Building and Environment 72 (2014) 232–242

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan

Han-Hsi Liang [a], Chen-Peng Chen [b], Ruey-Lung Hwang [a,*], Wen-Mei Shih [a], Shih-Chi Lo [c], Huey-Yan Liao [c]

[a] Department of Architecture, National United University, No. 1 Lien-Da, Kung-Ching Li, Miaoli 36003, Taiwan
[b] Department of Occupational Safety and Health, China Medical University, No. 91 Hsueh-Shih Road, Taichung 40402, Taiwan
[c] Architecture and Building Research Institute, Ministry of the Interior, 13F, No. 200, Sec. 3, Bei-Sin Road., Sindian District, New Taipei City 231, Taiwan

A R T I C L E I N F O

Article history:
Received 26 July 2013
Received in revised form
23 October 2013
Accepted 9 November 2013

Keywords:
Green buildings
Indoor environmental quality
Occupant satisfaction
Post-occupancy evaluation

A B S T R A C T

The preservation of indoor environmental quality (IEQ) is key to the well-being and productivity of office occupants. In Taiwan, the green building certification system established IEQ criteria to evaluate the performance of buildings in acoustics, lighting, ventilation and decoration but not the performance in delivering thermal comfort. This study investigated and compared the green and conventional office buildings in middle Taiwan on various aspects of IEQ during a period of active air-conditioning use. Among the monitored environmental variables, the levels of noise, illumination, and carbon dioxide in both types of buildings were in compliance with international or Taiwan's regulatory standards, but not that of volatile organic compounds. The degrees of overall IEQ satisfaction as well as the proportion of occupants voting for satisfaction in the green buildings were both greater than their counterparts in the conventional buildings. Of the specific areas of IEQ evaluated, including the acoustics, lighting, perception of thermal comfort of the occupants toward the thermal environment, and indoor air quality, a statistically significant difference was found between the mean score of satisfaction in the green buildings and that in the conventional buildings. The occupants sharing a concern on energy conservation were more amenable to slightly deficient IEQ. The system of green building certification in Taiwan was able to facilitate proper IEQ performance of the buildings, although a re-visit of the current criteria to incorporate thermal comfort-related criteria may be adequate.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

1.1. Indoor environmental quality and green buildings

As the green building movement continues, the focus has increasingly extended to issues of indoor environmental quality (IEQ) in relation to health and comfort of the indoor occupants. The IEQ refers to the performance of a building in delivering an indoor environment to its occupants that meets the expectations of keeping the occupants' health, wellbeing, and productivity. In the last decade, great efforts were directed to explore the impacts of acoustic quality [1], lighting [2,3], thermal comfort [4–6], indoor air quality (IAQ) [4,7,8], and overall IEQ [9–11] on the safety and productivity of building occupants. The utmost economic benefit that a green building brings to its users lies in the promotion of productivity and work efficiency [12]. The occupants of green office buildings have been found [13–16] to be associated with greater productivity, lower absenteeism, lower spending in health insurance, and lower rate of compensation claim. As the financial cost with human capital in an enterprise was frequently close to two orders of magnitude of the cost spent on energy consumption [17], the issues surrounding IEQ in green buildings should be well attended to, considering the substantial influences of IEQ on the productivity of office occupants [18,19].

The promotion of IEQ in green buildings gained momentum in recent years as a building of low energy consumption yet coupled with highly dissatisfied IEQ might not be more sustainable than those of high energy consumption. A variety of green building certification systems worldwide have incorporated the IEQ as a category of evaluation, e.g., the Leadership in Energy and Environmental Design (LEED) of the US, the Building Research Establishment Environmental Assessment Method (BREEAM) of the UK, and the Green Star of Australia. Nonetheless, a question remains to be clarified—*Are the schemes currently applied in green building*

* Corresponding author. Tel.: +886 37 381635; fax: +886 37 381643.
E-mail addresses: rueylung@nuu.edu.tw, rlhwang6202@gmail.com (R.-L. Hwang).

0360-1323/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.11.007

certification fostering buildings of IEQ satisfying their occupants [9,10]? Some studies reported an increase in the occupants' IEQ satisfaction thanks to the green building design, including those reported by Huizenga et al. [20], Armitage et al. [21], Abbaszadeh [22], and Issa et al. [23]. In contrast, others did not find a positive association between the IEQ satisfaction and the green buildings. Fowler and Rauch [24] studied twelve green buildings in the US and reported that the occupants were content with the overall IEQ but were satisfied with the sound-proof and thermal performance of these buildings only at levels below national benchmarks. Lee and Kim [25] compared the IEQ performance between green and conventional buildings based on the subjective perception of indoor occupants and derived at the same conclusions. Altomonte and Schiavon [26] evaluated the occupant satisfaction using a database featuring 144 buildings (65 LEED-certified), predominantly located in the US, and concluded that there was not a significant influence of LEED certification on the occupants' satisfaction with the indoor environmental quality. The occupants of the LEED buildings tended to be slightly more satisfied with the air quality and dissatisfied with the amount of lighting. Paul and Taylor [27] compared the IEQ perception of the occupants between a green building and a conventional one located in two Australian universities, and did not observe a superior level of comfort among the occupants of the green building. On the performance of maintaining adequate indoor temperature and air quality, the levels of satisfaction among the green building occupants were actually less compared to those observed from the occupants in the conventional building. In the UK, Leaman and Bordass [28] analyzed occupant surveys from 177 buildings and reported a higher rate for green buildings in the performance of ventilation and air quality compared to the level determined in conventional buildings. However, it was noted that the indoor environment of the green buildings tended to be warmer, less dry, and more stuffy during the summer. Reporting a higher level of satisfaction among the occupants toward the IEQ in green buildings, field surveys in China by Gou et al. [29–31] also identified a significant difference in the IEQ performance within the investigated green buildings, suggesting the involvement of additional factors influencing the IEQ satisfaction of indoor occupants. In South Africa, Thatcher and Milner [16] conducted a longitudinal comparison between the occupants in green vs. conventional buildings, and concluded that the GreenStar-accredited building did not increase the physical fitness, mental health, or perceived productivity of the occupants at a significant level.

1.2. Green building certification in Taiwan

In Taiwan, since the year 2001 all new buildings of public property have been required and those of private ownership recommended to certify for a green building label to reduce energy expenditure from new architectures and constructions. This effort had resulted in a total of 925 certifications of green buildings nationwide by the end of 2012. The green building certification system in Taiwan, known as EEWH, comprises four major categories of building evaluation [32]: Ecology, Energy saving, Waste reduction, and Health. The EEWH was launched in 1999 and later expanded to cover nine major indicators of building performance under the aforementioned categories, including biodiversity, greenery, water-soil content, energy savings, CO_2 emission reduction, construction waste reduction, indoor environment quality, water resource, and garbage/sewage improvement. The EEWH certified green buildings into five distinct levels: the certified, bronze, silver, gold, and diamond. Among these indicators the energy savings and water resource were mandatory criteria whereas the other seven are optional. To become a certified green building in Taiwan, the building must meet the two mandatory criteria and at least two other optional criteria selected in accordance with the characteristics of the building to be accredited.

A survey [33] targeting general public vs. experts in Taiwan's EEWH green buildings revealed that local consumers of architectural industry ranked the IEQ rather than the efficiency of energy conservation the most critical attribute of green buildings that concerned them. As Fig. 1 shows, of the 925 green buildings certified in Taiwan by 2012, only 28% (259 certifications) attempted the IEQ criterion. While the IEQ appeared to be a primary concern for local building occupants, it was less frequently an attribute that the builders and building owners would consider when certifying a building.

