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The Impact of Indoor Environmental Quality of Green Buildings on Occupants' Health and Satisfaction: A systematic review

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ABSTRACT

Introduction: The main benefits of green buildings for energy and water conservation have been investigated and well recognized in previous studies. However, indoor environmental quality (IEQ) and human health benefits of green buildings have not been examined comprehensively. This study aimed to conduct a systematic review over the current status of green and non- green buildings on their occupants' health and satisfaction.

Methods: A systematic search was conducted throughout the following databases: Science Direct, Google Scholar, and Springer. We reviewed 690 articles that examined the relationship between buildings and health. In total, after excluding the irrelevant titles and non-English articles, 40 papers were included in the final analysis. Articles that evaluated IEQ factors and occupants' health through surveys from 2005 to 2018 years were selected for investigation.

Results: The most important result of this study was identification of important factors in IEQ, including building design, aesthetics, and ergonomics, which have been less evaluated in previous research. Contrary to our assumption, the results of several studies indicated a further decline in IEQ parameters in buildings with Leadership in Energy and Environmental Design (LEED, USA) and Building Research Establishment Environmental Assessment Method (BREEAM, Europe) certification. However, performance improvements were reported in green buildings located in Asia (especially Singapore and Taiwan).

Conclusion: According to this systematic review, we cannot claim that occupants of the green buildings enjoy higher IEQ, satisfaction, or health, compared with the occupants of non-green buildings.

Keywords: Green building, Indoor environmental quality, Occupants' health

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Introduction

Green buildings are designed to minimize the environmental impact through energy and water conservation measures and limiting the local impact to the building site. Such buildings have directed the public attention to environmental issues and green buildings. On the other hand, only few people are familiar with the main purpose of green buildings that is to provide health and comfort for the occupants (1). Different green building certification programs and guidelines, including Leadership in Energy and Environmental Design (LEED, USA), Building Research Establishment Environmental Assessment Method (BREEAM, UK), and Green Star (Australia) have been established to define sustainable green buildings and provide appropriate rating measures (2). These systems classify the assessment tools into several categories, including energy, water usage, sustainable sites, materials and resources, and indoor environmental quality (IEQ) (3).

Since people spend more than 90% of their time in indoor environments, IEQ is one of the most important factors affecting the physiological and psychological health of occupants (4).

However, the human health benefits of green buildings and IEQ have not been thoroughly evaluated (1).

Considering the great significance of IEQ in green building certification, authorities are expected to pay particular attention to IEQ (5) and the occupants are predicted to be healthier than those residing in non-green buildings with no certification.

Research showed that the relationship between IEQ and health was very complex, since a wide range of environmental factors can affect the health of building occupants (6, 7). According to Fisk al. (2007) dampness problems and mold contamination cause health risks (8). In this regard, Apte et al. (2000) and Lewtas (2007) mentioned the relationship between Indoor air quality (IAQ) and SBS symptoms in occupants (7, 9). Furthermore, Houtman et al. (2008) and Jaakkola et al. (2013) agreed that poor indoor environmental quality (IEQ) has short- (e.g., sick building syndrome and building-related illness) and long-term (e.g., psychiatric problems, cardiovascular disease, asthma, and obesity) impacts on the resident's performance, productivity, as well as physical and mental health development (10, 11).

Globally, green building certification programs consider the parameters and indicators that are relevant to the health and comfort of the occupants in IEQ. According to Khoshbakht and et al. (2018), IAQ, thermal comfort, visual comfort, and acoustic comfort are important sub-domains of IEQ (12). Table 1 presents the public health problems associated with these sub-domains.

