A COMPARISON OF INDOOR ENVIRONMENTAL SATISFACTION BETWEEN TWO GREEN BUILDINGS AND A CONVENTIONAL BUILDING IN CHINA

Zhonghua Gou,[1] Stephen Siu-Yu Lau,[2] Zhidong Zhang[3]

ABSTRACT

Green buildings can have a more significant impact on their occupant health and productivity through improving indoor environment quality. However, post-occupancy studies invariably pointed out that green buildings were not always more comfortable and productive than non-green buildings. The article presents a comparison study between three buildings in Shenzhen aiming to examine the actual performance of green buildings from occupant point of view. The two green buildings marked a higher satisfaction on the health and productivity perception. However, in-depth examinations on IEQs showed some weaknesses in the two green buildings. On the comfort and satisfaction with the indoor air and temperature, the two green buildings performed better in summer but worse in winter. One of the two green buildings had significantly more noise from different sources than the conventional building. The other green building was significantly less satisfactory on the lighting environment than the conventional building. Implications were discussed for the green building designs and operations.

KEYWORDS

green buildings, LEED, GBL, post-occupancy evaluation, comfort and satisfaction

1 INTRODUCTION

China is facing many problems in the drift economic development process, such as shortage of natural resources, environmental pollution, increased energy consumption, etc. The development of green and energy-saving buildings has become an emphasis in the latest China national development plan. The concept of sustainable building has been introduced into China more than ten years. However, the local sustainable assessment system has been announced within three years. The U.S. LEED (Leadership in Energy and Environmental Design) system, as the first imported sustainable assessment system, has been used by developers to make decisions for their green projects since 2002. In 2006, the Evaluation Standard for Green Building (GB/T 50378—2006) was announced. In 2007, the Green Building

[1, 2, 3] Department of Architecture, the University of Hong Kong, Pokfulam Road, Hong Kong
[1] Corresponding author, Address: RB, Department of Architecture, The University of Hong Kong, Pokfulam Road, Hong Kong, Email: gouzhonghua@gmail.com, Fax: +852 2559 6484, Telephone: +852 68513000

Label (GBL) as a national sustainable building assessment system was announced. It is a green building rating tool promoted by the China Green Building Council of the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MHURD). The two systems (LEED and GBL) are currently the most popular green building rating systems coexisting in China.

The China GBL is the same with LEED for New Construction that uses the checklist scoring mode within the six categories (Figure 1) namely, "Land saving and outdoor environment, Energy saving and utilization, Water saving and utilization, Material saving and utilization, Indoor environmental quality (IEQ), and Operation and management". The scores distribution of each category in each system is a little bit different. LEED distributes the least scores in water category (7.3%) while the score distribution of water category (11.1%) is similar to IEQ category (14.3%) and site category (14.3%) in GBL. This consideration is based on the fact of severe shortage of water resources in China.

Today, the majority of research on green buildings focuses on physical attributes and environmental performance, such as energy or water efficiency, information about the experience of people in and around built environments lags far behind (USGBC 2010). Green buildings can have a more significant impact on their occupant health and productivity through improving indoor environment quality (Heerwagen 2000; Dearry 2004). The IEQ structures of the two rating systems are shown in Figure 2 and 3, respectively. The IEQ system encompasses indoor air quality (IAQ), thermal comfort, acoustics, lighting etc. The strategies of designing an acceptable IAQ in the green building rating systems can be categorized into two groups: avoiding the emission of pollutants and using ventilation to expel those pollutants which have been emitted. The thermal comfort credits mainly rely on engineering comfort standards or National Standards. Visual conditions are characterized by such parameters as daylight factor, artificial lighting, glare control, individual control and outdoor views. Acoustic issues in the LEED system do not receive the attention as thermal comfort, air quality and lighting. The acoustic requirements in the GBL system are mainly concerned with background noise control.

FIGURE 1. Scores distribution at 5 aspects in LEED and China GBL.