In the certification of green buildings in Taiwan, the IEQ was evaluated by the performance of the building in the acoustics, lighting, ventilation, and materials used in interior construction, with the aim being to facilitate an indoor environment that was healthful and comfortable to the occupants. However, thermal comfort was not considered an essential area of IEQ evaluation. Chiang and Lai [34] developed a rating system consisting of nine criteria for application in Taiwan's EEWH (Table 1). In this system, a building would meet the requirement in overall IEQ if the sum of the scores awarded in each individual criterion after weighting came to a total of 60 or greater. However, thermal comfort was not included as a criterion in this system, as the achievement of thermal comfort inside a building in Taiwan during hot summer days often required extensive usage of the air-conditioning (AC) and was considered a deviation from the energy-saving aspect of the green building initiative.

1.3. Study goals

This study was the first investigation that evaluated the occupants' satisfaction toward the IEQ performance of the EEWH-certified green buildings in Taiwan by means of post-occupancy evaluation. In the study, the levels of IEQ satisfaction of the occupants in green office buildings were assessed and compared to those in conventional office buildings. The post-occupancy evaluation employed in the study consisted of a field survey of subjective perception among indoor occupants and on-site environmental measurements. This study was unique in that it presented a thorough evaluation on the thermal perception of the occupants, who had been physiologically acclimatized to the heat frequently encountered in hot-and-humid weather, toward the IEQ of green buildings certified primarily to target a lesser use of energy. In addition, this investigation aimed to evaluate if the IEQ requirements presently prescribed in Taiwan's EEWH were sufficient.

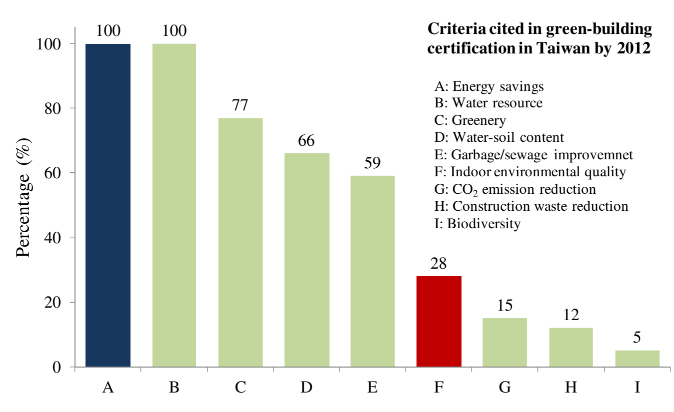

Fig. 1. Frequency of individual criteria cited in certification of and satisfied by buildings for a green building label in Taiwan.

Table 1
Criteria for rating indoor environmental quality of Taiwan's EEWH green building.

IEQ category	IEQ criterion	Score	Sub-total	Weight
Acoustics	Sound insulation: exterior walls	30	100	0.2
	Sound insulation: operable windows	35		
	Sound insulation: flooring	35		
Lighting	Transmission of visible light through glass windows	20	100	0.2
	Surface area of windows for daylighting	60		
	Anti-glare capacity of artificial lighting	20		
Ventilation	Intake of ambient air via natural or mechanical ventilation	100	100	0.2
Decoration	Amount of interior decoration	40	100	0.4
	Usage of environmental friendly building materials	60		

Table 2
Monthly distribution for mean, maximum, and minimum values of the ambient temperature and relative humidity in Miaoli County and Taichung City from April to October, 2012.

2012		Apr	May	Jun	Jul	Aug	Sep	Oct
Temperature (°C)	Mean	23.1	26.0	29.1	28.8	29.0	28.1	26.0
	Max	32.4	35.0	35.3	34.6	34.8	34.1	32.2
	Min	15.4	20.2	23.5	23.8	24.4	22.7	20.3
Relative humidity (%)	Mean	64.3	73.7	70.8	73.3	72.4	70.3	70.4
	Max	99.0	96.0	95.0	98.0	98.0	93.0	95.0
	Min	30.0	39.0	50.0	49.0	52.0	48.0	46.0

2. Methods

2.1. Study design and site description

This study adopted a post-occupancy evaluation in design to investigate the perceived satisfaction among indoor occupants toward the IEQ performance of green office buildings accredited by Taiwan's EEWH. In this approach, the evaluation process systemically targeted individual design components of a built environment for their effectiveness in fulfilling the intended functions, in this case, the improvement and maintenance of IEQ. The post-occupancy evaluation included a questionnaire survey on the IEQ satisfaction among the occupants of the office buildings and on-site measurement of the physical environment that took place simultaneously. The performance of the office buildings in indoor environmental quality was evaluated in the following areas: the acoustics (sound insulation), lighting (visible light transmission and glare reduction), thermal environment (temperature/humidity and thermal comfort), IAQ (ventilation and influences of carbon dioxide (CO_2)/volatile organic carbons (VOCs)), and the overall perception of the IEQ. The study was performed in the open-plan studios of five office buildings located geographically in mid Taiwan near the west coast, with three being EEWH-certified green buildings and the other two of a non-certified, conventional design. The EEWH-certified buildings were built in ten years. In comparison, the two conventional buildings were constructed prior to the enactment of Taiwan's EEWH when new constructions were not subject to accreditation. There were no previous studies conducted at these conventional buildings regarding their IEQ or reports indicating an inferior IEQ performance in these two buildings compared to those of the EEWH-certified buildings. The certified green buildings were located in Miaoli County and used as government offices. The conventional buildings were located in Taichung City, which was geographically south of but immediately next to Miaoli County, and these two buildings were used by private industry as office space (Fig. 2). These buildings were occupied in compliance with provincial codes at a density of 0.10–0.15 persons per square meters. As all the buildings evaluated in this study were used as office space, their occupants were government/industry employees involved in typical office functions (e.g., reading, writing, computer-typing in a composed posture, and occasional walking between the workstations for document delivery or communication) of a light metabolic load (a met of 1.1–1.3). During the period of investigation the clothing level of the office occupants was between 0.5 and 0.7 clo. The employees of a temporary work nature (i.e., those who worked part-time, as an intern, or on a contract of less than a year) were excluded.

The study was conducted from April to October of 2012, a period when the AC was operated daily in response to the hot-and-humid weather in Taiwan. Currently, Taiwan's regulatory agencies recommended a range of room temperature between 26 and 28 °C as the threshold of AC activation in managing AC use inside an office

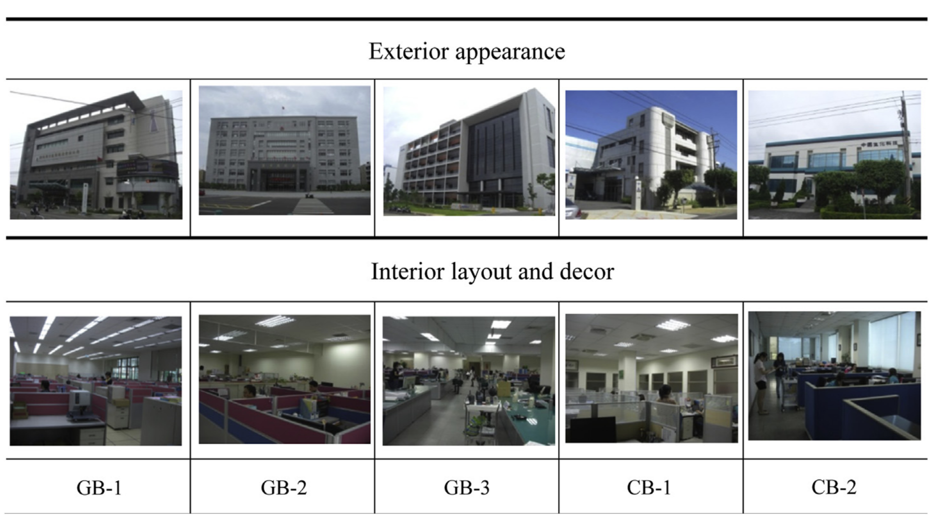

Fig. 2. Exterior appearance and interior layout of three green buildings (GB-1, GB-2, and GB-3; located in Miaoli County of Taiwan) and of two conventional buildings (CB-1 and CB-2; in Taichung City) evaluated in this study.

