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Satisfaction of Occupants on Indoor Environmental Quality in Green Versus Conventional School Building

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Abstract
With an increasing concern in the occupants' health, in recent years the indoor environmental quality (IEQ) that a green building may provide to its users is gaining visibility. This study compared the IEQ inside a school building of green design and that of a conventional design located in middle Taiwan through IEQ monitoring and questionnaire survey, and realized the potential contribution of the green building in meeting the comfort requirements of its occupants. The evaluation was conducted in seven classrooms on each campus in May and June of 2012, with 105 and 108 students participating in the green and conventional building, respectively. The monitored IEQ parameters included those related to thermal comfort and indoor air quality, and the survey consisted of questions evaluating the occupants' satisfaction in five areas, the overall environment, acoustics, ventilation, lighting, and thermal status. The monitoring results show: with the air-conditioning in use the thermal status in both buildings was maintained at a similar level; the noise and lighting were also of a comparable level between these buildings. However, both buildings failed to maintain an indoor concentration of carbon dioxide and volatile organic compounds below the regulatory recommendations. The occupants of green building were more satisfied with the IEQ in all IEQ areas (39-50%) than those of conventional building (33-42%). These findings demonstrated that green building design might potentially improve the IEQ perception in Taiwan's schools. However, additional efforts are required to ensure that the IEQ in these schools meet the regulatory demands.

Keywords - indoor environmental quality; green building; school; perception and satisfaction

1. Introduction

In recent years the green building has become a focal point in architectural design and development around the globe owing to its energy-saving and environmentally sustainable attributes. In Taiwan, a system for evaluating green building was established in 1996 when Taiwan's Council for Economic Planning and Development adopted "Green Building" as a key initiative in "Policies on Sustainable Development of Building and Planning". Later, Taiwan's Ministry of the Interior implemented the "Green Building and Residential Environment Technology Program" to assess the attributes of various architectures in association with energy/water consumption, drainage, and environmental harmony in sub-tropical weather, and subsequently developed Taiwan's official system for green building evaluation in 1999 [1]. As of April, 2012, a total of 3,238 green building labels or candidate certificates had been issued by this evaluation system since its inauguration.

Along with the global movement in green building design, various efforts have embarked on evaluating the effects green building design on indoor environmental quality (IEQ). I.G. Monfared and Sharples [2] reported that a divergence between the anticipation vs. actual perception of the occupants on green building was often observed in association with the satisfaction of the occupants toward the overall green building approach. Abbaszadeh et al. [3] conducted a large-scale IEQ evaluation aiming to identify the satisfaction of the indoor occupants in green vs. non-green building toward the IEQ in relation to the building design. In a study investigating the perception of the occupants on green building, Deuble and de Dear [4] observed that the level of IEQ satisfaction was positively correlated to the environmental belief of the indoor occupants, supporting the hypothesis of environmentally concerned individuals being more in favor of the green building design. Leaman and Bordass [5] performed an IEQ evaluation on different designs of buildings and also reported a difference in the satisfaction between the users of the green and conventional buildings toward IEQ. In Toronto, Canada, the study by Issa et al. [6] found that in schools where green buildings were the primary architecture the teachers rated the IEQ, the lighting, and the thermal environment better than those in the conventional schools did. Guo et al. [7] in their observations concluded that the green building movement began to gradually weigh more on the IEQ-relevant issues, particularly on concerns of the occupants' health. Guo et al. [8] also explored the causes of green buildings failing the expectations of the occupants and recommended strategies for improvement in the future design of green building. Paul and Taylor [9] demonstrated that in terms of human comfort the green building did not always excel over the

conventional building. Furthermore, the evaluation of IEQ in green building has now being used to devise strategies of green building improvement. For examples, Singh et al. [10] through a case study demonstrated the hardware and software investments that would be required of for an LEED office building to comply with the criteria for IEQ improvement and the benefits that might result from the improvement. Fowler and Rauch [11] in their evaluation of an LEED-certified building found a greater level of satisfaction among the occupants of the LEED building when compared to those expressed by the occupants of a conventional building in terms of the working environment, thermal comfort, indoor air quality, lighting, acoustics, tidiness, and ease of maintenance.

