Development and application of an indoor environmental quality audit to hospital wards in the tropics

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ABSTRACT

Hospitals are among the most complex indoor facilities with numerous end uses of spaces, functions and occupants. They require efficient HVAC systems to provide highly demanding indoor conditions from health and comfort perspective for both patients and medical personnel. Good Indoor Air Quality (IAQ) is necessary, not only for promoting healthy indoor work environment, but also to help in prevention and treatment of diseases. This research attempts to investigate the IAQ in a hospital in the tropics. The study focuses on two places, namely, the Endoscopy Unit (EU) and Medical Day Care (MDC) wards of the hospital. The objective and subjective measurements were conducted to determine its indoor environmental quality and comfort level of the occupants. The results from the research found that the chemical contaminant levels in both places were below the threshold level. The average temperatures for EU and MDC wards were at 20.7ºC and 22.2ºC, respectively. For humidity level, the RH at 75% was recorded for the EU ward and RH at 71% was measured for the MDC ward. The results also indicated that the air velocity and particle counts were below the maximum limits. Based on the subjective measurement results, only 75% of the EU ward occupants and 56% of the MDC ward occupants were feeling comfort. The results strongly suggested that a further research on the adaptive thermal comfort model in hospitals in the tropics must be conducted.

KEYWORDS

Indoor air quality audit, Tropical hospital, Thermal comfort, Contaminations, HVAC systems

NOMENCLATURE

ACC	Ambulatory Care Center	HVAC	Heating, Ventilating and Air Conditioning
AHU	Air exchange unit	HVAC&R	Heating, Ventilating and Air Conditioning and Refrigeration
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers	IAQ	Indoor Air Quality
CFM	Cubic Feet per Minute	IEQ	Indoor Environmental Quality
CO	Carbon Monoxide	NO_2	Nitrogen Dioxide
CO_2	Carbon Dioxide	PM	Particulate Matters
DBT	Dry-bulb temperature	RH	Relative Humidity
EU	Endoscopy Unit	TVOCs	Total Volatile Organic Compound
HCOH	formaldehyde	VOCs	Volatile Organic Compounds

INTRODUCTION

The Indoor Air Quality (IAQ) is defined as the air quality within and around buildings and structures. It relates to the health and comfort of building occupants. ASHRAE (2004) defines acceptable IAQ as the air in which there are no known contaminants at harmful concentrations as determined by authorities and substantial majority 80% or more of the exposed people do not express dissatisfaction. The contaminants include carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde, volatile organic compounds (VOCs) and particulate matters (PM). Good IAQ is essential for promoting healthy indoor environment and avoiding varieties of health problems (allergies, respiratory problems, eye irritation, etc.). Besides office premises, hospital and health care buildings are among the most complex indoor facilities. They require efficient Heating, Ventilation and Air Conditioning (HVAC) systems to provide highly demanding indoor conditions from health and comfort perspective for both patients and medical personnel. Moreover, good IAQ is helpful in prevention and treatment of disease. Study has found that patients in controlled environments generally have more rapid physical improvement than those in uncontrolled conditions (ASHRAE, 2009). Furthermore, the US Environmental Protection Agency has identified IAQ is one of the most important environmental health problems in 1990. Two million patients a year are estimated to acquire infection in United States hospitals while they are hospitalized for other health problems (Riley, 2009). Wang (2005) investigated the concentration of particles matters PM_{10}/$PM_{2.5}$ in four hospitals in Guangzhou, China. Study revealed that average indoor data for $PM_{2.5}$ and PM_{10} were 99.06μg m^{-3} and 128μg m^{-3}, respectively. For outdoor concentration, an average of 97.86μg m^{-3} was found for $PM_{2.5}$, and an average of 99.06μg m^{-3} was found for PM_{10}. These conform to the USEPA standard that has

set 150 μg m^{-3} as the maximum limit for average, 24-hour PM_{10} ambient concentration. However, the concentration of $PM_{2.5}$ was higher than the USEPA standard level of 35 μg m^{-3} for average, 24-hour, ambient concentration.