Table 3
Categories of information collected in the questionnaire.

Category	Question
Background information	Age; sex; years of working in the investigated building; view on energy conservation
Satisfaction toward IEQ	Acoustic comfort, visual comfort, thermal comfort, indoor air quality (IAQ), and overall comfort
Source(s) of dissatisfaction	▪ Acoustics-related: noise from outside; noise from inside; ability of sound insulation (sound-proof): windows; ability of sound insulation (sound-proof): walls and flooring ▪ Visual-related: amount of artificial light; glare from artificial light; amount of daylight; glare from daylight; direct exposure to solar radiation (directly sunlit) ▪ Thermally related: too warm; too cold; too humid; too dry; draughty air; still air ▪ IAQ-related: odors; foul air

building. However, throughout the course of this study the AC in the evaluated buildings was activated daily during the office operation hours (8:30 am to 5 pm). This was a result of the room temperature inside these buildings being consistently above the target threshold. Table 2 shows the distribution of the ambient temperature and relative humidity in Miaoli County and Taichung City from April to October of 2012 monitored hourly by Taiwan's Central Weather Bureau. It demonstrated a range of maximum ambient temperature between 32.2 and 35.3 °C in these areas during the daytime in this period, corresponding to the pattern of consistent and frequent AC use in these buildings. All five buildings were monitored/surveyed once per month, and each monitoring/survey session lasted for two days, both in the morning and the afternoon. The activation of AC in these buildings and the setpoint of indoor temperature were verified during the field trip. Throughout the course of this study, the setpoint of indoor temperature was 26 °C in two green buildings and 28 °C in the third, while the temperature in the two conventional buildings was set to be 28 °C.

2.2. Survey on occupant satisfaction

In this study, the questionnaire survey aimed to explore the subjective perception and satisfaction of office occupants toward the quality of the acoustics, lighting, thermal comfort, indoor air, and overall IEQ in the building. The questionnaire was developed referencing those adopted in studies of similar objectives and designs [25,26,29], reviewed by an expert working group, and followed by testing and modification via pilot survey before being finalized. The pilot survey was conducted by a group of 15 employees from an office building also located in mid Taiwan but independent of those included in this study. During the actual survey, a paper copy of the questionnaire was delivered by the surveyors in person to the office occupants who volunteered to participate so to boost the rate of questionnaire return. As summarized in Table 3, the information collected by the questionnaire could be categorized into three main categories: background information, satisfaction toward IEQ, and source(s) of dissatisfaction. Each area in the category "Satisfaction toward IEQ", including the acoustic comfort, visual comfort, thermal comfort, IAQ, and overall comfort, was evaluated by a question of a standardized format consisting of a 7-point scale from which the respondent could choose a rank equivalent to their current sensation. As an example, the entry identifying the satisfaction on the thermal environment in the office appeared in the questionnaire as:

"*How satisfied are you with the current thermal environment in this office?*

□ *Very satisfied* □ *Satisfied* □ *Slight satisfied* □ *Neither* satisfied *nor dissatisfied*

□ *Slightly dissatisfied* □ *Dissatisfied* □ *Very dissatisfied*"

When the occupants' responses were pooled for analysis, the rank selected from the 7-point scale in each questionnaire was transformed into an integer between +3 and −3, corresponding respectively to the rank of "very satisfied" to "very dissatisfied" sensation. If the respondent selected a neutral sensation ("neither satisfied nor dissatisfied") or a negative perception ("slightly dissatisfied", "dissatisfied", or "very dissatisfied") in the question, he/she would be requested to further identify the source(s) of the neutral or dissatisfied sensation from a list tabulated in Table 3.

2.3. Measurement of indoor environment

In this study, environmental monitoring was performed in all buildings for a variety of climatic as well as IAQ variables to provide a comparison with the results of questionnaire survey and to identify the sources of IEQ dissatisfaction. On the days of field trips, the environmental monitoring was conducted from 9:30 am to 12:00 am and then from 2:00 to 4:30 pm. A total of 99 and 84 measurements were conducted respectively in the three green buildings and the two conventional buildings in this study. To prevent a potential interference on the IEQ perception of the respondents as a result of knowing the environmental conditions

Table 4
Specifications of equipments for measurement of indoor climatic parameters.

Climatic parameter	Device	Accuracy
Air temperature (dry-bulb temperature)	K-type thermocouple[a] (Center 314 Temperature/Humidity Datalogger, Center Tech, Taipei, Taiwan)	±0.1 °C
Globe temperature	K-type thermocouple and standard globe[a] (Center 314 Datalogger)	±0.1 °C
Relative humidity (RH)	RH sensor[a] (Center 314 Datalogger)	±3%
Air speed	Omni-directional anemometer (DeltaOHM HD2103.2 Thermo- Anemometer, Caselle di Selvazzano, Italy)	±0.02 m/s[b]
Sound level	Sound level meter (Center 322 Datalogger, Center Tech, Taipei, Taiwan)	±1.5 dB
Illuminance	Light meter (TES-1335 Light Meter, TES Electrical Electronic Corp., Taipei, Taiwan)	±3% rdg ±0.5 FS[c]
Carbon dioxide (CO_2) concentration	Non-dispersive infrared sensor (DeltaOHM RH-Temperature-CO_2 HD37B17D Datalogger, Caselle di Selvazzano, Italy)	±50 ppm plus 3% of the measurement
Volatile organic compound (VOC) concentration	Photoionization detector (ToxiRAE PLUS PID PGM 30 Personal VOC Gas Monitor, San Jose, CA, USA)	±2 ppm or ±10% of reading[c]

[a] The sensors were radiation-shielded but not aspirated.
[b] The specified accuracy was valid when the observed air velocity was between 0.00 and 0.99 m/s.
[c] The light meter was calibrated to standard incandescent lamp of 2856°K; the photoionization detector was calibrated to 100 ppm of isobutylene.

Table 5
Background information on the respondents completing questionnaire.

	Number of respondents (n)	Sex		Energy conservation		Age distribution			
		Female	Male	Concerned	Less concerned	<30	30–40	40–50	>50
Green buildings	134	83	51	80	54	39	48	30	17
Conventional buildings	99	42	57	67	32	29	41	16	13
Total	233	125	108	147	86	68	89	46	30

inside the office, the measurements were all performed after the questionnaire survey was completed. The measurement was conducted in a walk-through manner, in which the equipments gauging the air temperature (t_a), globe temperature (t_g), relative humidity (RH), air speed, sound level, concentration of CO_2, and concentration of VOCs were all placed on a carrying cart to record the environmental variables at a height of 1.1 m from the floor, simulating the exposure of the occupants to the indoor air near the breathing zone when seated. The equipment cart was placed next to the workstation of the occupant when individual spot measurement took place. In the spot measurement, the environmental variables were recorded continuously for 20 min, and an average was generated for this measurement period. For the level of lighting on the workstation, a hand-held light meter was used to extract a realistic approximation of the illumination received by the employee. The equipments used in the environmental monitoring as well as their specifications were summarized in Table 4. The t_a, (t_g), and air speed were converted to the operative temperature (t_o) following the equations presented in ISO 7726 [35].

