate occupant satisfaction.

Table 10. Post occupancy analysis approach in most influence articles in green building research.

No	Source	POE Purpose	Indicator	Analysis method
1	Al Mughairi *et al.*, 2023	Evaluate building performance and readiness level to improve IEQ and implement home automation through occupants' perception	Subjective: 1.The duration of occupancy, the age of building any renovation undertaken, willingness to do building renovation; 2. IEQ, natural and artificial lighting, IAQ, availability of room temperature control, readiness to improve IEQ; 3. building automation	Descriptive statistic and literature review
2	Su *et al.*, 2022a	Evaluate energy performance and indoor environment	Physical: electricity consumption; indoor environment (temperature, humidity, CO_2, $PM_{2.5}$, illumination) and outdoor (temperature, humidity, wind speed, $PM_{2.5}$)	Correlation (Pearson)
3	Liang *et al.*, 2014	Evaluate occupant satisfaction in green and non-green building	Physical: temperature, humidity, air speed, sound level, illuminance, CO_2, VOC. Subjective: thermal sensation, acoustic, visual, IAQ	Correlation (Pearson)
4	Altomonte and Schiavon, 2013	Evaluate occupant satisfaction in green and non-green building	Subjective: building; workspace; IEQ (ease of interaction, furnishing, lighting, maintenance, visual comfort, air quality, visual privacy, noise, temperature, sound privacy)	Correlation (Spearman)
5	Cheung *et al.*, 2021	Evaluate occupant satisfaction	Subjective: temperature, humidity, air movement, comfort on dress, lighting daylight, glare, outside view, stuffiness, odours, noise, sound privacy, cleanliness, space, furnishings, individual control, overall privacy	Regression
6	Hirning *et al.*, 2017	Validate glare probability model in green and non-green building	Physical and subjective: discomfort glare	Regression
7	Leder *et al.*, 2016	Evaluate occupant attitude, satisfaction	Physical: air speed, temperature, humidity, CO_2, lighting, noise Subjective: acoustic, lighting, ventilation, temperature, privacy, overall environmental, job satisfaction	Regression
8	Newsham *et al.*, 2009	Evaluate energy performance compare to energy credit	Physical: electricity consumption	Regression
9	Deuble and de Dear, 2012	Improve component of POE questionnaire	Physical: air and global temperature Subjective: thermal, visual, acoustic, IAQ, health and productivity, general, New Ecological Paradigm	Regression
10	Brown *et al.*, 2010	Examine the interaction between green building design and workplace design practice	Subjective: cultural shift and environmental objectives, occupant comfort, health, productivity, and overall satisfaction	Descriptive statistic

Furthermore, the goal of this research is to identify the indicators used in POE studies in green buildings. According to Roumi *et al.* (2022), measurements in IEQ studies are divided into two approaches, objective and subjective measurement. Based on Table 10, POE in green building studies is conducted with three classifications: objective measurements (Su *et al*., 2022a; Newsham *et al*., 2009), subjective measurements (Al Mughairi *et al*., 2023; Altomonte and Schiavon, 2013; Cheung *et al*., 2021; Brown *et al*., 2010), and combination of objective and subjective measurements (Liang *et al*., 2014; Hirning *et al*., 2017; Leder *et al.*, 2016; Deuble and de Dear, 2012). In physical measurements related to this topic, three indicators consistently appear across three include temperature, humidity, and CO_2 (Su *et al*., 2022a; Liang *et al*., 2014; Leder *et al*., 2015). Meanwhile, subjective measurements consistently include four indicators, such as thermal, visual, acoustic, dan IAQ across several articles (Liang *et al*., 2014; Altomonte and Schiavon, 2013; Cheung *et al*., 2021; Leder *et al*., 2016; Deuble and de Dear, 2012).

The final discussion point of this study is to identify the analysis methods used in this topic. Regression analysis is the most commonly used method among the top 10 POE articles on green building studies, followed by correlation analysis, and descriptive statistics. The decision of analysis methods is based on the data measurement scale and research objectives (Escudero-Gómez *et al.* 2023; Gairaa *et al*., 2022).

These applications of POE collectively underscore its critical role in advancing green building research by providing performance, occupant satisfaction, and environmental awareness. Through such multi-dimensional evaluations, POE facilitates a nuanced understanding of the efficiency of green building strategies and their impact on occupants, thereby contributing to the ongoing development of green building practices.

4. Conclusions

The bibliometric and scientometric analysis of POE field research on green buildings, utilizing VOSviewer software, has yielded a dataset encompassing 116 articles, 48 journals, 326 authors, 249 organizations, and 27 countries, culminating in a total of 897 keywords. Based on the research objectives, the conclusions are:

1. This analysis has identified Tsinghua University in China as the most productive institution, with the US and China leading the contribution. The journal “Building and Environment” emerged as the most active source, while the author Cole Raymond J. made the most significant contributions to this research area. At the same time, the most frequent keywords in this topic are POE, green buildings, and office buildings.
2. Based on the selected cluster of frequently used keywords in green building research using POE methods, office, and LEED standard are the most studied. These findings reveal opportunities for researchers in the POE domain to expand more investigation beyond the commonly studied office and residential buildings to include hospitals, retail spaces, hospitality, warehouses, and light industry. Additionally, other green building standards still need to be explored to enrich the use of POE globally.
3. According to the top 10 selected articles, office and LEED are the most researched, while most project locations are studied in the US and Canada. Moreover, the most dominant purpose of POE is to evaluate occupant satisfaction. IEQ indicators such as temperature, humidity, and CO_2 are

most commonly used. Meanwhile, the IEQ indicators for the subjective approach include thermal, visual, acoustic, and IAQ. Regression analysis is the most adopted method of analysis, where the choice of this method depends on the data scale and research objectives.

This study's insights contribute a perspective to the ongoing development of research on POE in green buildings. The mapping of the field's current states provides information for researchers and practitioners eager to enhance the quality of green building standards and practices. By identifying gaps and opportunities within the literature, this work catalyzes further exploration and innovation in the quest for sustainable building solutions.

Like most other research, this study has limitations, namely the scope of discussion limited to the general utility of POE, although it has focused on green building studies. The author believes that exploring literature reviews on POE in green buildings with more specific topics will provide deeper insights in developing POE methods, especially to promote green buildings globally.

The author suggests a systematic literature review study with a more specific topic for each building type. This is because each building type's operational stage varies, including the behavior of its users. Therefore, it is necessary to conduct literature review studies of POE research that examine environmental quality assessment models across different typologies, such as hotels, offices, hospitals, campuses, residences, shopping malls, or green infrastructure. The aim would be to identify commonalities across these types in terms of the indicators used and the variety of analysis methods, to detect the target environmental quality assessment indicators that are appropriate and leveraging to be integrated into the design concept or recommendations for building managers to improve quality of life and satisfaction of the user in a built environment.

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