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Original Article

Indoor Air Quality Assessment in a Radiantly Cooled Tropical Building: a Case Study

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Abstract

Background: Many studies have been conducted to assess the indoor air quality (IAQ) of buildings throughout the world because it is closely related to comfort, safety and work productivity of occupants. However, there is still lack of available literature about IAQ in tropical buildings that apply radiant cooling systems in conditioning the indoor air.

Methods: This paper reports the results obtained from an IAQ audit that was conducted in a new radiantly cooled building in Malaysia, by focusing on the IAQ and thermal comfort parameters.

Results: It was identified that the measured concentration levels for the five indoor air contaminants (CO, CO_2, TVOC, formaldehyde and respirable particulates) were within the threshold limit values (TLVs) specified in the IAQ guidelines. Besides, no significant difference was found between the contaminant levels in each floor of the studied building, and a majority of the respondents did not encounter any form of physical discomfort. There is a risk of condensation problem, judging from the measured RH level.

Conclusion: An increase of airflow rate and more dehumidification work in the studied building can be made to improve IAQ and prevention of condensation problem. Nevertheless, these schemes should be implemented carefully to avoid occupants' discomfort. Relocation of workstations was suggested, especially for the lower floors, which had higher occupancy levels.

Keywords: Indoor air quality (IAQ), Radiant cooling systems, IAQ audit, Indoor air contaminants, Condensation

Introduction

The level of air movement has a direct impact on the air quality in buildings (1). In interior spaces of high-rise buildings, the air movement is largely dependent on the use of air-conditioners, since natural ventilation is impractical in some of the enclosed spaces such as the lift lobby and meeting rooms, owing to the building safety requirements (2). Cooling of interior spaces by using a combined radiant-convective air-conditioning system is a relatively new technology for people in the tropics, although this system has been used in the moderate climate for many years. The use of such a combined system in cooling and dehumidification of indoor air has gained popularity in tropical buildings due to its effectiveness in reduction of peak cooling load demand and subsequently, the energy cost. Yet, the available literature about the IAQ conditions in tropical buildings that are cooled via the radiant-convective approach is rather meagre at present. The concerns on potential condensation problem in buildings often limited the application of this type of cooling system (3 - 4). Hence, a tropical building in Malaysia that was equipped with a radiant slab cooling system was selected for IAQ audit in this study. This type of audit is particularly useful in identifying the health related issues in buildings (5). Both physical measurement and questionnaire survey methods were used by referring to guidelines prescribed in ASHRAE Standard 62.1 (6) and DOSH ICOP (7). It was aimed to analyse the concentration levels of air contaminants, thermal environment, air-change effectiveness as well as the occupants' health conditions.

Materials and Methods

This IAQ audit was administered in a radiantly cooled building in Putrajaya, Malaysia to identify the conditions of IAQ after a formal approval was obtained from the administrative department. The five major indoor air contaminants (CO, CO_2, TVOC, formaldehyde and suspended particulates) specified in DOSH ICOP (7) were measured by using calibrated IAQ meters and the psychological parameters of occupants were assessed via the questionnaire survey method. A portable multi-function anemometer with an accuracy of ± 0.05% was used to measure the ambient air temperature, air velocity and relative humidity (RH). The meters were positioned at about 1m above the ground level and centre of the office space by adhering to the specifications provided in the abovementioned IAQ guidelines. Besides, the air-change effectiveness of the studied building was measured by applying the tracer-gas method, in which the CO_2 gas was released into a selected meeting room and the concentration decay was then measured. Figure 1 presents the equipment used and the measurement work in progress. An ANOVA test was also carried out to identify the significance of pollutants in each floor of the building under consideration.

a. TVOC meter

b. CO/CO_2 meter and anemometer

c. Arrangement of measuring equipment

d. Subjective assessment – Questionnaire survey

Fig. 1: IAQ meters used and the measurement work in progress

Results

Concentrations of chemical parameters

The concentration levels of CO, CO_2, TVOC, suspended particulates (PM_{10}) and formaldehyde gas in a radiantly cooled building were measured in October 2012. This office building was a new governmental building that had only operated for about 15 months when the audit was conducted. For each floor of the building, at least 10 air samples were collected and analysed. The range of CO_2 concentration level was found as within 438 – 889 ppm and the measured CO concentration range was 0 – 3 ppm. Both TVOC and PM_{10} were found to be low in this work, where the concentration levels were within 0 – 0.1 ppm and 0.0676 – 0.0686 mg/m^3 respectively. Likewise, the concentration of formaldehyde gas was very low as compared to the prescribed threshold limit value (TLV) in DOSH ICOP (7) and a range of 0 – 0.03

ppm was measured, although new fabric furniture and office equipment were found within the office compartment. The results of the ANOVA analysis show that the variation in contaminant levels between floors was not statistically significant, as tabulated in Table 1.

Thermal comfort parameters

The use of radiant cooling is often associated with potential condensation problem, and this is a major concern for building engineers. The range of ambient air temperature was measured as between 23.1 to 24.5 °C. The measured air velocity ranged from 0.01 to 0.18 m/s, while the measured RH level varied between 51.6 and 63.8%. In this case, the RH level is a good indicator for possibility of condensation problem in buildings. From here, the dew point temperature was estimated at around 13.9 to 15.3 °C.

Air-change effectiveness

A vacant office room in level 2 of the selected building was tested for air-change effectiveness during lunch time. This enclosed room was served by the same air-conditioning duct as other parts of the floor. CO_2 gas was released into the room and allowed to mix with the indoor air before measurement was carried out. By referring to the concentration decay profile (Fig. 2), it was found that the air exchange rate was about 34.5 minutes or 2070 seconds, which is also the time required for the CO_2 concentration to return to the normal level. Hence, the air change per hour was calculated as 1.74.