2.4. Questionnaire respondents

To better characterize the IEQ perception of the occupants who made observations on a long-term basis, only the questionnaires completed by the employees that had been working in the evaluated buildings for more than one year were included in the final analysis. A total of 233 valid questionnaires were retrieved from the survey for analysis, with 134 being generated by the occupants from green buildings and 99 from conventional buildings. Among these questionnaires, 125 (54%) were completed by females and 108 (46%) by males. One hundred and forty-seven respondents (63%) were concerned with issues related to energy conservation. Further detail on the distribution of the respondents in different age categories and by the types of buildings they worked in was summarized in Table 5.

3. Results

3.1. Quality of indoor environment

Fig. 3 shows in box-plot the distribution of the t_a, mean radiant temperature (t_r), t_o, RH, air speed, sound level, illuminance, CO_2 concentration, and VOC concentration in the evaluated office buildings. The IEQ in an office building may be influenced by miscellaneous factors that are diverse in attribute (e.g., those arising as a function of mechanical operation, managerial strategy, and personal behavior), and the interaction among these factors often renders a cause-effect interpretation for the influence of individual factors on the IEQ difficult. Thus, the following discussions shall focus on describing the overall, statistical trends in distribution of these variables in the green vs. conventional office buildings as well as a comparison of the observed distributions to international standards or Taiwan's national benchmarks.

The climatic variables typically examined in evaluating the thermal status in an indoor environment include t_a, t_r, t_o, RH, and air speed. For the green buildings and the conventional buildings included in this study, the t_o in the period of study ranged from 24.1 to 28.6 °C (mean = 25.6 °C) and from 26.7 to 29.3 °C (mean = 27.6 °C), respectively (Fig. 3c). A comparison between Fig. 3(a) and (c) revealed that the distribution of t_a in both the green and conventional buildings (24.1–28.1 °C and 24.3–28.5 °C in green and conventional buildings, respectively) closely tracked that of t_o (24.3–28.5 °C and 26.7–28.9 °C), suggesting that the t_o as determined was primarily attributed to the convective heat in the building. When the distribution of t_r in the green buildings (25.0–28.3 °C; mean = 26.4 °C) and in the conventional buildings (27.1–29.1 °C; mean = 28.0 °C) was compared to that of t_o, the radiant heat added to the t_o to a greater extent in the case of conventional buildings, although the influence was less than significant compared to that of t_a. The level of RH observed was similar between both types of buildings (Fig. 3d), ranging from 52.9 to 71.3%, with the mean being 63.2% for the green buildings and 61.5% for the conventional buildings. As for the air speed inside the office, more than 75% of the observations were less than 0.2 m/s in both types of buildings (Fig. 3e), an appropriate value for occupancy, according to the ASHRAE Standard 55 [36].

The ASHRAE Standard 55 also suggested an upper limit of 27.2 °C (under the condition of a clothing level of 0.5 clo and an RH of 50%) for the 80% comfort zone in an indoor environment for the t_o. While a comparable national benchmark did not exist in Taiwan, for the purpose of energy conservation, Taiwan's regulatory agencies suggested not to use the AC for air cooling inside a building when the temperature was below 28 °C and not to set a target temperature below 26 °C if the AC was used. As shown in Fig. 3c, most observations from our spot measurements in both types of buildings did not exceed this upper limit. Some spots of temperature sampling showed a t_o greater than 28 °C, as they were situated immediately next to the windows. The maximum of sound level as observed in both the green and conventional buildings was 65 dB (Fig. 3f). However, overall the green buildings were more serene than the conventional buildings, with their mean sound level being 53 dB (40–62 dB), 3 dB less than the mean of 56 dB for the conventional buildings (; 46–63 dB). As far as the lighting was concerned (Fig. 3g), the mean value of illuminance measured in the green buildings was 826 lux (520–1320 lux), and the levels detected at all sampling spots were greater than 500 lux, the value recommended by the International Commission on Illumination (CIE) [37]. In comparison, a mean level of 554 lux (360–1120 lux) was observed for the lighting in the conventional buildings, and the observations made in approximately 40% of the sampling spots were less than the CIE recommendation. In the evaluated buildings the workstations of most employees were not situated directly to a window. As the lighting was measured on the surface of the employee's workstation (approximately 0.7–0.8 m from the floor), the readings presented here should be construed as the illumination provided by the lighting equipment. For the IAQ, regardless of the building type the concentration of CO_2 detected in nearly all sampling spots was lower than the Taiwan's national standard, 1000 ppm [38] (Fig. 3h). The minimum, mean, and maximum of CO_2 concentration in the green buildings were 648, 749, and

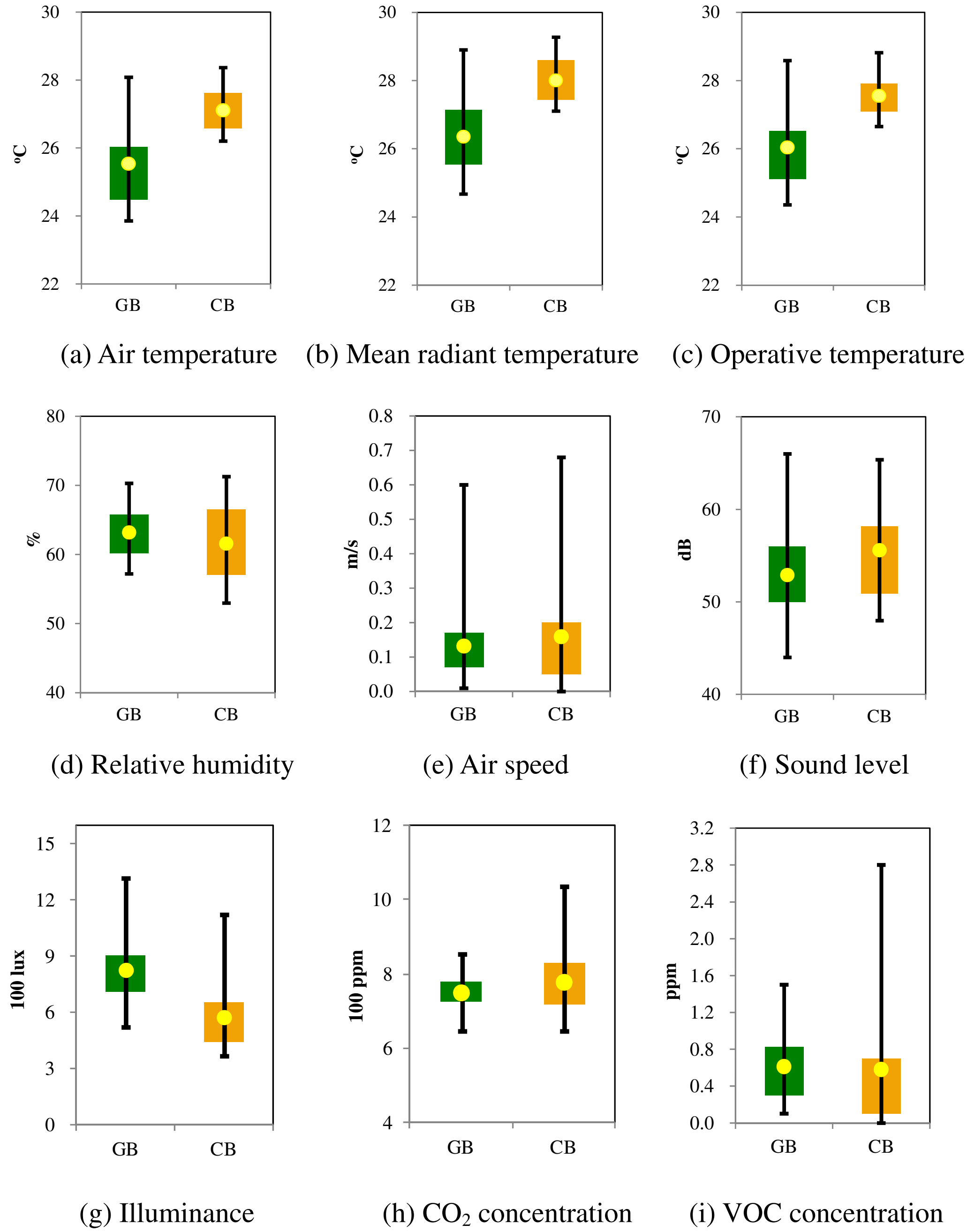

Fig. 3. Distribution of environmental variables in green buildings (GB) and conventional buildings (CB) from April to October of 2012.