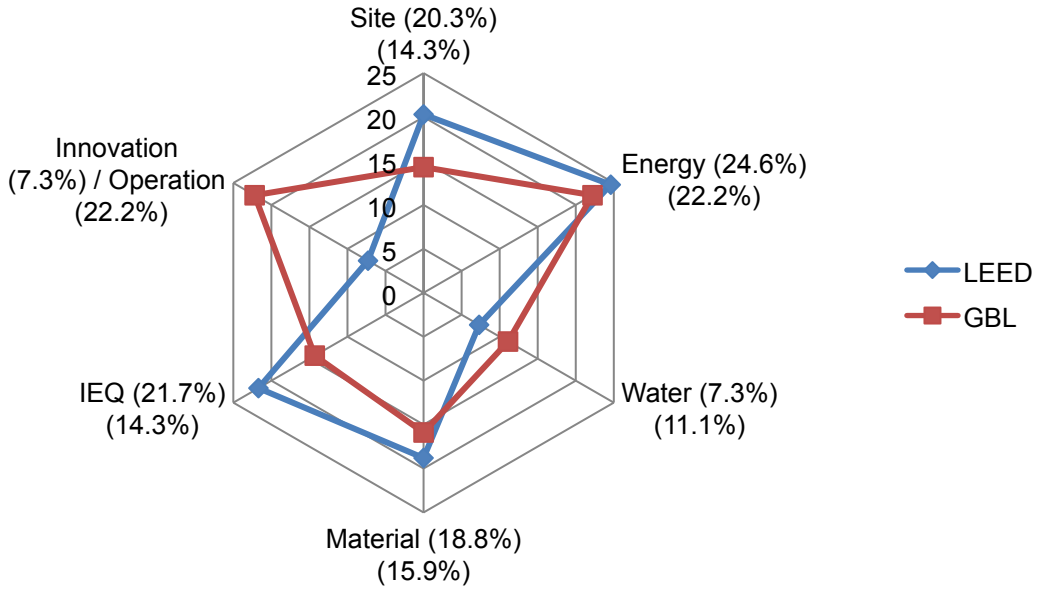
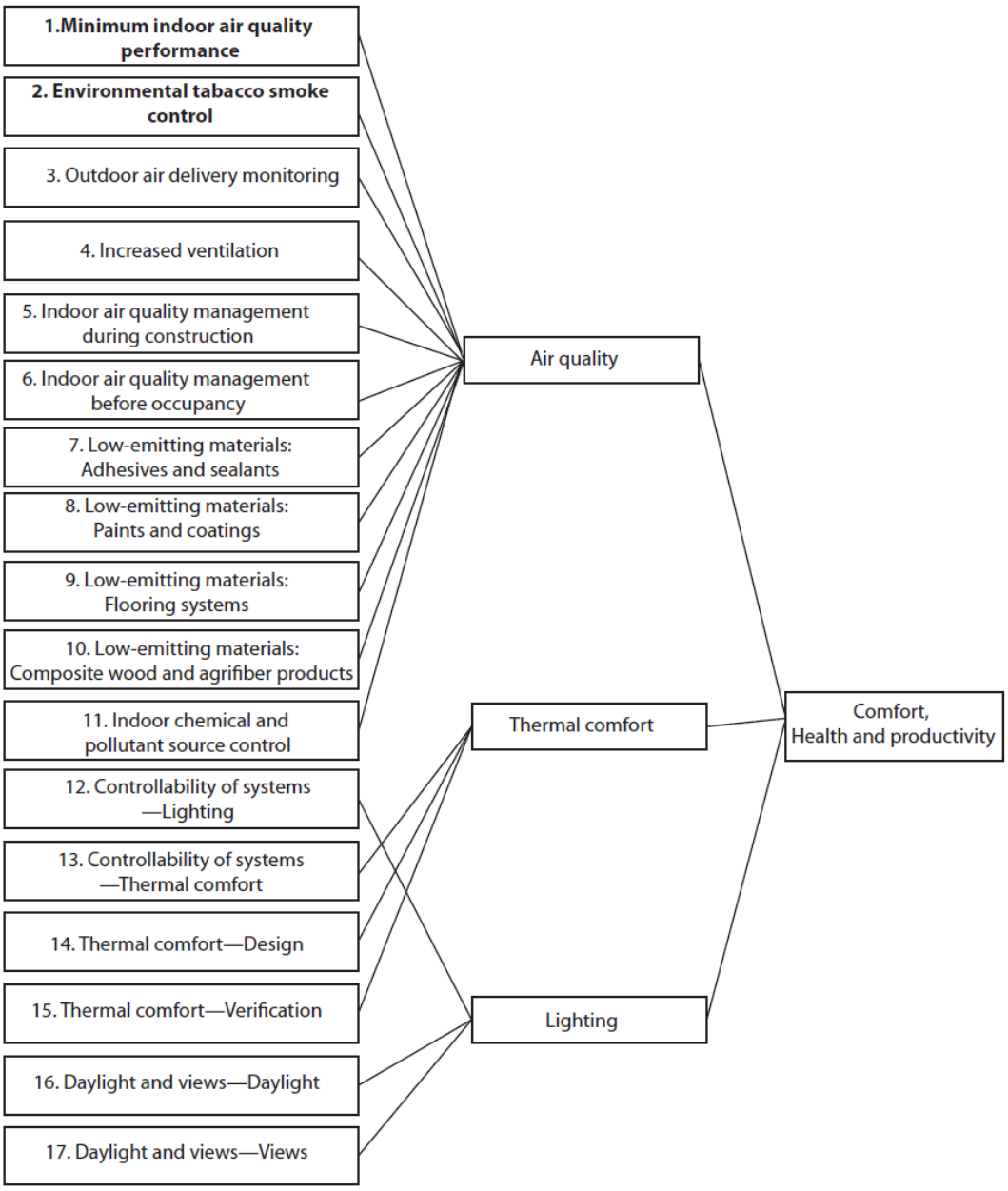
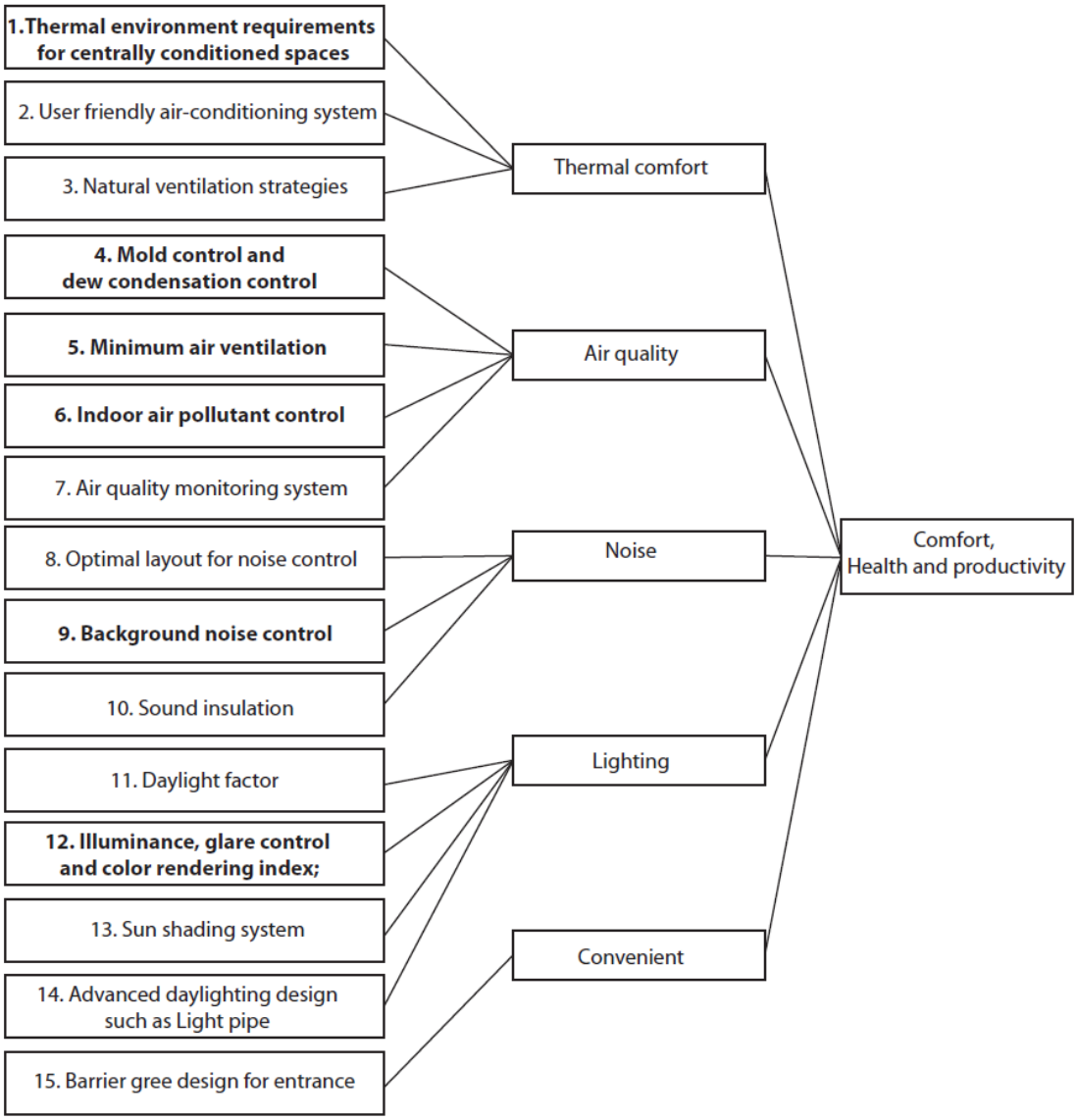


FIGURE 2. IEQ structure in LEED.