Table 1. The impact of IEQ sub-domains on health (13)

Indoor air quality	Sick building syndrome (SBS), building-related illness (BRI), headache, nausea, drowsiness, shortness of breath, fatigue, heart failure, cancer (at high concentrations), signs of inflammation (e.g., temporary burning of the eyes and nose or sore throat), asthma, respiratory infections, chest pain, pulmonary and cardiac diseases, lung cancer, and stroke
Thermal comfort	SBS, dry skin, irritability symptoms, itching, red skin, respiratory problems, infection, and reduced concentration
Visual comfort	Discomfort, dry eye, reduced concentration and visual function, early eye fatigue, and headache
Acoustic comfort	Lack of comfort (headache, fatigue, and irritability), internal ear inflammation, sleep disorder, mental stress, cardiovascular disease, and temporary or permanent loss of hearing

As mentioned earlier, these four sub-domains play a major role in most evaluation systems. However, some researchers believe that building occupants are simultaneously exposed to other environmental parameters, assessment of which is influenced by indoor environment. These factors, less widely discussed, include outdoor access, building design, furniture, cleanliness, building

maintenance, personal control, and ergonomics (12, 14). In the present study, we aimed to review the relevant studies in order to identify other IEQ parameters and evaluate their effects on health.

Methods

We applied a systematic review approach (15) and searched the scientific databases to identify the research papers on health and IEQ of green buildings. Despite the wide range of articles in this area, a limited number of papers investigated the green standards and compared green buildings with non-green buildings. Since the main objective of this study was to collect and evaluate the findings on the performance of green buildings compared with non-green buildings, our search was limited to research articles with no time restrictions. The latest version of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was also used in this study (16).

In December 2018, electronic databases and journals, including Science Direct, Google Scholar, and Springer were searched with the following keywords: "green buildings", "green certification", "built environment" and "health".

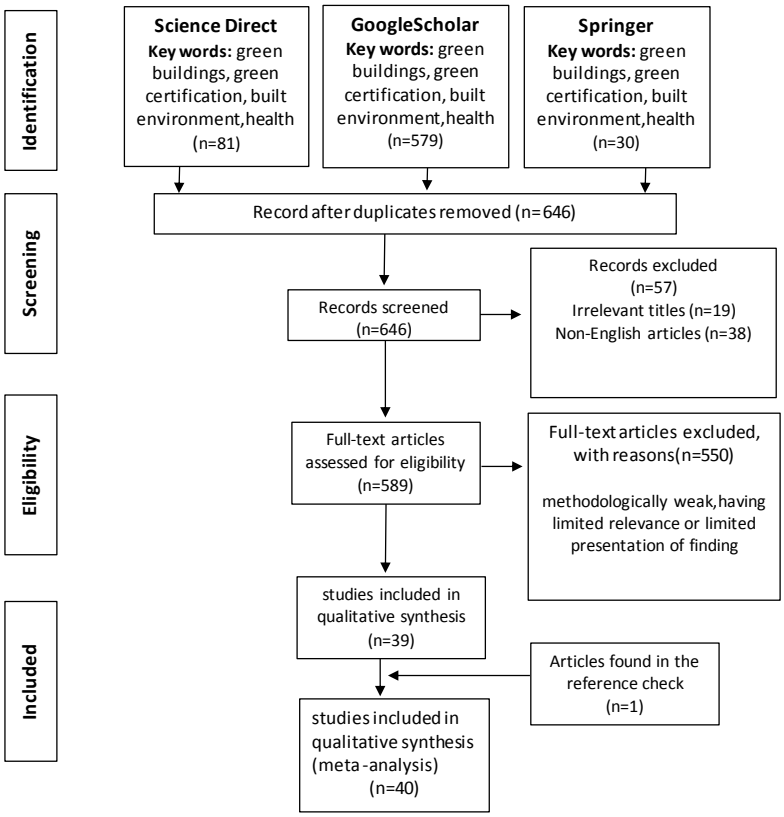

Figure 1. The process of article selection from journal databases

In addition, articles were selected from the reference list of articles found in the database search. Figure 1 represents the process of article selection from the selected databases for review in this study.

Results

A total of 40 articles were included in our review. These studies had applied different evaluation tools and questionnaires as research tools. Table 2 contains information related to the lists of the key research and methodological characteristics of the selected studies.