856 ppm, respectively, whereas their counterparts measured in the conventional buildings were 654, 783, and 1080. The mean VOC concentration (Fig. 3i) in the green buildings and conventional buildings was 0.61 ppm (0.10–1.50 ppm) and 0.58 ppm (0.00–2.80 ppm), respectively; both values were higher than the 0.56 ppm recommended by Taiwan's Environmental Protection Administration [38].

As previously introduced, both the green and conventional buildings evaluated in this study shared a similar AC management scheme. Under this scheme, the AC was activated daily during the office operation hours as in the day the room temperature inside these buildings was seldom below the target threshold. In addition, all these buildings shared a similar interior design and density of occupancy, and the office occupants were primarily engaged in typical office works of low metabolic load. These office functions did not suggest a significant gain of heat from activities inside the office. The illuminance was greater in the green buildings compared to that in the conventional buildings (Fig. 3g), which appeared to suggest a potential inner gain of heat from the solar/artificial lighting. However, in the investigated green buildings the energy-efficient fluorescent lamps T5 were used, which had a lower lighting power density than the fluorescent lamps T8 in the conventional buildings. Thus, in the green buildings a greater illumination could be achieved without the cost of higher energy consumption and subsequent heat gain compared to the condition in the conventional buildings. This was evidenced by the lower t_r in the green buildings compared to the level in the conventional buildings (Fig. 3b). As the distribution of t_a in both types of buildings was comparable to that of t_r, the direct solar radiation did not seem to be a significant source of heat gain in these buildings neither. We suggested that the t_o as observed in the conventional buildings was primarily influenced by the room temperature targeted and set by the building management; particularly as the distribution of t_o readings in these buildings (Fig. 3c) closely tracked the setpoint in room temperature controlled in each of the monitored buildings. The higher setpoint observed in the conventional buildings could be associated with the private ownership of these buildings, which typically was inclined more toward cost-effective strategies in energy management.

3.2. Satisfaction on indoor environmental quality

While the measurement of physical environment as discussed in the last section shows a compliance of major environmental variables in these buildings to the regulatory or recommended standards, the results of such measurements did not indicate if the occupants were comfortable with the IEQ in these buildings. For comparison, the data from questionnaire surveys were divided into the green building group and the conventional building group. For each question in the questionnaire, the votes of “very dissatisfied” (−3), “dissatisfied” (−2), and “slightly dissatisfied” (−1) were pooled into a single category of “uncomfortable” while those of “very satisfied” (+3), “satisfied” (+2), and “slightly satisfied” (+1)

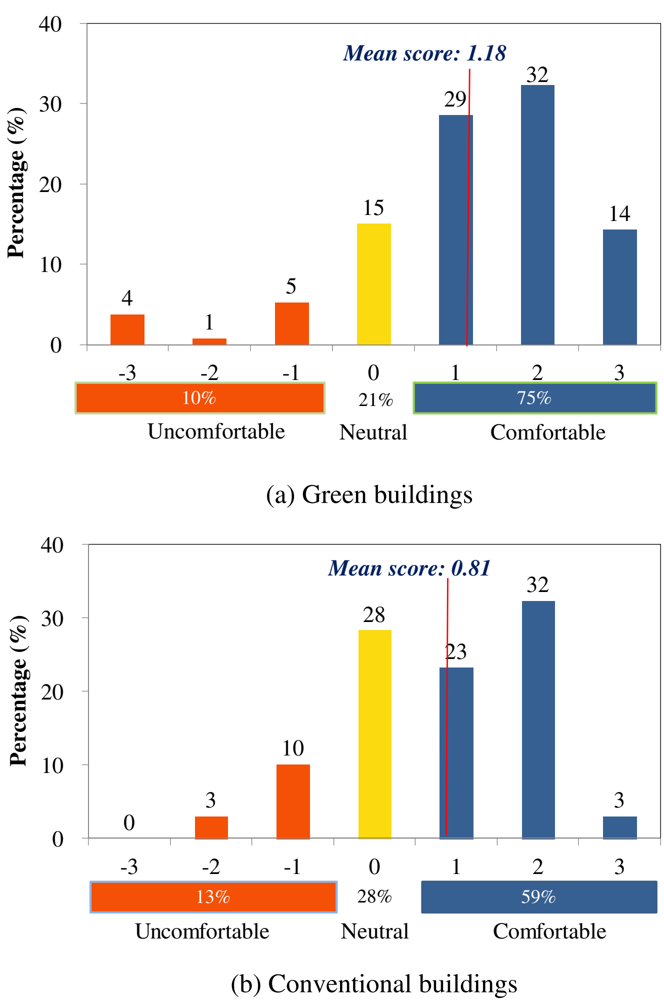

Fig. 4. Distribution in frequency of votes corresponding to different levels of comfort toward IEQ as expressed by indoor occupants in questionnaire survey.

into the category of “comfortable”. Fig. 4 shows the distribution of frequencies demonstrating the overall IEQ satisfaction and comfort level of the occupants in the office buildings. As the results show, only about 10% of the respondents in the green building group were uncomfortable with the overall IEQ in their workplace (Fig. 4a), suggesting that in general the green buildings was able to deliver an indoor environment of comfort to their occupants. Thirteen percent of the occupants in the conventional building group voted “uncomfortable” to the overall IEQ (Fig. 4b). Although the ratios of uncomfortable votes were similar between both groups, more people (28%) were neutral to the overall IEQ in the conventional buildings than the percentage (15%) in the green buildings. The contrast between both groups was further enlarged in the “comfortable” category—only 59% of the respondents in the conventional building group sensed the IEQ as comfortable whereas 75% in the green building group claimed the same perception. The mean score of votes on IEQ in the green building group was 1.18 (i.e., equivalent to a sensation in between slight satisfaction and satisfaction), 0.37 higher than the mean of 0.81 reported for the conventional building group (between neutral and slight satisfaction).

Fig. 5 demonstrated the distribution in frequency of reports for the sources contributing to an uncomfortable or neutral IEQ sensation. Again the “uncomfortable” frequency was calculated as the ratio of the votes on “very dissatisfied”, “dissatisfied”, and “slightly dissatisfied” in the questionnaire survey to the total votes. In both the green buildings and conventional buildings, “too warm” was the top source underlying the uncomfortable and neutral IEQ sensation; over 75% of the respondents indicated their workplace as being too warm. In the case of green buildings, the sources of uncomfortable sensation that immediately followed “too warm” were, in the descending order, “foul air”, “odors”, “noise (inside)” and “still air”. For conventional buildings, the second to the fifth sources were “odors”, “foul air”, “still air”, and “too humid”. The sources that least contributed to the uncomfortable sensation included “glare (artificial light)”, “glare (daylight)”, “draughty air”, “too dry”, and “too cold” in both the green and conventional building groups; these issues were addressed by less than 15% of the respondents.

In the survey, the respondents were asked to express their perception, as a level of comfort, towards individual areas of IEQ concern, including the building’s performance in acoustics, lighting, thermal status, and IAQ. As shown in Fig. 6, the levels of comfort among the employees working in the green buildings in all areas were significantly higher than their counterparts in the conventional building group. However, in both groups the occupants were less comfortable with the thermal conditions and the IAQ than with the acoustic and lighting performance of the buildings. In the case of thermal performance, more occupants in the conventional buildings opted for an uncomfortable perception than did for the comfortable sensation. Corresponding to the sources of uncomfortable sensation identified in Fig. 5, these results suggested that poor thermal conditions and IAQ in these buildings, as shown in Fig. 3, were the main accounts for the negative response of the occupants toward the thermal environment they worked in.