Although green buildings are claimed to be able to improve health and productivity by providing satisfactory and comfortable indoor environments, studies are needed to validate the relationships. Post-occupancy evaluation (POE) studies in western countries (Abbaszadeh, Zagreus et al. 2006; Leaman and Bordass 2007; Leaman, Thomas et al. 2007) invariably pointed out that green buildings were not always more comfortable and productive than non-green buildings. The discrepancies identified highlighted the limitations of the existing state of knowledge on designing healthy and productive green buildings. China is leading the world construction market. It is significant to examine whether the indoor environment in the green buildings is more satisfactory and productive than that in non-green buildings.

FIGURE 3. IEQ structure in GBL.



2. METHODOLOGY

2.1 Buildings of study

Three buildings are involved in this study. They are located in Shenzhen, a major city in the south of China. Shenzhen is now reputedly one of the fastest growing cities in the world. The city is also leading the national green building practice. Shenzhen is situated in the subtropical part of China that has a humid subtropical climate. Winter is mild and relatively dry; summer is very humid and hot.

The first building under study is Vanker Center (Figure 4). Vanke is the largest residential real estate developer in China. The center is completed and awarded LEED for New Construction Platinum (the max level in LEED) in 2009. The building is a mixed-use development for hotel, offices, serviced apartments, and public parks. The building appears as if it

were once floating on a higher sea. The decision was inspired by the hope to create views over the lower developments of surrounding sites to the South China Sea, and to generate the largest possible green space open to the public on the ground level. The project employs many state-of-the-art green features such as photovoltaic panels, grey water recycling, rain water harvesting, green roofs, dynamically controlled operable louvers, and high-performing glass (Figure 5). Renewable materials are used throughout this building for doors, floors, and furniture. More information about design details and energy performance of this building can be found in other studies (Ai and Wang 2010; Chen, Ai et al. 2010; Wang 2010).

The second green building is the Headquarter of Shenzhen Institute of Building Research (Figure 6). It is certified by China Green Building Design Label Three Star (the max level in GBL) and completed in March 2008. The office building is located in the north of Shenzhen. Employing 40 technologies such as solar-energy generation, natural ventilation, gray-water recycling, and super-efficient water cooling systems, this building serves as a showcase for green design in China. A 12-story outdoor atrium is created on the east side that captures

FIGURE 4. Case 1: The Vanke Center.

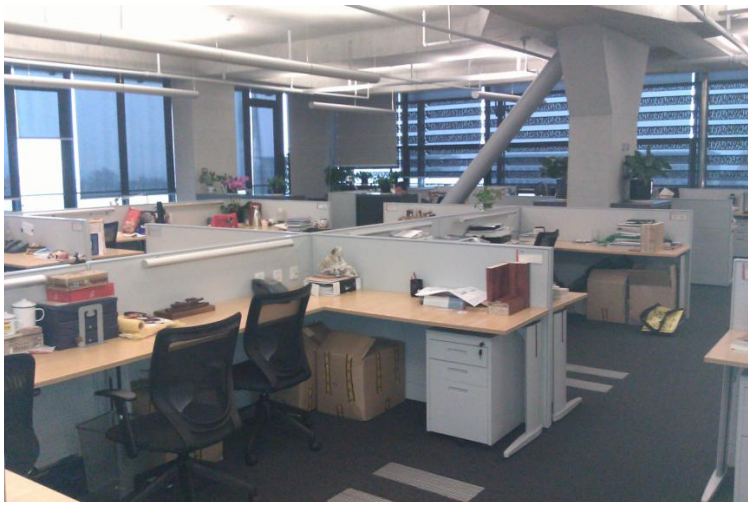


FIGURE 5. The indoor environment of Case 1.

FIGURE 6. Case 2: The headquarter of Shenzhen Institute of Building Research.

southeasterly breezes and brings daylight and breeze deep inside (Figure 7). The building adopts mixed-mode ventilation combining natural ventilation and mechanical ventilation. The mechanical cooling system is operated only during June to September. More information about design details and energy performance of this building can be found in other studies (Yuan, Ye et al. 2010; Cheng 2011).

The third building under study is a non-green building, Daqing Center (Figure 8 and 9). It is located in Shenzhen's CBD area. It is built in 2005. The building is operated under central air-conditioning and its windows are operable partially.

2.2 Occupant survey

For a rigorous approach to the assessment of the occupant comfort and satisfaction, Building Use Studies (BUS) Occupant Survey Method is used in this study. Building Use Studies (BUS) Occupant Survey Method is a questionnaire survey and benchmarking method for rapid and comprehensive study

FIGURE 7. The indoor environment of Case 2.

of user needs in a range of building types (Bordass, Leaman et al. 2001; Bordass and Leaman 2005a; Bordass and Leaman 2005b). Developed in the UK and used internationally, a benchmark database is available. The method uses self-completion occupant questionnaire. The main body of the survey is a three-page questionnaire administered by hand. The data analysis further includes a comprehensive set of benchmarks covering comfort, health, productivity, control, furniture, and space etc. More details about this method can be found in other studies (Leaman and Bordass 2001).

Table 1 and Table 2 list the structure of the BUS questionnaire. The scale of the answer is from 1 to 7 for all aspects except productivity perception that is from –20% to +20%. It should be noted that based on extensive research (Oseland and Bartlett 1999; Leaman and Bordass 2006), it is found that perceived health and productivity as used in the BUS survey is one of the best available indicator that is common to all respondents in a building, and enables comparison across buildings.

FIGURE 8. Case 3: The Daqing Center.

FIGURE 9. The indoor environment of Case 3.