Figure 2 shows the geographical distribution of studies in Table 2, exploiting the geographical distribution of selected green buildings.

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Table 2. Review of articles on IEQ in green and non-green building

Reference/date	Sample		Country	Green building programme	Type of study
	Green	Non-green			
Huizenga et al. (17)	25(16+9)	1	US/Europe	LEED	Post-occupancy Surveys
Abbaszadeh et al. (18)	21 (15+6)	160	US/UK/Europe	LEED	Post-occupancy Surveys
Edwards (19)	1		UK	BREEAM	Physical Measurements / compared to survey benchmarks
Leaman (20)	22	23	Australia	N.A	Post-occupancy Surveys
Leaman & Bordass(21)	177		UK	Several	Post-occupancy Surveys
Paul & Taylor(22)	1	2	Australia	N.A	Post-occupancy Surveys/ Physical Measurements
Lee & Kim (23)	15	200	US	LEED	Post-occupancy Surveys
Lee & Guerin (24)	15		US	LEED	Post-occupancy Surveys
Brown & Cole (25)	1	1	Canada	LEED	Post-occupancy Surveys
Baird (26)	30		Worldwide	Several	Post-occupancy Surveys
Lee & Guerin (27)	5		US	LEED	Post-occupancy Surveys
Hwang (28)	1		Korea	KGBC	Post-occupancy Surveys/ Physical Measurements
Brown et al. (29)	1	1	Canada	LEED	Pre and Post-occupancy Surveys
Thomas (30)	1		Australia	Green Star	Post-occupancy Surveys / compared to survey benchmarks
Zhang and Altan (31)	1	1	UK	N.A	Post-occupancy Surveys
Issa et al (32)	20	10	Canada	N.A	Pre and Post-occupancy Surveys
Singh (33)	2	2	US	LEED	Pre and Post-occupancy Surveys
Gou ,Lau, and Shen (34)	2	1	China	LEED	Pre and Post-occupancy Surveys
Baird et al. (35)	31	109	North America /Europe	BREEAM /LEED	Pre and Post-occupancy Surveys
Mccunn & Gifford (36)	15		Canada	LEED	Pre and Post-occupancy Surveys
Deuble & de Dear (37)	2		Australia	NA	Post-occupancy Surveys/ Physical Measurements
Rashid et al. (38)	1		US	LEED	Post-occupancy Surveys / compared to survey benchmarks
Thatcher and Milner (39)	1		South Africa	Green Star	Pre and Post-occupancy Surveys / compared to survey benchmarks
Gou, Prasad, and Lau (40)	9(5G+4L)	5	China	GBL/ LEED	Post-occupancy Surveys
Newsham et al. (41)	12	12	US/Canada	LEED and LEED CANADA	Post-occupancy Surveys/ Physical Measurements
Altomonte & Schiavon (42)	65	79	US/Europe	LEED	Post-occupancy Surveys
Menadue et al. (43)	4	4	Canada	Green Star	Post-occupancy Surveys
Agha-Hossein et al. (44)	1	1	UK	BREEAM	Post-occupancy Surveys / compared to survey benchmarks
Liang et al. (45)	3	2	Taiwan	EEWH	Post-occupancy Surveys/ Physical Measurements
Hedge et al. (46)	2	1	Canada	LEED Canada	Post-occupancy Surveys
Pei et al. (47)	10	42	China	GBL	Post-occupancy Surveys/ Physical Measurements
Kim et al. (48)	2	2	US	LEED	Post-occupancy Surveys
Tham et al. (49)	1	1	Singapore	GREEN MARK	Post-occupancy Surveys/ Physical Measurements
Ravindu et al. (50)	2	2	Sri Lanka	LEED	Post-occupancy Surveys/ Physical Measurements
Altomonte et al. (51)	1	1	UK	LEED	Post-occupancy Surveys