4. Discussion

4.1. Variation in satisfaction between green versus conventional buildings

Table 6 summarized the mean score of satisfaction voted by the occupants of green buildings vs. conventional buildings toward the performance of the studied buildings in acoustics, lighting, thermal conditions, and IAQ. To verify the difference observed in

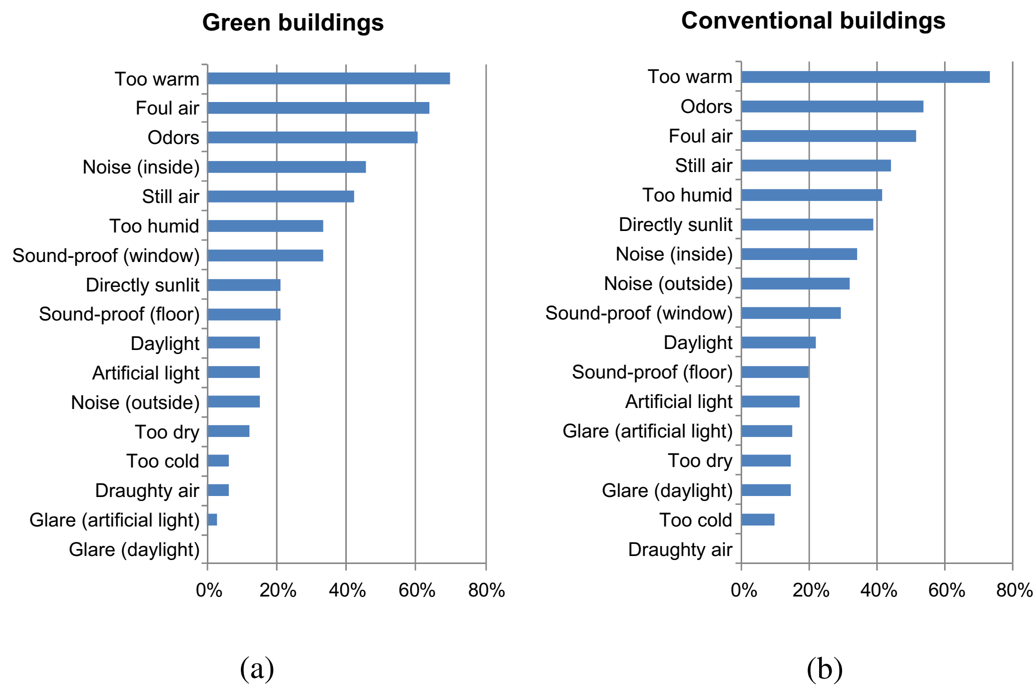

Fig. 5. Distribution in frequency of reports for different sources contributing to uncomfortable and neutral sensation toward indoor air quality.

satisfaction, the mean scores rated for the specific IEQ areas and for the overall IEQ between the two building groups were statistically compared using the two-tailed t-test. As shown in Table 6, for all of the concerned IEQ areas as well as for the overall IEQ, the means for the green building group were greater than those for the conventional groups. For the acoustic and lighting performance, the green buildings scored mean values of over 0.9 (indicating a perception close to "slightly satisfied") while the conventional buildings only scored values of around 0.6, with the difference in the score of acoustic performance between the green buildings (0.99) and conventional buildings (0.63) being statistically significant. For the provision of lighting, the score for the green buildings (0.92) also appeared to excel over its counterpart for the conventional buildings (0.65), although the difference was not considered statistically significant ($p > 0.05$). Among specific IEQ areas, the green buildings scored less in the thermal performance and IAQ, with the mean values in both categories being greater than but approaching zero (suggesting a slightly-satisfied-to-neutral perception). These values, however, were still much greater than those rated for the conventional buildings (between 0 and -1; a neutral-to-slightly-dissatisfied perception) at a statistically significant level ($p < 0.05$). It should be noted that in all buildings, green and conventional alike, of all the evaluated categories the rating for overall IEQ was the most prominent. This phenomenon was perhaps attributed to that the respondents were not specifically instructed to confine their perception of the overall IEQ as a comprehensive indication of acoustic, lighting, thermal, and IAQ performance of the building. As a result, the respondents might have introduced other considerations in their delivery of a grade for the overall IEQ, such as the effects from the aesthetics, atmosphere, and the space available for their workstations.

4.2. Satisfaction on individual areas versus overall environmental quality

As previously discussed (Table 1), the thermal comfort of indoor occupants was not currently included as a criterion of IEQ evaluation in Taiwan's EEWH. However, our results found the air temperature inside the office a primary source of dissatisfaction or discomfort for the occupants as far as the overall IEQ was concerned (Fig. 5). Should the thermal comfort be included as an IEQ criterion when the green buildings were certified in hot-and-humid areas such as Taiwan? To elucidate on the significance of individual IEQ aspects, including the thermal comfort, to the perception for the overall IEQ, the ratings on each aspect of the IEQ from questionnaires were pooled and correlated to those determined for the overall IEQ by means of the Pearson correlation. As Table 7 shows, the perception of the occupants for all of the specific IEQ areas under evaluation was correlated to that for the overall IEQ at a statistically significant level ($p < 0.001$), with the lowest Pearson correlation coefficient being observed in the correlation between the lighting and the overall IEQ.

4.3. Gender and view on energy conservation as factors in satisfaction

The perception of the occupants working in office buildings might be subject to influences from factors other than those associated with climatic and chemical variables controlling the physical environment. For instance, the background information collected from questionnaire surveys revealed that approximately 37% of the survey respondents were not highly concerned with issues surrounding energy conservation (Table 3). Whether the view of the respondents on energy use played a role in their IEQ perception and to what extent this factor might affect the perception was another area of interest in understanding the complexity involved in the IEQ evaluation. To examine these effects, the survey data were partitioned dichotomously into groups of gender as well as groups of viewpoint on energy conservation (including the concerned and less concerned groups). The gender was selected as a factor of investigation as research had shown a difference between males and females in the requirements of IEQ and thermal comfort as a result of gender-specific variation in physiology and physical fitness [39–41]. Again, to verify the authenticity of any observed

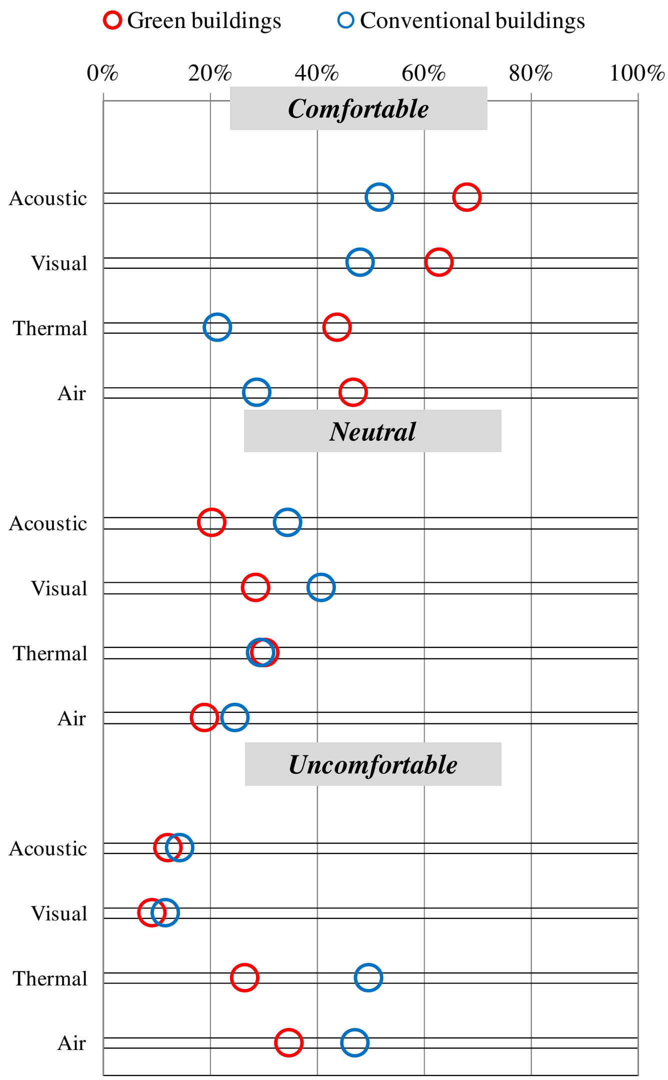

Fig. 6. Level of comfort among office occupants toward performance of buildings in specific areas of indoor environmental quality.