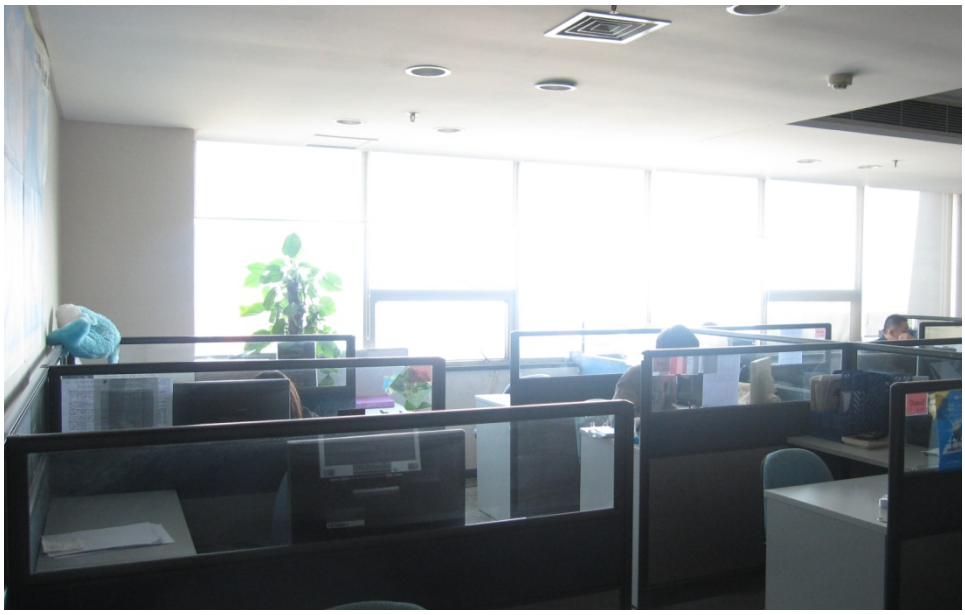


TABLE 1. BUS questionnaire structure.

	Item	Grade 1	Grade 7
IEQ Satisfaction	Temperature in summer	Unsatisfactory	Satisfactory
	Temperature in winter	Unsatisfactory	Satisfactory
	Air in summer	Unsatisfactory	Satisfactory
	Air in winter	Unsatisfactory	Satisfactory
	Noise	Unsatisfactory	Satisfactory
	Light	Unsatisfactory	Satisfactory
	Overall	Unsatisfactory	Satisfactory
IEQ characteristics	Temperature in summer	Too cold	Too hot
		Stable	Varies during the day
	Temperature in winter	Too cold	Too hot
		Stable	Varies during the day
	Air in summer	Dry	Humid
		Fresh	Stuffy
		Odorless	Smelly
		Still	Draughty
	Air in winter	Dry	Humid
		Fresh	Stuffy
		Odorless	Smelly
		Still	Draughty
	Natural light	Too little	Too much
	Glare from Sun and sky	None	Too much
	Artificial light	Too little	Too much
	Glare from lights	None	Too much
	Noise from colleagues	Too little	Too much
	Noise from other people	Too little	Too much
	Other noise from inside	Too little	Too much
	Noise from outside	Too little	Too much
	Unwanted interruption	Too little	Too much
Individual control over the indoor environment	Control over cooling	No control	Full control
	Control over heating	No control	Full control
	Control over ventilation	No control	Full control
	Control over lighting	No control	Full control
	Control over noise	No control	Full control
Self-report	Perceived healthy	Less health	More healthy

In the first green building, 53 occupants responded the survey. As it is a new building, only a small part of office space is occupied. The respondents represented 40% of all current users in this building. In the second green building, 182 people responded this survey, representing 73% of all office workers in this building. In the conventional building, 72 occupants responded the survey, representing 50% of office workers who have normal workstations in this building.

TABLE 2. BUS questionnaire productivity self-report.

Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building? (By "environmental conditions" we mean the combined effect of the previous topics covered in the questionnaire e.g. air quality, temperature, lighting, noise etc. taken as a whole.)								
–20% or less	–15%	–10%	–5%	0	+5%	+10%	+15%	+20% or more
1	2	3	4	5	6	7	8	9

3 ANALYSIS

3.1 Indoor Environment Quality

Figure 10 shows the mean scores for the IEQ satisfaction. The LEED Platinum building (GB1) and the GBL Three-star building (GB2) scored higher than the conventional building (CB) in summer temperature satisfaction (GB1: 4.68; GB2: 4.98; CB: 3.59) and summer air satisfaction (GB1: 4.6; GB2; 5.04; CB: 3.65). They also scored higher in IEQ overall satisfaction (GB1:4.87; GB2: 5.41; CB: 4.52). However, the two green buildings scored lower than the conventional in lighting satisfaction (GB1: 4.51; GB2: 5.03; CB: 5.39) and winter temperature satisfaction (GB1: 3.5; GB2: 4.51; CB: 4.93). GB1 scored higher than CB in noise satisfaction while GB2 scored lower (GB1: 5.0 GB2: 4.55; CB: 4.96). GB2 scored higher than CB in winter air satisfaction while GB 1 scored lower than CB (GB1: 3.66; GB2: 4.86; CB: 4.07).

Figure 11 shows the mean perception scores for the indoor air and temperature in summer. The temperature in the conventional building was colder (GB1:4.02; GB2: 4.48; CB: 4.85) and less stable (GB1: 3.68; GB2: 3.83; CB: 3.96) than that in the two green buildings. The air was more humid (GB1: 4.02; GB2: 4.29; CB: 3.27), more fresh (GB1: 3.45; GB2: 3.67; CB: 3.85), less smelly (GB1: 2.87; GB2: 3.24; CB: 3.42), and more draughty (GB1: 4.04; GB2: 4.48; CB: 4) in the two green buildings.

FIGURE 10. mean satisfaction scores for IEQ.