Physiological parameters

Table 2 presents the percentage of physical discomfort reported by the respondents. Out of the 42 respondents who participated in the questionnaire survey, 16 of the respondents (38%) stated that they had experienced one or more physical discomfort events. It is observed that lethargy and dry skin were the most prevalent symptoms, where 17.1% of the respondents claimed they had experienced such discomfort. Besides, 14.3% of the respondents suffered from headache and blocked nose, while 11.4% and 8.8% of them experienced dry eyes and flu-symptoms respectively. A small number of them also complained about dry throat and skin itch symptoms.

Table 1: Significance of each IAQ parameter in different floors using ANOVA

Indoor Pollutants	TLVs (DOSH ICOP, 2010)	Mean for each level	Std Deviation / Std Error	95% Confidence Interval For Mean (LB/ UB)	X^2	*P
CO_2	C1000	544.40 ppm	108.27/ 24.21	493.73 / 595.07	1.81	0.180
Formaldehyde	0.1 ppm	0.002 ppm	0.0058/ 0.0007	0.00006 / 0.00283	0.37	0.829
Particulates (PM_{10})	0.15 mg/m^3	0.0683 mg/m^3	0.001067 / 0.000132	0.0680/ 0.0685	0.56	0.693
CO	10 ppm	1.065 ppm	1.16 / 0.14	0.78 / 1.35	0.03	0.998
TVOC	3 ppm	0.083 ppm	0.038 / 0.005	0.07 / 0.09	0.36	0.835

*Significant if $P < 0.05$

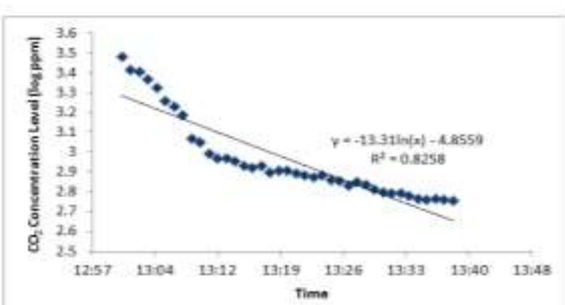

Fig. 2: Concentration decay profiles

Table 2: Complaint on physical discomfort

Symptoms	Total	Percentage (%)
Dry eyes	4	11.4
Dry throat	1	2.9
Skin itch	1	2.9
Headache	5	14.3
Lethargy	6	17.1
Blocked nose	5	14.3
Flu-symptoms	3	8.6
Nose itch	4	11.4
Dry skin	6	17.1

Discussion

From the outcomes of the field assessments, no significant association was found between the measured indoor contaminant levels in each floor of the building and the concentrations of major air contaminants were controlled below the TLVs. This indicates that the integrated airside system was effective in controlling the air pollutant levels by providing adequate outside air and good air circulation, especially at the lower floors of the office building. Interestingly, the measured Formaldehyde gas level is contrary to the results reported in an IAQ study carried out in Singapore (5), where the measured data exceeded the recommended limit of 0.1 ppm although new furniture and office equipment were available in both cases. This may be due to the size of the building area and locations selected for measurement in the field survey, where the distance apart from respective building equipment may directly affect the air pollutants' concentration level recorded.

It was reported that if the RH is higher than 50%, the probability of condensation forming on walls, ceiling and windows is greater and this may lead to mould growth and other airborne diseases (8). This problem can be eliminated by maintaining the RH level at a "safety range" of 30 – 50% by incorporating an integrated air-side system (9). In this work, although no visual sign of mould or fungal growth in the building was observed, the RH level was slightly higher than the recommended safety zone for the formation of condensation on building interior surfaces. It was also observed that the level of human occupancy had directly influenced the RH level, especially at the lower floors which had higher ratios of occupants to net floor area. Therefore, in order to prevent any potential condensation problem which may lead to biological contamination in the indoor areas, it was suggested that an increase of air movement and more dehumidification work of the AHUs are required. However, this should only be carried out cautiously at selected building zones by taking the physical discomfort of occupants into consideration, as complaints on the physiological symptoms such as dry skin and dry eyes were also obtained in this work. An increase of return air temperature is another effective method to address the condensation problem, but this scheme is applicable only if a majority of the occupants could be thermally comfortable at a higher air temperature setting. Therefore, a full-scale thermal comfort assessment was suggested prior to actual implementation. Based on the low percentage of physiological complaints received, it can be assumed that most of the occupants found the IAQ conditions acceptable. As the building under study was a newly built one, there is a need for further work to be administered in the upcoming years especially the biological samplings to measure the bacteria and fungi growth.

Conclusions

The IAQ condition in a tropical building that was equipped with a radiant slab cooling and an integrated airside system was systematically analysed. The following conclusions are drawn from the results of this work:

i) The chemical contaminant levels were found to be within the acceptable ranges stipulated in the local IAQ guideline. No statistical difference was found between the measured IAQ parameters in each floor of the building under survey. This shows that the assessed workplaces were safe and healthy for the occupants.

ii) It was identified that the RH level in the office building was slightly higher than the "safety range". This has suggested a potential risk of condensation if the surface temperatures are below the dew point temperature. An increase in air ventilation rate and more dehumidification work are therefore suggested.

iii) The air change effectiveness was observed to be above satisfactory level, which proposed that a radiantly cooled building that uses a decentralised approach in cooling and dehumidification of indoor air could provide the inhabitants with a productive working environment. For future work, more effort is required to identify the relationship between the measured contaminants' concentration levels towards physiological parameters of occupants in this type of building and biological samplings are recommended.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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