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Lin et al.(52)	10	8	China	GBL	Post-occupancy Surveys
Sediso &Lee (53)	2	2	North Korea	G-SEED	Post-occupancy Surveys
Thatcher and Milner (54)	3	2	South Africa	Green Star south Africa	Pre and Post-occupancy Surveys
Altomonte et al. (55)	2	2	UK	BREEAM	Postoccupancy Surveys
Lee et al. (56)	8	6	Singapore	GREEN MARK	Post-occupancy Surveys/ Physical Measurements

Figure 2. Dispersion map of the reviewed articles around the world

Evaluation of IEQ parameters

Table 3 shows a summary of the findings and indicators in 40 articles reviewed in this study. The horizontal column indicates the most commonly discussed 20 IEQ factors in all evaluated studies.

Table 3. Summary of the findings reported in articles related to IEQ factors in green and non-green buildings

Author (year)	Environmental factors									Personal control										
	Thermal comfort		IAQ				Amount of light		Noise	Control		Privacy		Operational					Satisfaction	
	T.C	T	F.A	V	S	L	D.L	V.C	N	P.C	V.P	S.P	P	C	E	S.N	I	A	D	H
Huizenga et al. 2005	↑		↑			×			×					↑		×				
Abbaszadeh et al. 2006	↑		↑			×	↓		×				↓			↓				
Edwards 2006	↑	↓		↓		↓			↓										↑	
Leaman et al. 2007	×	↓	×	↓		↓			↓								↑		↑	↑
Leaman & Bordass 2007	↓	×	↑	↓	↓	↑	↓		×							↓	↑		↑	↑
Paul & Taylor 2008	×			×				×	×									×		↑
Lee & Kim 2008	↑		↑			↓			↓				↓	↑	↑	↓				
Lee & Guerin 2009		↓	↑			↓			↓					↑	↑	↓				
Brown & Cole 2009	↑	↓	↓			↑				↑					↑		↑		↑	
Baird 2010		↓				↑	↓		↓										↑	↑
Lee & Guerin 2010	×	↓	↑			↓			↓											
Hwang 2010						↓	↓													
Brown et al. 2010	↑	×	↑			↓	↓	↑	↓					↑		↑	↑	↑	↑	↑
Thomas 2010	↑	↑	↑	↑	↑	↑	×	↑	↓							×	↑		↑	↑
Zhang and Altan 2011	↑					↑			×											
Issa et al.2011	↑		↑	↑		↑	↑													
Gou ,Lau, and Shen 2011	↓	×	↓		↓	↑	↓		×			↓	↓			↓				
Singh 2011							×		×				×							↑
Baird et al. 2012	↑	↑	↑		↑	↑			×	×				↑	↑				↑	↑
Mccunn & Gifford 2012										↓					↓	×			×	
Deuble & de Dear 2012	↑	×		×		×			×										↑	↑
Rashid et al.2012		↓				↓				↓			↓	↓			×		↑	
Thatcher and Milner 2012	↑		↓	↑	↓	↓			↑											×