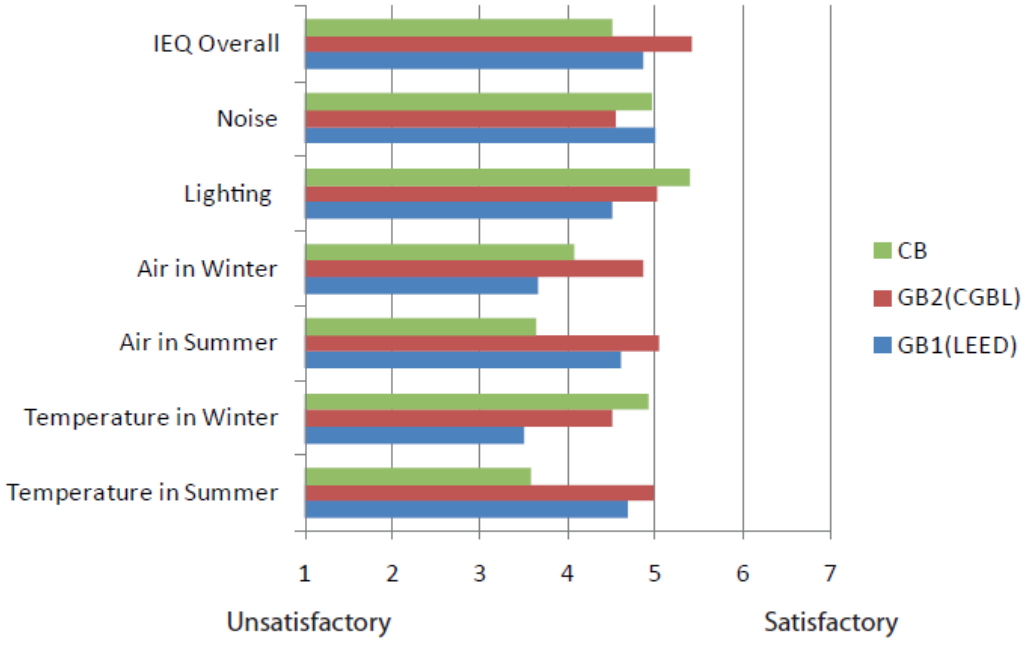


FIGURE 11. Mean perception scores for the temperature and air in summer.

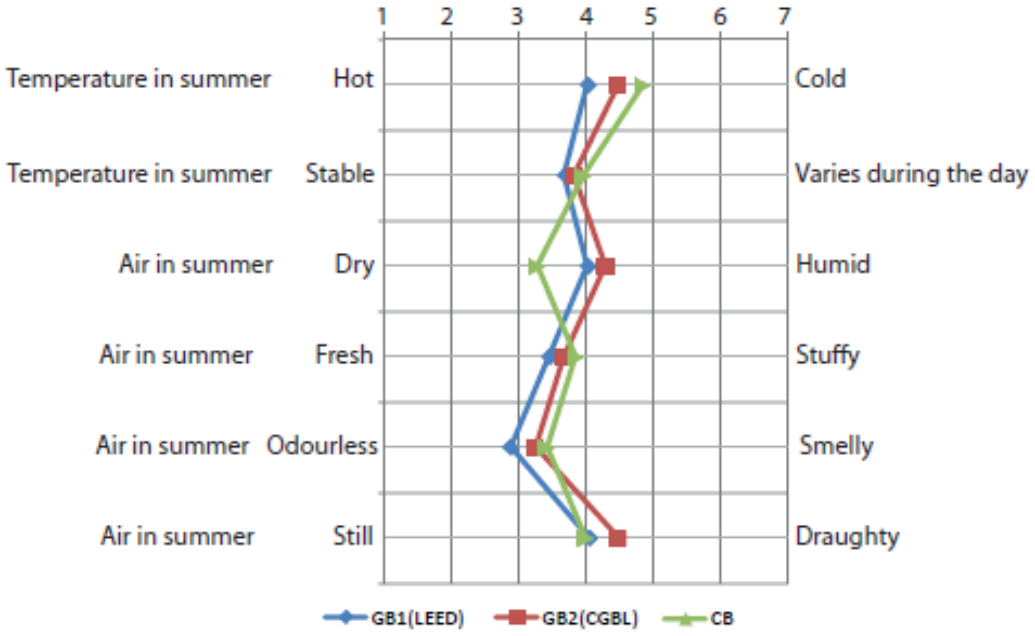


Figure 12 shows the mean perception scores for the indoor air and temperature in winter. The temperature in the two green buildings was colder (GB1:5.79; GB2: 5.07; CB: 3.88) and more varied (GB1: 4.34; GB2: 4.19; CB: 3.8) than that in the conventional building. Compare to the air in the conventional building, the air in the two green buildings was more humid (GB1: 3.72; GB2: 4.14; CB: 3.38), more fresh (GB1: 3.74; GB2: 3.9; CB: 3.96), and less smelly (GB1: 2.83; GB2: 3.37; CB: 3.48). The air in GB2 was more draughty than that in GB1 and CB (GB1: 3.96; GB2: 4.7; CB: 4.15).

Figure 13 shows the mean perception scores for the lighting environment in the three buildings. GB1 had more artificial light (GB1: 3.9; GB2: 4.15; CB: 4) and more glare from lights (GB1: 2.92; GB2: 3.28; CB: 3.21) than GB2 and CB. The two green buildings had more natural light than the conventional building (GB1: 4.17; GB2: 4.45; CB: 4). Glare from sun and sky was perceived more in GB1 than in GB2 and CB (GB1: 3.82; GB2: 3.2; CB: 3.68).

Figure 14 shows the mean scores for the noise environment in the three buildings. The conventional building had less noise from colleagues (GB1: 4.15; GB2: 4.07; CB: 4), less noise from other people (GB1: 3.6; GB2: 3.81; CB: 3), and less other noise from inside (GB1: 3.53; GB2: 3.89; CB: 2.79). GB2 had more noise from outside than CB and GB1 (GB1: 2.55; GB2: 4.41; CB: 3). The conventional building's users reported less unwanted interruptions than the two green building users (GB1: 3.3; GB2: 3.93; GB3: 3.18).

Figure 15 shows the mean scores for the individual control in the three buildings. The green building users perceived more individual control over cooling (GB1: 4.13; GB2: 4.79; CB: 3.04) and less individual control over heating (GB1: 1.96; GB2: 3.26; CB: 3.52) than the conventional building users. The lighting control was perceived more in the two green buildings than that in the conventional building (GB1: 5.04; GB2: 5.22; CB: 4.84). The users in GB2 perceived less noise control (GB1: 3.88; GB2: 3.38; CB: 3.84) and more ventilation control (GB1: 4.25; GB2: 4.53; CB: 4.28) than that in GB1 and CB.

FIGURE 12. Mean perception scores for the temperature and air in winter.