differences, the mean scores of satisfaction between the gender groups and between the energy viewpoint groups were compared using the two-tailed *t*-test.

As Table 8 shows, the mean score rated by female participants in this study on the overall IEQ (1.14) was 0.29 greater than the level voted by male participants (0.85). For the thermal comfort, the score from the females (0.0) was also higher than that from the males (−0.24). While the differences observed were not statistically significant, they suggested that the female participants were more content with the overall IEQ and the thermal status inside the investigated buildings. As for the influence from the view on energy conservation, the results show that the respondents with a greater concern for energy expenditure were more tolerant of the IEQ in their working environment than those of a lesser concern. The mean score rated by the group of concern for energy consumption was 1.16 for the overall IEQ, 0.39 higher than the level reported for the group of lesser concern. The difference widened when it was the thermal comfort being evaluated—the score from the group of concern was 0.44 higher than that from the group of lesser concern. It should be noted that for the group of lesser concern the average score on thermal comfort was only −0.37, suggesting a neutral-to-slightly-dissatisfied perception. The differences between the groups of different views on energy use were all statistically significant ($p < 0.05$).

Table 6
Average scores of satisfaction voted by occupants of green buildings and conventional buildings in specific areas of IEQ.

Area of IEQ concern	Green buildings	Conventional buildings	p value[a]
Acoustic	0.99	0.62	0.030[b]
Visual	0.92	0.65	0.081
Thermal	0.23	−0.52	0.000[b]
Air quality	0.13	−0.35	0.016[b]
Overall	1.18	0.81	0.028[b]

[a] Two-tailed *t*-test was employed to compare score from green building group versus that from conventional building group in each area of IEQ concern.
[b] denotes a statistical significance of test result at a level of $p < 0.05$.

The awareness of environmental issues among indoor occupants has been shown [28,30,42] to associate with the level of acceptance or tolerance to the IEQ. Frequently, the requirement of energy usage for delivering a thermally comfortable environment would disagree with the energy-saving approach practiced in the workplace for limiting the use of AC. However, the occupants with an elevated level of environmental concern, particularly those who identified with the concept of green buildings, were more amenable to less-than-ideal IEQ conditions in the buildings that they worked in. The results observed in this study on the effect of environmental awareness on IEQ perception suggested that: the indoor occupants sharing a greater concern with environmental issues might tolerate poor IEQ performance to a greater extent, and their displeasure toward specific aspects of IEQ did not necessarily transform into dissatisfaction on the overall IEQ.

5. Conclusions

The green building movement has revolutionized the way the architectural industry envisions and designs buildings for promotion of environmental sustainability. Among the numerous efforts in this movement, the establishment of green building certification systems worldwide is one of the most prominent and ensures a systematic approach to continuing these efforts. However, the majority of researches to date have shared a strong focus on the effectiveness of green buildings in energy-saving and less on keeping an IEQ appropriate for indoor occupants. In this study, the IEQ in both the EEWH-certified and non-certified office buildings in Taiwan were evaluated using a post-occupancy approach to obtain feedback from their occupants on how well these buildings performed in meeting the occupants' IEQ demands. As an evidence-based approach, this study provided an opportunity to examine if the current criteria established in Taiwan's EEWH delivered on developing a healthy and productive working environment. The inclusion of non-EEWH-certified buildings also served as a baseline of comparison to facilitate a better understanding on the contribution of Taiwan's green building certification system toward ensuring an IEQ inside the green office buildings and needed improvements. The primary findings of the study included:

Table 7
Pearson correlation between perception of office occupants toward individual areas of IEQ and satisfaction on overall IEQ.

Overall IEQ	Acoustic	Visual	Thermal	Air quality
Correlation coefficient	0.642	0.445	0.555	0.588
p value[a]	0.000**	0.000**	0.000**	0.000**

[a] ** denotes a statistical significance of correlation at a level of $p < 0.001$.

Table 8
Average scores of satisfaction on a 7-point scale voted by occupants in groups of gender and groups of different view on energy conservation toward overall IEQ and thermal comfort.

	Statistical quantity[a]	Sex		View on energy conservation	
		Female	Male	Concerned	Less concerned
Overall IEQ	Mean	1.14	0.85	0.77	1.16
	p value	0.108		0.029[b]	
Thermal comfort	Mean	0.00	−0.24	−0.37	0.07
	p value	0.233		0.033[b]	

[a] Two-tailed t-test was employed to compare scores from groups of gender and groups of different view on energy conservation in each area of IEQ concern.
[b] Denotes a statistical significance of test result at a level of $p < 0.05$.

(1) The on-site monitoring of environmental variables indicated a compliance of major constituents of environmental quality with international recommendations and Taiwan's regulatory standards. On average, the green buildings provided a better quality in the t_o, air speed, illumination, CO_2 concentration, and VOC concentration, whereas the conventional buildings excelled in the RH and sound level.
(2) The results of questionnaire survey indicated that the occupants in the green buildings were more satisfied with the overall IEQ (a mean score of 1.08 on a 7-point scale ranging from +3 to −3) than those in the conventional buildings (0.81). Green and conventional buildings alike, the t_o being too warm was the top reason why the occupants were uncomfortable with the IEQ.
(3) Regarding the occupants' perception toward specific aspects of IEQ, the findings suggested a superior satisfaction from the employees working in green buildings for the building performance in acoustics, lighting, thermal conditions, and IAQ, compared to the perception expressed by those working in conventional buildings. Except for lighting performance, the difference in levels of satisfaction between the occupants in green buildings and those in conventional buildings were all statistically significant.
(4) The analysis of overall IEQ and thermal comfort satisfaction between the respondents of different views on energy conservation indicated that the occupants sharing a concern of energy conservation were more amenable to the IEQ inside the building than those less concerned with the issue; the difference was statistically significant. Gender-wise, female participants were more satisfied with the overall IEQ and the state of thermal comfort than the male participants were. The difference, however, was not statistically significant ($p > 0.05$).

While these findings provided a snapshot on the overall and specific areas of IEQ performance in the EEWH-certified vs. non-certified buildings, limited by the information available on the certification details and employee's socioeconomic status, this study did not further compare between the green and conventional buildings and or characterize how various sources might have introduced uncertainty to the observed differences in the IEQ performance. For example, if the scores achieved in different IEQ criteria by these certified buildings during the certification were available, the differences in IEQ performance attributable to the design of these buildings would be possible—a building receiving a passing grade in the certification might not distinctly excel over a building not certified simply because of being built at an age prior to the enactment of the certification system. Similarly, to fully characterize the adaptive behaviors of office occupants toward a less-than-ideal thermal environment, information on the employee's educational and socioeconomic backgrounds in relation to their view on energy conservation is needed.