The study described here investigated the effects of a green school building on IEQ in Taiwan. For the green building erected in school here, the building was typically used at a high frequency and density. In this study, the IEQ inside the school building of the green design and a building of a conventional design was monitored and the subjective perception among the students surveyed, and the potential contribution of the green building in meeting the comfort requirements of its users was analyzed.

2. Study Design and Methods

Two school buildings located on different campuses in middle Taiwan, one of a certified green building design and the other of a conventional design, were simultaneously monitored for IEQ parameters and surveyed for the occupants' IEQ perception. The evaluation was conducted in 7 classrooms on each campus in May and June of 2012. The monitored IEQ parameters included those related to the thermal comfort and indoor air quality, and the survey consisted of questions evaluating the occupants' satisfaction in five specific areas of IEQ, the overall environment, acoustics, ventilation, lighting, and thermal status.

To evaluate the IEQ in the classrooms, a walk-through monitoring of environmental variables was conducted alongside the questionnaire survey of subjective perception. In all sessions of walk-through monitoring, microclimatic parameters directly relevant to human thermal comfort, including the air temperature, relative humidity, air speed, and globe temperature, and those associated with indoor air quality, including the concentrations of carbon dioxide (CO_2) and volatile organic carbon (VOC), were measured. Also monitored were the levels of noise in the room and of lighting from a height equivalent to the desktop of the student's seat. To minimize the interruption of monitoring activities to the class in session, only portable equipments were used in the walk-through monitoring—the equipments were installed on a cart to grant portability for access to various sampling points in the room. In each session the monitoring was continued

for at least 20 min; and the average of the data recorded in this period was used to represent the overall distribution of the monitored parameter. For each classroom included in the study, the questionnaire survey and environmental monitoring were conducted twice a day, once between 10:30 to 12:00 am and the second from 2:00 to 4:30 pm. To reduce the possibility of a potential bias introduced in the questionnaire survey, the tasks in environmental monitoring were performed only after the questionnaire survey was complete.

The questionnaire survey provided an opportunity for the students to grade, subjectively, the IEQ of the space they were in based on their long-term observation and perception. The questionnaire consisted of two parts. Part I requested personal information including the age, the sex, and the individual's knowledge on issues relevant to energy-saving/carbon use reduction, IEQ, and green building, whereas Part II gauged the specific perception of the individual toward different aspects of IEQ in the surveyed classroom. For each question in the questionnaire, the perception was ranked by choosing from one of the following 7 grades: -3, -2, -1, 0, 1, 2, and 3. In this scale, the number "0", the positive numbers, and the negative numbers indicated a neutral, satisfied, and dissatisfied perception, respectively. The greater or less the number was, the stronger the named sensation.

Five areas of IEQ were evaluated in the questionnaire survey, including the overall environment, acoustics, ventilation, lighting, and thermal status. For each area 3-5 specific questions were provided. For the perception on the overall environment, the questions included if the building was appealing vs. unattractive, if the building made the surveyed individual tense vs. relaxing, if the building appeared as dull vs. colorful, and if the overall environment was satisfactory. On the front of acoustics, the surveyed individual was asked if the outdoor/indoor environment was noisy, if the acoustic insulation by the windows, walls, or flooring was sufficient, and if the acoustic performance of the building was satisfactory. For ventilation, the individual was asked to rate the movement of the indoor air, the odor of the air, the grogginess caused by the air, and if the ventilation was satisfactory. The questions on lighting included the sufficiency of the indoor lighting provided by artificial lighting vs. from natural lighting, the glare, and if the lighting was satisfactory. For thermal status, the questions consisted of the perception of solar radiation indoors, the sensation of hotness vs. coldness, the sensation of dryness vs. wetness, and if the occupants were satisfied with the thermal status.

3. Results and Discussion

A total of 105 and 108 students participated in the study in the green building and the conventional building, respectively; all of them were

registered college and graduate students, with an age below 30. Their gender distribution and their current understanding to issues related to energy conservation, green building, and IEQ were summarized in Table 1. As the energy conservation and carbon use reduction were current issues raising global attention, over 90% of the students from both the green building and the conventional building groups shared their concern. Interestingly, the level of concern with the green building-related issues was 4% lower in the green building group than that in the conventional building group. However, for the IEQ-related issues the students sharing concern in the green building group was 28% more than those showing a similar concern in the conventional group.