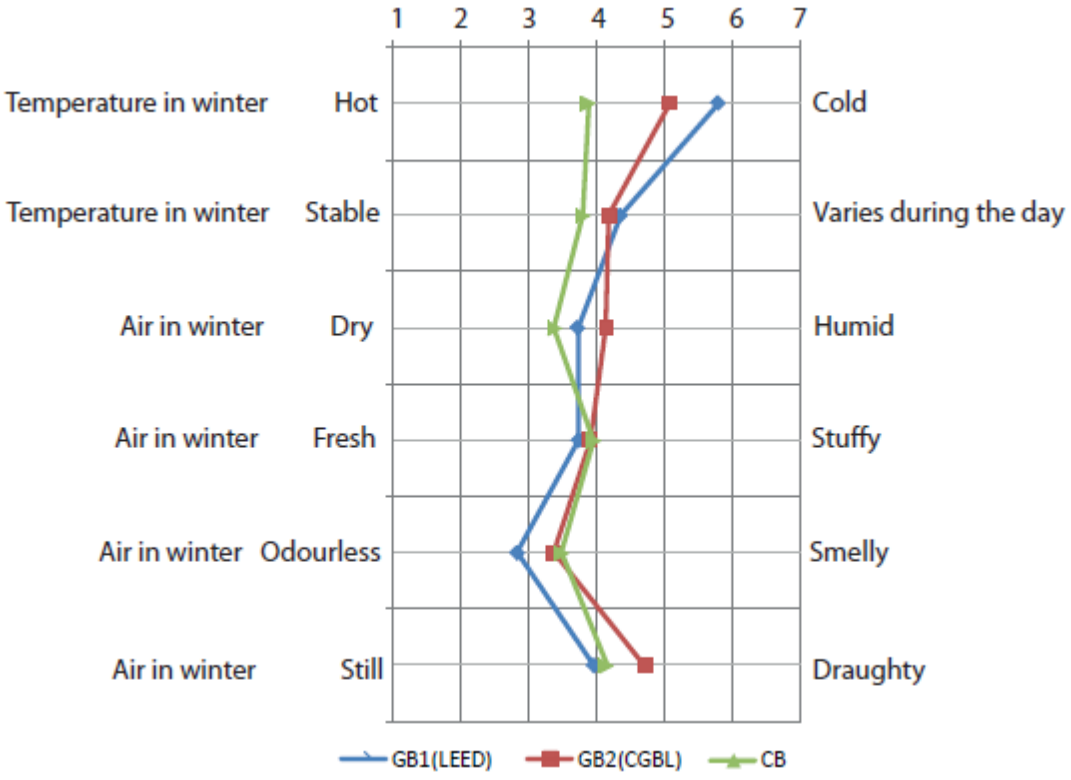


FIGURE 13. Mean perception scores for the lighting environment.

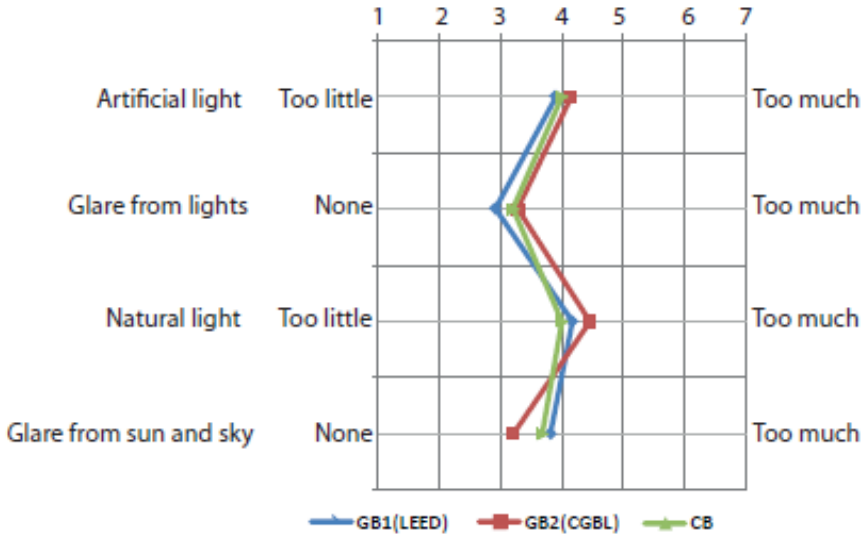


FIGURE 14. Mean perception scores for the noise environment.