The requirement of thermal comfort and that of energy savings did not always agree with each other, as the delivery of a thermally comfortable environment often required a greater usage of AC in the summer, particularly in areas of hot-and-humid climate. In Taiwan, as of current the EEWH excluded the thermal comfort as an IEQ evaluation criterion out of the same concern. While the employees of a greater environmental awareness were more acceptable of a thermally less-than-comfortable environment, as our study showed, the satisfaction of the office occupants toward the overall IEQ was also significantly correlated to their perception in the thermal performance of the buildings. A re-visit on this issue is essential and perhaps revision of IEQ criteria in Taiwan's green building certification is required to facilitate a balanced emphasis on energy-saving and thermal comfort in the accreditation of green buildings in Taiwan.

Acknowledgments

The funding to this study was provided by the Architecture and Building Research Institute, Ministry of the Interior, Taiwan, under the project number 10163B001.

References

[1] Kaarlela-Tuomaala A, Helenius R, Keskinen E, Hongistoa V. Effects of acoustic environment on work in private office rooms and open-plan offices – longitudinal study during relocation. Ergonomics 2009;52:1423–44.
[2] Abdou OA. Effects of luminous environment on worker productivity in building spaces. J Archit Eng 1997;33(3):124–32.
[3] Nicol F, Wilson M, Chiancarella C. Using field measurements of desktop illuminance in European offices to investigate its dependence on outdoor conditions and its effect on occupant satisfaction, and the use of lights and blinds. Energy Build 2006;38:802–13.
[4] Mahbob NS, Kamaruzzaman SN, Salleh N, Sulaiman R. Correlation and regression studies of indoor environmental quality (IEQ), human productivity, comfort and stress level in office buildings. Adv Sci Lett 2013;19(1):342–5.
[5] Kosonen R, Tan F. Assessment of productivity loss in air-conditioned buildings using PMV index. Energy Build 2004;36:987–93.
[6] Mohamed S, Srinavin K. Forecasting labor productivity changes in construction using the PMV index. Int J Ind Ergon 2005;35:345–51.
[7] Wyon DP. The effects of indoor air quality on performance and productivity. Indoor Air 2004;14(7):92–101.
[8] Kosonen R, Tan F. The effect of perceived indoor air quality on productivity loss. Energy Build 2004;36:981–6.
[9] Haynes BP. The impact of office comfort on productivity. J Facil Manag 2008;6:37–51.
[10] Fisk WJ, Black D, Brunner G. Benefits and costs of improved IEQ in U.S. offices. Indoor Air 2011;21(5):357–67.
[11] Fisk WJ, Rosenfeld AH. Estimates of improved productivity and health from better indoor environments. Indoor Air 1997;7(3):158–72.
[12] Kats G, Alevantis L, Berman A, Mills E, Perlman J. The costs and financial benefits of green buildings. Report to California's sustainable building task force. Washington DC, USA; 2003.
[13] Singh A, Syal M, Grady SC, Korkmaz S. Effects of green buildings on employee health and productivity. J Public Health 2010;100:1665–8.
[14] Ries R, Bilec MM, Gokhan NM, Needy KL. The economic benefits of green buildings – a comprehensive case study. Eng Econ 2006;51(3):259–95.
[15] Loftness V, Hartkopf V, Poh LK, Choi J, Snyder M. Sustainability and health are integrated goals for the built environment. Proc Healthy Build 2006;1:1–17.
[16] Thatcher A, Milner K. The impact of a green building on employees' physical and psychological wellbeing. Work 2012;41:3816–23.
[17] Yudelsen J. The green building revolution. Washington, DC, USA: Island Press; 2008.
[18] Thomas LE. Evaluating design strategies, performance and occupant satisfaction – a low carbon office refurbishment. Build Res Inf 2010;38(6):610–24.
[19] Leaman A, Thomas L, Vandenberg M. Green buildings: what Australian building users are saying? EcoLibrium 2007;6:22–30.
[20] Huizenga C, Abbaszadeh S, Zagreus L, Arens E. Air quality and thermal comfort in office buildings – results of a large indoor environmental quality survey. Proc Eighth Int Conf Healthy Build 2006;3:393–7.
[21] Armitage L, Murugan A, Kato H. Green offices in Australia: a user perception study. J Corp Real Estate 2011;13(3):169–80.
[22] Abbaszadeh S, Zagreus L, Leher D, Huizenga C. Occupant satisfaction with indoor environmental quality in green buildings. Proc Eighth Int Conf Healthy Build 2006;3:365–70.

[23] Issa MH, Rankin JH, Attalla M, Christian AJ. Absenteeism, performance and occupant satisfaction with the indoor environment of green Toronto schools. Indoor Built Environ 2011;20(5):511–23.
[24] Fowler KM, Rauch EM. Assessing green building performance: a post occupancy evaluation of 12 GSA buildings. WA, USA: Department of Energy; 2008.
[25] Lee YS, Kim SK. Indoor environmental quality in LEED-certified buildings in the US. J Asian Archit Build Eng 2008;7(2):293–300.
[26] Altomonte S, Schiavon S. Occupant satisfaction in LEED and non-LEED certified buildings. Build Environ 2013;68:66–76.
[27] Paul W, Taylor P. A comparison of occupant comfort and satisfaction between a green building and a conventional building. Build Environ 2008;43:1858–70.
[28] Leaman A, Bordass B. Are users more tolerant of 'green' buildings? Build Res Inf 2007;35:662–73.
[29] Gou Z, Lau SSY, Chen F. Subjective and objective evaluation of the thermal environment in a three-star green office building in China. Indoor Built Environ 2012;21:412–22.
[30] Gou Z, Prasada D, Lau SY. Are green buildings more satisfactory and comfortable? Habitat Int 2013;39:156–61.
[31] Gou Z, Lau SY, Zhang Z. A comparison of indoor environment satisfaction between two green buildings and a conventional building in China. J Green Build 2012;7(2):89–104.
[32] ABRI. EEWH green building evaluation system of Taiwan. Taipei, Taiwan: Architecture and Building Research Institute (ABRI), Ministry of the Interior; 2009.
[33] Huang CS. Construct predictive model to important factors of green structure difference comparison between experts and consumers [M.S. thesis]. Kaohsiung, Taiwan: I-Shou University; 2008.
[34] Chiang CM, Lai CM. A study on the comprehensive indicator of indoor environment assessment for occupants' health in Taiwan. Build Environ 2002;37:387–92.
[35] ISO. ISO 7726-1998: ergonomics of the thermal environment – instruments for measuring physical quantities. Geneva, Switzerland: International Organization for Standardization (ISO); 1998.
[36] ANSI/ASHRAE. Standard 55-2004: thermal environmental conditions for human occupancy. Atlanta, GA, USA: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE); 2004.
[37] CIE. CIE S 008/E-2001 (ISO 8995-1-2002): lighting of work places – part 1: indoor. Vienna, Austria: International Commission on Illumination (CIE); 2001.
[38] Taiwan EPA. Indoor air quality act. Taipei, Taiwan: Taiwan Environmental Protection Administration (Taiwan EPA); 2011.
[39] Karjalainen S. Thermal comfort and gender – a literature review. Indoor Air 2012;22(2):96–109.
[40] Indraganti M, Rao KD. Effect of age, gender, economic group and tenure on thermal comfort – a field study in residential buildings in hot and dry climate with seasonal variations. Energy Build 2010;42:273–81.
[41] Chen CP, Hwang RL, Chang SY, Lu YT. Effects of temperature steps on human skin physiology and thermal sensation response. Build Environ 2011;46:2387–97.
[42] Deuble MP, de Dearb RJ. Green occupants for green buildings – the missing link? Build Environ 2012;56:21–7.