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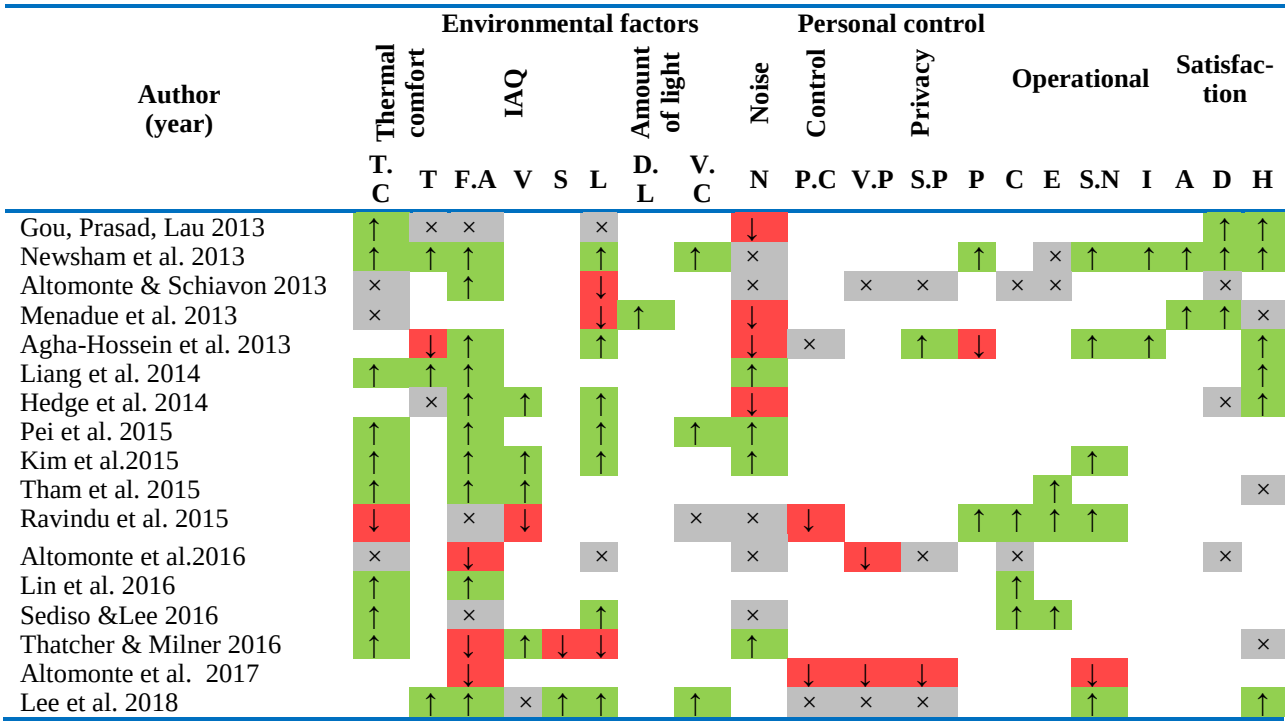

Note: (↑) Higher satisfaction in Green buildings, (↓) Lower satisfaction in Green buildings, (×) No significant differences

Abbreviators:

T.C: Thermal Comfort, **T:** Temprature, **F.A:** Fresh Air, **V:** Ventilation , **S:** Smell/ Odur, **L:** Lighting, **D.L:** Daylight/ glare, **V.C:** Visual Comfort **N:** Noise/ Acoustic, **P.C:** Personal Control , **V.P:** Visual Privacy, **S.P:** Sound Privacy, **P:** Privacy , **C:**Cleanliness , **E:** Ergonomic/ Furniture **S.N:** Space needs / Office layout**, I:** Image, **A:** Aesthetics, **D:** Design, **H:** Health

Assuming that all indicators are taken into consideration in a single study, articles evaluating more than 50% of the indicators were considered comprehensive. According to this definition in our systematic review, about 23% of the papers were considered comprehensive.

Table 4. Comparison of changes in the assessment indicators of green buildings

Parameter	Higher satisfaction in Green buildings	Lower satisfaction in Green buildings	No significant differences
Thermal comfort	53%	8%	15%
Temperature	10%	20%	15%
IAQ /Fresh air	50%	15%	10%
Ventilation	15%	10%	10%
Smell/ Odur	8%	10%	0
Lighting	38%	30%	13%
Daylight/ Glare	5%	15%	3%
View /Visual comfort	13%	0%	5%
Noise / Acoustic	13%	25%	40%
Personal Control	3%	10%	8%
Visual privacy	0	5%	5%
Sound privacy	3%	5%	8%
Privacy	5%	13%	3%
Cleanliness	20%	3%	5%
Ergonomic/ Furniture	18%	3%	5%
Space needs/ office layout	15%	15%	8%
Image	20%	0	3%
Aesthetics	8%	0	3%
Design	30%	0	8%
Health	38%	0	10%

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Comparison of the rate of change in indicators after applying the green building guidelines in the selected studies (Table 4) showed more than 50% of improvement in 5% of indicators, including thermal comfort and air quality. However, the lighting index dropped by 30% and the noise index showed no significant changes (in 40% of cases) among all factors.