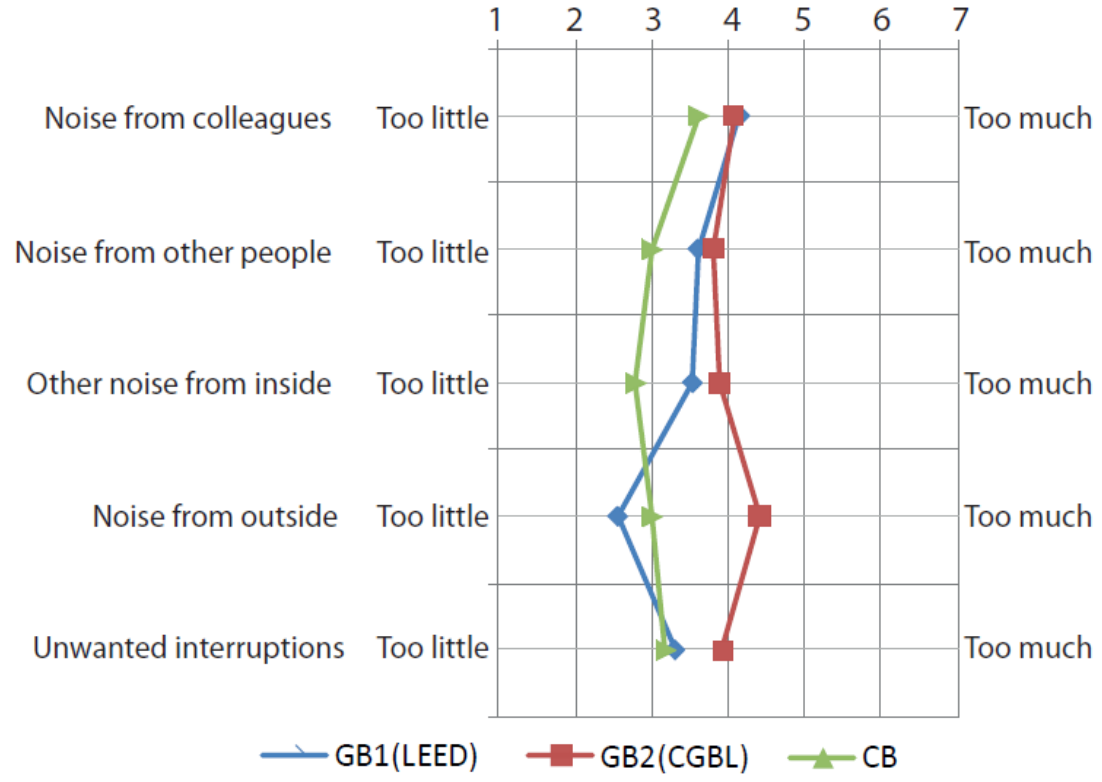
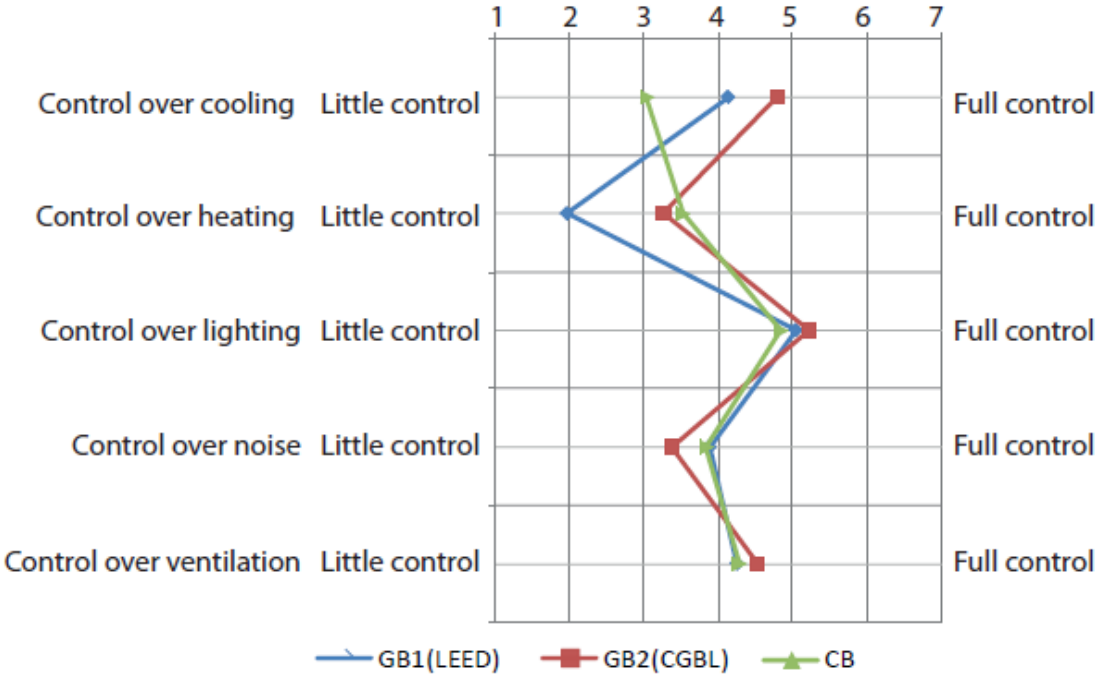


FIGURE 15. Mean perception scores for the individual control.



3.2 Perceived health and productivity

Figure 16 and 17 compare the mean scores for the perceived health and productivity in the three buildings. Three buildings all scored positively on the health and productivity perception. The two green buildings were healthier than the conventional building. The two green buildings were more productive than the conventional building. The GB1 users averagely reported a 14.23% increase in their productivity; and the GB2 users averagely reported a 13.18% increase in their productivity.

FIGURE 16. Mean scores for the perceived health.

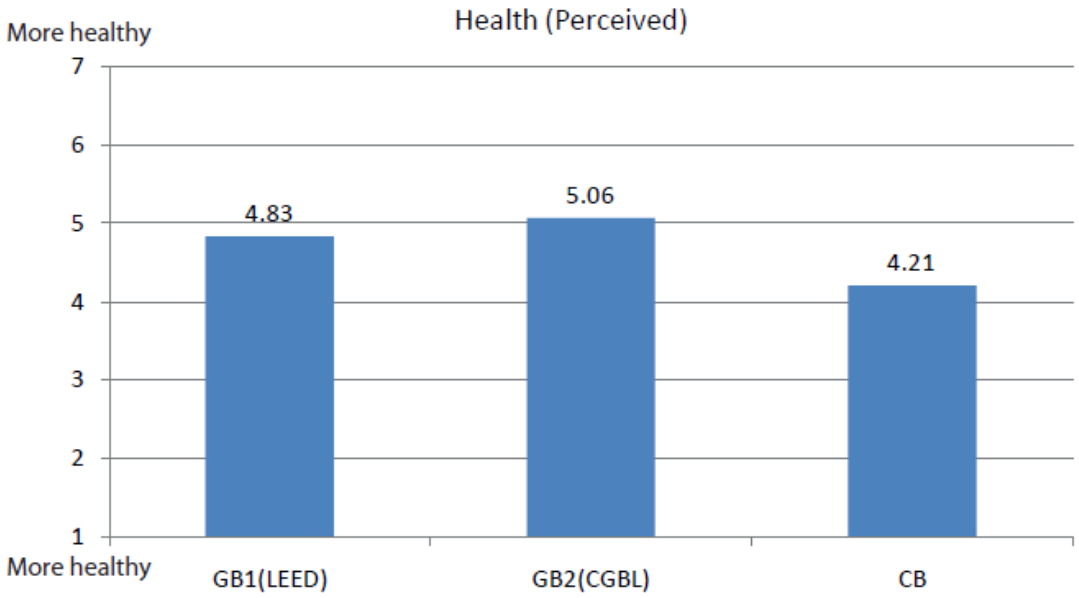
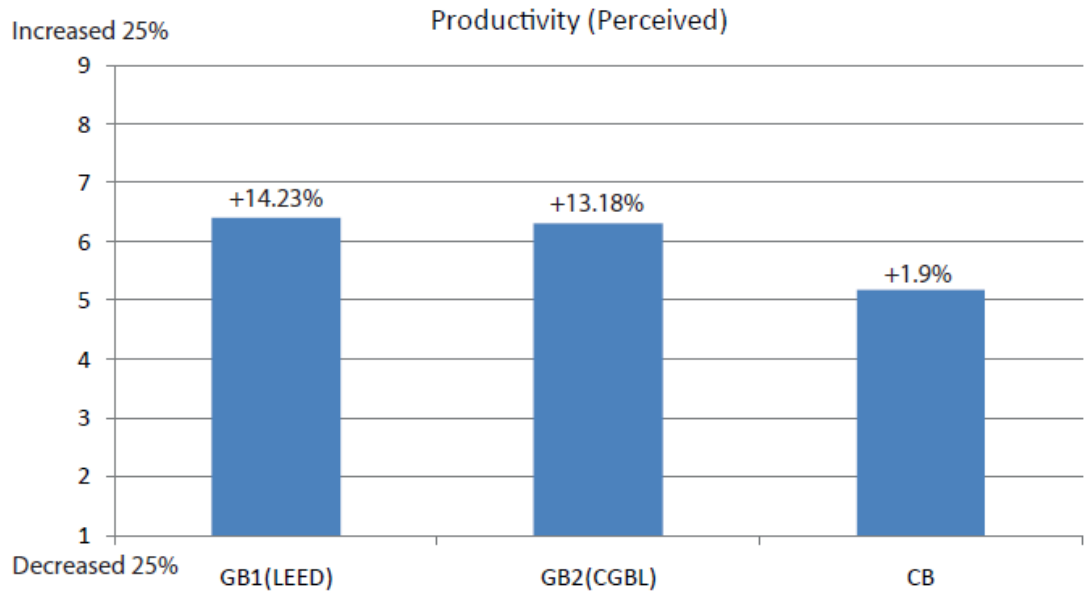