In the study there were 7 individual classrooms monitored in each of the green and conventional school buildings. As the monitoring was conducted when the class was in session, the air-conditioning was used in all the classrooms during the monitoring. Table 2 summarized the results of the IEQ measurements.

Table 1 Distribution of gender and understanding on issues related to energy conservation, green building, and IEQ of participants surveyed in this study

	Sex		Issues on Green Building		Issues on Energy Saving/ Carbon Use Reduction		Issues on Indoor Environmental Quality	
	Male	Female	C‡	NC	C	NC	C	NC
GB†	24%	76%	79%	21%	92%	8%	86%	14%
CB	37%	63%	83%	17%	91%	9%	58%	42%

†GB= Green Building, CB= Conventional Building

‡C= Concerned, NC=Not Concerned

Table 2 Summary of indoor environmental monitoring conducted in green building versus conventional building in this study

		Ta‡ (°C)	Tg (°C)	RH (%)	v (m/s)	CO_2 (ppm)	VOC (ppm)	NL (dB)	LL (lx)
GB	Mean	26.2	27.1	63	0.3	1308	3.2	59	644
	Max	26.7	28.7	76	0.9	1820	12.2	71	867
	Min	25.2	26.1	50	0.1	1040	0.2	51	402
	S.D	0.7	1.0	9	0.3	261	4.5	7	164
CB	Mean	25.7	26.4	74	0.1	1141	4.5	61	491
	Max	26.6	27.4	78	0.1	2227	9.0	67	637
	Min	24.5	25.3	63	0.0	810	0.5	51	421
	S.D.	0.8	0.8	5	0.0	506	2.6	6	87

‡Ta= Air Temp, Tg= Globe Temp, RH= Relative Humidity, v= Air Speed, NL= Noise Level, LL=Lighting Level

The thermal performance of the green building and the conventional building was similar, as demonstrated in the air temperature, globe temperature, and relative humidity measured at each site, and was sufficient to maintain a thermally comfortable environment for the indoor occupants. For the air movement in the classrooms, the mean air speed in the conventional building was 0.1 m/s, approaching the lower limit of the range of 0.1-0.8 m/s as recommended in ASHRAE Standard 55. On the performance of ventilation, the Taiwanese Environmental Protection Administration (EPA) recommended as a part of its "Indoor Air Quality Recommended Values" that the indoor concentrations of CO_2 and VOCs be maintained respectively at a level below 1,000 and 3 ppm. In this study, both the green building and conventional building failed to meet these criteria. On the acoustic performance, the mean level of noise in the green building was 59±7 dB, not significantly different from the level of 61±6 dB reported for the conventional building. As for the lighting in the building, the level detected at the desktop in the green building ranged from 402 to 867 lx (mean = 644 lx), while the level in the conventional building was between 421 and 637 lx (491 lx). While in general the lighting appeared to be better in the green building, both types of building sufficiently provided a lighting level fitting in the range of 300-750 lx, a range recommended in Taiwan's national standards.

Table 3 summarized the results of questionnaire survey on the perception of the students toward the IEQ in the green vs. conventional building, based on their long-term observation and perception. The "Satisfied" percentage was the ratio of those voting for +1, +2, and +3 on the 7-grade scale to the total votes, whereas the "Dissatisfied" percentage was the ratio of the votes on -1, -2, and -3 to the total votes. The "Neutral" was the percentage of votes cast on "0" on the scale.

Table 3 Results of questionnaire survey for perception of students toward IEQ in green building vs. conventional building

	GB			CB		
	S‡	N	D	S	N	D
Overall Environment	49%	27%	25%	42%	33%	25%
Acoustics	50%	33%	17%	38%	32%	30%
Lighting	49%	36%	16%	40%	45%	15%
Thermal Status	39%	41%	20%	38%	43%	19%
Ventilation	39%	35%	26%	33%	30%	37%