According to our findings, the indicators selected in our study can be classified into four groups of environmental, personal, performance and maintenance, as well as satisfaction indicators based on the study by Baird in 2010. Environmental indicators are measured by assessment tools based on specific criteria, while other factors can be examined individually and through surveys. Table 4 represents the share of each indicator in percentage. Based on this categorization, technical indicators including thermal comfort showed the highest improvement (53%), the lighting index had the most significant drop (30%), and the noise index remained unchanged most consistently (40%).

Comparison of green building assessment systems and guidelines

Table 5 indicates the changes in indicators based on the type of instructions and certification for green buildings. In most studies (29 out of 40 papers), green buildings were compared with non-green buildings and five studies rated green buildings based on local standard guidelines and criteria.

Table 5. Changes in indicators based on the type of assessment system for green buildings

Green building programme	Overall	Samle	Higher satisfaction in Green buildings	Lower satisfaction Or No differences in Green buildings
LEED	48%	195	18%	20%
BREEAM	10%	19	23%	19%
Green Star	10%	8	25%	14%
GBL	7%	25	18%	7%
KGBC	2%	1	0	10%
EEWH	2%	3	25%	0
GREEN MARK	5%	9	28%	15%
G-SEED	2%	3	20%	10%
NA	14%	176	13%	22%

In total, 40 studies had followed green building guidelines, including studies by Baird 2012 and Gou 2013, which had applied guidelines of BREEAM/LEED and GBL/LEED, respectively. Moreover, Leaman, Bordass, and Baird (2010) compared several green certifications, while the rest of studies (90%) only used one assessment system. The most commonly used certification was LEED (48%), while KGBC, EEWH, and G-SEED showed the lowest frequencies. It should be noted that in 15% of the studies, type of certificate was not clear.

Discussion

The reviewed studies reported controversial findings regarding green building certification, IEQ, and occupants' health and satisfaction. Some studies confirmed the benefits of green buildings. In this regard, Abbaszadeh et al. showed that despite insignificant differences in terms of lighting and noise indices, the overall comfort of green buildings was higher than that of conventional buildings (18). Moreover, Edward (2006) observed improvements in thermal comfort, health, mental image of work environment, interior design, and most importantly, health of occupants in a green building with a BREEAM certification in the UK according to the guidelines (19).

Leaman and Baird, in two independent studies found that physical health improved in green buildings (20, 21, 26, 35). In addition, Brown et al.

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reported that the green buildings were healthier; 41% of the respondents were healthier on average (29). Some researchers also found a significant relationship between health and green buildings (28, 30, 31, 40). In North America, Newsham et al. evaluated 12 pairs of green and conventional buildings and reported higher performance of green buildings in terms of IEQ, satisfaction, and health (41).

Liang et al. also indicated that the occupants' overall health, perception, and IEQ satisfaction were higher in green buildings (coughing, sneezing, and neck or back pain were less common). In their study, health problems of the staff in office environments were mostly related to furniture and ergonomics (45). Moreover, Canada and Singapore reported better health outcomes (e.g., headache, unusual fatigue, and skin sensitivity) in green buildings (46, 56).

On the other hand, some studies did not report any improvements in the IEQ of green buildings with certification. In this regard, Altomont and Schiavon, in a comparative study over LEED and conventional buildings concluded that no significant difference was observed in the IEQ of buildings with and without LEED certification (42). Similar findings were reported in their subsequent studies in the UK, based on BREEAM guidelines in 2017 (55). In another study from China, Gou et al. did not indicate any significant differences in IEQ satisfaction between green and conventional buildings (34).

Other researchers did not report any significant improvements in the mental health, job satisfaction, or willingness to stay in green building among the occupants (22, 39, 42, 43). In another study from Singapore, Tham et al. found that although people perceived air quality as fresher and ergonomics as more satisfactory in green buildings, they rejected any association between green building certification and reduction of SBS symptoms or sick leave. They proposed a more comprehensive research plan, including a larger number of buildings (50).