Realizing the importance of good IEQ, this study attempts to investigate the IEQ in the Hospital Tengku Ampuan Rahimah, Klang, Malaysia. The results of this study will serve as an important guide for HVAC&R design engineers to design an optimised HVAC&R systems for maximum IEQ level in hospitals in the tropics.

METHODS

Methodology of IEQ Audit

The systematic approach for the IEQ audit has been developed and applied to the hospital building. This methodology has been established some years ago and has undergone refinements to establish a comprehensive and accurate IEQ profile of a building (Christopher, 2007). The IEQ audit starts with understanding the background of the building, followed by the objective measurements, then by subjective assessment through a questionnaire, and finally the data analysis is completed. At the beginning, the Endoscopy Unit (EU) and Medical Day Care (MDC) unit were identified as the location for the study. The next stage of the audit is the objective measurement and subjective measurement. The objective measurement includes measurement of temperature, relative humidity (RH), air velocity, air flow rate (CFM), formaldehyde (HCOH), CO_2, total volatile organic compounds (TVOCs) and particle pollutants. For the subjective assessment, questionnaires and interviews were conducted, which involved the hospital staff, patients and visitors to provide a subjective feeling on the environment. The collected assessment from this audit can be used to assess the air quality in the hospital and recommendation can be made as well.

RESULTS AND DISCUSSIONS

Evaluation of concentrations of Chemical Contaminants

In this study, the levels of contaminants' concentration in EU and MDC wards were measured. It is found that the average concentrations of CO_2 in EU and medical daycare wards

are 594 ppm and 622 ppm respectively. These values are acceptable since they are below the maximum limit suggested by ASHRAE, Code of Practice IAQ, Malaysia and Code of Practice IAQ in office, Singapore. Maximum level of CO_2 for these three standards is 1000ppm (ASHRAE, 2004; MOHR, 2005; MOE, 1996). CO concentrations level measured in both wards are 1.45 ppm (EU) and 1.74 ppm (Medical Day Care). These are considerably low and healthy levels in comparison to the maximum level permitted by just mentioned standards. The maximum level of CO required by ASHRAE (2004) and Singapore IAQ guideline (MOE, 1996) is 9 ppm. However, the requirement of MOHR, Malaysia (2005) is slightly higher, that is 10ppm.

The same scenario happened for the formaldehyde level in EU and MDC wards. The measured levels are below the maximum limit suggested by all three standards just mentioned. EU ward has average 0.03 ppm formaldehyde concentration while the MDC ward has average 0.038 ppm. This indicates there is no concern on formaldehyde level. Only ASHRAE standard (2004) includes the maximum concentration level for nitrogen dioxide. ASHRAE standard (2004) sets 3 ppm as the maximum concentration level for this contaminant. Measured values are far below this limit. It is also below the limit set by the Canadian guideline for residential IAQ, which states that maximum limit for 1 hour exposure must be less than 0.25 ppm (ASHRAE, 2009). Excessive nitrogen dioxide (NO_2) exposure will give adverse effects to human health such as decreasing lung function and increasing the risk of respiratory symptoms (ASHRAE, 2009). It might come from odour from medicines, anesthetics, smoke from cigarettes by irresponsible patrons and general workers. TVOC levels in both wards are not the major concern since the measured levels are definitely within the MOHR(2005) and MOE(1996) standards. Maximum level of TVOCs for the just mentioned standards is 3 ppm and measured data for both wards are below this level.

Air Exchange rate

ASHRAE standard (2009) suggests minimum total air changes per hours for patient rooms and intensive rooms should be 4 and 6 air changes per hour, respectively. Referring to the ASHRAE standard (2009), the hospital has achieved the minimum total air changes per hour in the current study. The air exchanges rate of the supply air in the hospital wards are approximately 10 to 14 times an hour. The Air Handling Unit (AHU) room has a good ventilation system because it consists of fresh air entering, return air and exhaust air.

Evaluation of thermal comfort

Vertical study of the air temperature difference within the conditioned space was conducted by using the height above the floor measurement as recommended by ASHRAE standard (2004). Air temperature at the 0.1m, 0.6m and 1.1m levels was measured for sedentary occupants at the specified locations while standing activity measurement were at 0.1m, 1.1m and 1.6m levels.