‡S= Satisfied, N= Neutral, D= Dissatisfied

As the results show, a higher degree of satisfaction was manifested in all IEQ areas for the green building. In particular, nearly half of the students

in the green building were satisfied with the overall, acoustic, and lighting performance of the green building. The students were less content with the thermal performance and ventilation of the green building—only 39% of the students were satisfied in these two categories. In contrast, for the conventional building the level of satisfaction ranged between 33 and 42%, with the greatest satisfaction observed in the overall environment and the least in the ventilation. These results were consistent with those observed in the environmental monitoring. For examples, as shown in Table 2 the ventilation was considered inadequate as interpreted from the generally low air speed and the high concentrations of CO_2 and VOC. In a similar manner, the ventilation was rated as the least satisfied area of the IEQ in the questionnaire survey. For the lighting performance, although the levels observed in both the green and conventional buildings were within the range recommended for an indoor environment by Taiwan's national standards, the better lighting in the green building compared to that in the conventional building was also reflected in the higher satisfaction to the lighting performance of the green building. The environmental monitoring was unable to differentiate the thermal performance between the two types of buildings. Likewise, the subjective perception toward the thermal performance was close too between the green building and the conventional building groups.

In the questionnaire, the surveyed students were also requested to evaluate the comprehensive IEQ in both types of school buildings. As Fig. 1 shows, 47% of the students in the green building were satisfied with the overall IEQ, 9% greater than the level reported by the students in the conventional building. In comparison, the rate of dissatisfaction for the overall IEQ in the green building was only 21%, 10% lower than the level observed in the conventional building.

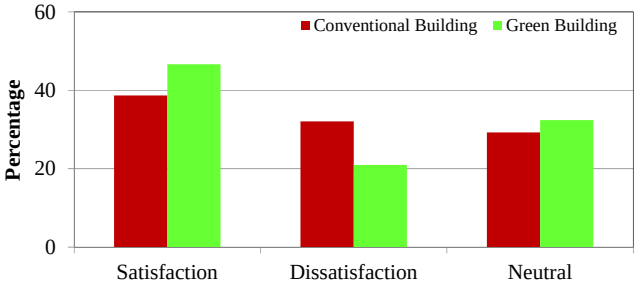

Fig. 1 Perception toward overall indoor environmental quality in green building vs. conventional building

Fig. 2 summarized the mean perception of the students in the green vs. conventional building in each of the five IEQ areas as well as in the comprehensive IEQ; again the level of satisfaction grew with the positive number increasing and the level of dissatisfaction deteriorated with the negative number decreasing. For the green building, the rating of perception in all areas of IEQ and in the comprehensive IEQ was all positive, with the highest score marked on acoustic performance and the lowest on ventilation. A mean perception between 0 and 1 on the scale for all categories of IEQ as observed in the case of green building suggested that the occupants shared a neutral-to-slightly-satisfied perception toward the IEQ in the green building. In comparison, the rate of satisfaction in all categories of IEQ performance as well as in the comprehensive IEQ for the conventional building was lower than their counterpart for the green building. The ventilation of the conventional building was even rated, on average, below 0, indicating a neutral-to-slightly-dissatisfied perception. As previously discussed, the ventilation appeared to be an IEQ area that could be improved upon in both types of buildings, and the finding here suggested a greater demand in the case of the conventional building.

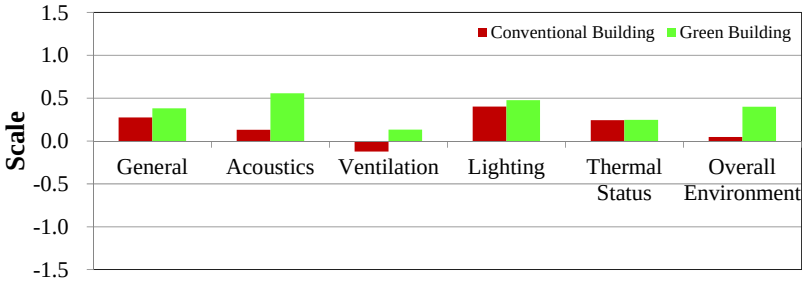

Fig. 2 Mean perception of students of green building vs. conventional building in each of the five areas of indoor environmental quality (IEQ) as well as in comprehensive IEQ

4. Conclusions and Recommendations

People spent over 80% of their waking hours everyday inside the buildings, and thus creating a comfortable environment for the occupants should be central to architectural design. As the green building movement weighs more on the IEQ performance of the building, it is essential to relate the IEQ evaluation to the perception or comfort requirements of the occupants. By means of environmental monitoring and survey of subjective perception, this study compared between a green building and a conventional building on two distinct campuses in Taiwan, and explored if a green building certified in accordance with the criteria established by the

government did provide an indoor environment of an IEQ satisfactory to the occupants. The key findings from the study included:

The results of environmental monitoring revealed that, thanks to the use of air-conditioning, both the green and the conventional school buildings were able to maintain a thermally comfortable environment. Both types of buildings were also able to control the levels of noise and lighting to an adequate level as recommended by Taiwan's national standards. However, both buildings failed to meet the recommendations of Taiwan's EPA on the building's ventilation performance. On the subjective perception of IEQ, the green building delivered a better performance on the overall environment, acoustics, lighting, thermal status, and ventilation than the conventional building did. The rate of satisfaction in all areas of the IEQ for the green building was between 39 to 50%; their counterpart for the conventional building ranged from 33 to 42%. The rate of satisfaction for the comprehensive IEQ toward the green building was 47%, 9% greater than the level reported for the conventional building. In contrast, the rate of dissatisfaction for the green building was only 21%, 10% lower than that observed in the case of conventional building.

When the mean perception on different aspects of IEQ as well as on the comprehensive IEQ between these two types of buildings was compared, in all categories the green building was rated between 0 and 1, a score indicative of a neutral-to-slightly-satisfied perception among the occupants. The green building scored the highest mark on the category of acoustics and lowest on ventilation. The conventional building received lower rate in all areas of IEQ and in the comprehensive IEQ than the green building did, with the score on ventilation being less than 0 and indicating a neutral-to-slightly-dissatisfied perception. The findings from the environmental monitoring were consistent with those extracted from the questionnaire survey.

It was noteworthy that, along with the increasing attention around the world on energy conservation and green building, the students participating in this study were also concerned with these issues—over 90% of the students shared an interest on the issues with energy saving/carbon use reduction and over 80% with green building. However, on average only about 50% of the students expressed a concern with the IEQ, with the occupants of the green building being 28% more concerned than the occupants in the conventional building.

5. Acknowledgment

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6. References

[1] "Explanation and evaluation of the Green Building Handbook" (2003)
[2] I.G. Monfared, S. Sharples, Occupants' perceptions and expectations of a green office building: a longitudinal case study, Architectural Science Review, Volume 54, Issue 4, 2011, pages 344-355
[3] S. Abbaszadeh1, L. Zagreus1, D. Lehrer1 and C. Huizenga1, (2006), Occupant satisfaction with indoor environmental quality in green buildings, Proceedings of the Eighth International Conference for Healthy Buildings 2006: Creating a Healthy Indoor Environment for People, Lisbon, Portugal
[4] M. Deuble, R. de Dear, Green Occupants for Green Buildings: The Missing Link?, Proceedings of Conference: Adapting to Change: New Thinking on Comfort, Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk
[5] A. Leaman, B. Bordass, Are users more tolerant of 'green' buildings? Building Research & Information (2007) 35(6), 662–673
[6] M.H. Issa, J.H. Rankin, M. Attalla, A.J. Christian, Absenteeism, Performance and Occupant Satisfaction with the Indoor Environment of Green Toronto Schools, Indoor and Built Environment 2011;20;5:511–523
[7] Z.H. Gou, S.Y. Lau, J Shen , Indoor Environmental Satisfaction in Two LEED Offices and its Implications in Green Interior Design, Indoor and Built Environment, 2011; 000:1-12
[8] Z.H. Gou, S.Y. Lau, F.N. Chen, Subjective and Objective Evaluation of the Thermal Environment in a Three-Star Green Office Building in China, Indoor and Built Environment 2011; 000:1-12
[9] W. L. Paul, P. A. Taylor, A Comparison of Occupant Comfort and Satisfaction between a Green Building and a Conventional Building, Building and Environment 2008; 43:1858-1870
[10] A. Singh, M. Syal, S. Korkmaz, S. Grady, Costs and Benefits of IEQ Improvements in LEED Office Building, Journal of Infrastructure Systems
[11] K. M. Fowler, E. M Rauch,. (2008). Assessing green building performance: A post occupancy evaluation of 12 GSA buildings, Pacific Northwest National Laboratory.

AUTHOR INDEX

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