Our findings showed that among general indicators (i.e., personal, performance and maintenance, as well as satisfaction), health had the highest improvement (38%). In a closer investigation, 18 studies from a total of 40 (45%) reported health related changes in residents of green building. We found that two thirds of these studies were performed after 2011, which represents that the effects of building characteristic on occupants' health was taken into consideration recently.

Administrative design was associated with the greatest dissatisfaction rate (15%) and health index was the most unchanged factor from the perspective of occupants (10%). Although environmental and technical indicators were examined in 50% of the studies, three main indicators of privacy (i.e., auditory and visual privacy) as well as environmental control, architectural design, aesthetic factors, ergonomics, and cleanliness, which accounted for about 55% of all indicators, were studied in almost 24% of the articles.

The findings showed no decline in the EEWH system, while KGBC exhibited no improvement. On the other hand, in LEED buildings, the rate of improvement (18%) was lower than the rate of decline (20%).

Limitations

Several important assessment systems, such as DNGB, Green Globes, CASBEE, and health-related certificates, such as LBC and WELL, were not examined in the selected studies. Furthermore, some important factors integrated in the IEQ section of some certificates, such as immunity, biophilia, attention to the disabled, and human scales were not included in these studies. Generally, each green building was rated based on the total score achieved from each section according to the instruction. In these papers, the score for each item was not reported. Therefore, the IEQ score of each building remained unknown and a green building with a low score could be evaluated as a high-rated building.

Most studies did not take the sample size into account. Many of these articles were case studies or had a limited sample size; this increased the risk

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of error and prevented the accurate analysis of IEQ-related design and health features. Only in 15% of the studies, IEQ was examined before and after housing and compared with that of other conventional buildings. However, in other studies, green buildings were compared with the conventional ones; this can be problematic regarding the fact that non-green buildings may be older than green ones.

Furthermore, differences in factors, such as age, gender, and residence time between green and non-green buildings can influence the decision-making regarding the health and general comfort of the occupants. For instance, if surveys of newly built green buildings were conducted after a short period, a possibility of bias may exist. This phenomenon is referred to as the "honeymoon effect" by Singh et al. (57).

Strengths

As mentioned earlier, important indicators, such as personal control, design, aesthetics, privacy (e.g., personal, audio, visual), ergonomics, and furniture can have major impacts on the physical and mental health of the occupants. Since the majority of related research focused on environmental indicators, we are faced with a need for future studies to include a larger number of buildings to accurately assess the above-mentioned indicators. This phenomenon, as one of the important findings of this paper, has not been examined in previous studies.

Figure 2 illustrates that while most studies were conducted in the North America, the geographic dispersion was acceptable, since at least one systematic review was conducted in each of the five continents. This issue is important for examining different guidelines with respect to climate and culture and can be very useful in future studies.

Despite the long establishment of LEED in USA and BREEAM in UK, the results showed better performance of green buildings in Asia (especially Singapore), indicating the progress and improvement of green building guidelines in Asian countries.

Conclusion

Following the establishment of green building certifications, a series of studies evaluated IEQ satisfaction in green buildings on a global scale. This systematic review aimed to evaluate the health and satisfaction of occupants in green buildings. Although the results showed improvement of health index in 38% of studies, the type of improvement was not documented. In this regard, reduction of SBS symptoms and headache as well as improvement of sleep disorders were reported. Indoor environmental problems can arise from a variety of issues, which have not been described in these studies (e.g., falling off high places due to inappropriate design or stress due to the inaccuracy of directions). Therefore, the assumption that green buildings are generally superior to non-green buildings in terms of health and overall comfort is not fully supported. Since some studies suggested the occupants' satisfaction with IEQ of non-green buildings, further research is recommended in this area.

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Conflict of Interest

The authors declare no conflict of interest.

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