FIGURE 17. Mean scores for the perceived productivity.



3.3 T-test

A t-test was conducted to assess whether the means of two groups (GB1 and CB) were statistically different from each other. Compared to the conventional building, the LEED Platinum building (GB1) was more satisfactory on the summer temperature (p=0.003); its summer indoor temperature was less cold (p=0.030). The LEED building's summer indoor air was more satisfactory (p=0.002) and was less dry than the conventional building. However, users in the LEED building were less satisfactory on the winter indoor temperature (p=0.001) and the temperature was much colder (p=0.000) than that in the conventional building. The lighting environment in the LEED building was less satisfactory (p=0.029). Users in the LEED building reported that they were healthier (p=0.045) and more productive than those in the conventional building (p=0.002). There were not significant differences existing on the noise environment.

A t-test was conducted to assess whether the means of the GBL building (GB2) and the conventional building (CB) were statistically different from each other. Compared to the conventional building, the GBL building (GB2) was colder in winter (p=0.000). The GBL building was less dry in winter (p=0.021) than the conventional building, and its winter indoor air was more satisfactory (p=0.002). The GBL building's summer indoor temperature (p=0.000) and air (0.000) was more satisfactory. The summer air in the GBL building was less dry than that in the conventional building (p=0.000). The GBL building had more noise from colleagues (p=0.006) and more other noise from inside (p=0.000). The unwanted interruptions were more frequent in the GBL building (p=0.011). The GBL building was more satisfactory overall (p=0.000), and the users perceived that they were healthier (p=0.000) and more productive (p=0.001).

A t-test was conducted to assess whether the means of the LEED building (GB1) and the GBL building (GB2) were statistically different from each other. The GBL building's winter temperature (p=0.001) and air (p=0.000) were more satisfactory than the LEED building. The LEED building's winter temperature was much colder (p=0.000) and its air was drier (p=0.024) and more still (p=0.003). In summer, the GBL building's indoor temperature was colder (p=0.031) and its air was more draughty (p=0.044) than the LEED building. Compared with the LEED building, the GBL building had much more noise from outside (p=0.000) and the unwanted interruptions were more frequent (p=0.023). The glare from sun and sky in the GBL building was also significantly more than that in the LEED building (p=0.030). The GBL building's indoor environment overall was more satisfactory than the LEED building (p=0.004). There were no differences on the perceived health and productivity between the two green buildings.

4 FINDINGS

Compared to the conventional building, the LEED Platinum building was more satisfactory on the summer temperature (the conventional building was too cold in summer). The LEED building's summer indoor air was also more satisfactory (the conventional building was too dry in summer). On the other side, the conventional building was more satisfactory on the winter indoor temperature (The LEED building was too cold in winter) and also more satisfactory on the lighting environment. The LEED building users reported that they were healthier and more productive than those in the conventional building.

Compared to the conventional building, the GBL three-star building was more satisfactory on the winter air quality (The conventional building was too dry in winter), and also

more satisfactory on the summer air and temperature (The conventional building was too dry in summer). However, the GBL three-star building was colder in winter. On the noise environment, the GBL building had more noise from colleagues, more other noise from inside, and more frequent unwanted interruptions. The GBL building's users perceived that they were more satisfied at the IEQ overall, and they were healthier and more productive.

5 IMPLICATIONS

The article presents a comparison study between three buildings in Shenzhen aiming to examine the actual performance of green buildings from occupant point of view. The two green buildings marked a higher satisfaction on the health and productivity perception. However, in-depth examinations on IEQs showed some weaknesses in current green building rating systems and design practices.

Green building design in hot-humid climate areas should not neglect winter conditions. On the comfort and satisfaction with the indoor air and temperature, the two green buildings performed better in summer but worse in winter. Although maximizing natural ventilation is an important sustainable design strategy to reduce energy load in the summer, the discomfort that could be caused by the cold air should be avoided during the winter in hot-humid climate areas where heating is not considered in the building design (Gou, Lau et al. 2011).

Green building rating systems should include noise control in open-plan office settings. Acoustic issues in most green building rating systems do not receive the attention as thermal comfort, air quality and lighting. The most outstanding problems associated with the open-plan office are frequent complaints of loss of privacy, aural distractions and frequent interruptions by other employees (Hedge 1982; Hedge 1984; Vischer 1996; Vischer 2005). In this study, the GBL building had significantly more noise from colleagues, more other noise from inside, and more frequent unwanted interruptions than the conventional building. The current green building rating systems are only concerned with background noise control. More considerations on the nature of open-plan layout design should be included in green building rating systems and design practice.

Green building design needs more stringent daylighting standards. The conventional building was significantly more satisfactory on the lighting environment than the LEED building. There was no significant difference on the natural light between the two green buildings and the conventional building. Daylighting is a very important sustainable design strategy that can save energy and provide a healthy working environment. The daylighting-related criteria in the green building rating systems rely on design standards that are widely used in conventional buildings (e.g. China GBL standard requires that 75% of office space satisfies the requirements in GB/T 50033 of Building Daylighting Design Standards). Compliance with these standards may not differentiate a green building from a non-green building. More stringent daylighting designs are required.

Even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment (Humphreys 2005; Gou, Lau et al. 2011). One obvious reason is that people differ and therefore not all are satisfied by the same conditions. Occupants adapt in various ways to the conditions they face, both physically and psychologically (Brager and de Dear 1998). Therefore, the result of the survey cannot be generalized as a difference between green buildings and non-green buildings. More post-occupancy studies are needed to verify the result and provide feedback to green building designs and operations.

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