Air Temperature

At the EU, the average calculated air dry-bulb temperatures (DBT) are recorded as 20.8 °C, 20.7°C, 20.7 °C and 20.7 °C with a variance of 0.8 °C for 0.1m, 0.6m, 1.1m and 1.6m, respectively. It is observed that the temperature did not vary significantly at different heights above the floor. These average temperatures were found to be slightly below the acceptable range of indoor air temperature of 22.5-26.0 °C, as recommended in the ASHARE standard (Constantinos et al, 2007). Singapore MOE's standard (1996) can be referenced for tropical country comparison, but the standard specified the same minimum indoor air temperature as recommended by ASHRAE (2004). Thus, sedentary and standing occupants are predicted to encounter slightly cold discomfort such as cold feet and headache. While in the MDC unit, the average calculated air dry-bulb temperatures are 22.1°C, 22.1°C, 22.2°C and 22.3°C with a variance of 1.77°C for 0.1m, 0.6m, 1.1m, and 1.6m, respectively. The average air temperatures are slightly lower than both ASHRAE and Singapore standards. Patients in the ward may experience slightly cold conditions. Standing occupants are predicted to experience cold feet. Sleeping occupants are predicted to experience even more severe cold discomfort, as the metabolic heat is only 0.8 met (ASHRAE, 2004).

Air Humidity

At the EU, from review of the measured data, the result implies that the humidity is high. The relative humidity measured at four different heights above the floor was 75.1%, 74.7%, 74.7%, and 74.7% with variance 1.9% from the height above the floor to ceiling. These values have exceeded the maximum permissible humidity levels of 60% and 70%, which have been recommended by ASHRAE (2004) and the MOE, Singapore (1996). A similar scenario occurred in the MDC unit. Generally, the humidity levels at four different heights above the floor are

found to exceed the maximum recommended humidity level of both mentioned standards. The measured relative humidity in the MDC unit is found to be slightly better and lower in comparison to the EU Unit. The average relative humidity measured at different heights above the floor are found at 71.3%, 71.3%, 71.3% and 71.1% with variance of 1.41%. The calculated average dew point temperature for the EU is 16.1ºC with a variance of 0.4ºC, while the dew point for the MDC unit is 17.0^{o}C with a variance of 0.9^{o}C. In order to keep the air humidity always below 70% for human health, the cooling coil in the AHU of the EU and MDC units must be controlled to a temperature lower than the dew point temperatures.

Air Velocity

Air velocity measurement is conducted at the centre of each pair of diffusers in the specified location. Air drafts can cause undesired local cooling of the body caused by air movement. The air velocity measured in the EU is varying from 0.03m s^{-1} to 0.11m s^{-1}. The calculated average air velocity is 0.05 m s^{-1} with variance of 0.003 m s^{-1}. The air velocity measured easily complies with the maximum limits of both the ASHRAE (2004) and the Singapore standard (MOE, 1996), which is 0.25m s^{-1}. Thus, the occupant is not expected to experience much air draft. In addition, the air velocity measured in the unit MDC is varying from 0.02 m s^{-1} to 0.14 m s^{-1}. The calculated average air velocity is 0.06 m s^{-1} with variance of 0.002 m s^{-1}. Little air draft is expected as the values measured are still far from the maximum limit of air speed stated by the ASHRAE and Singapore standards.

Evaluation of Particulate Matter

In both EU and MDC units, particle counts of aerodynamic diameter of 0.3μm, 0.5μm, 1μm, 3μm, 5μm, and 10μm are detected within the threshold of clean air, which is 35×10^{6} particles/m^{3}. This shows that the spaces are well kept with cleanliness. Particles of 0.3μm have the largest count in every sampling point. A probable source of this particle size is the Ambulatory Care Center (ACC), closely located to a multi-storey car park. The exhaust gas may have caused a high number of particles in the occupant space, such as carbon soot from the exhaust pipe of aged cars. Secondly, there is a new construction in progress a few hundred metres away from the ACC building. Pilings from the soil caused micro dusts to accumulate at the occupant space. Airflow resistance on the wall might cause paint dust to suspend in the air in

the period of paint aging before the wall needs repainting. Finally, there is a garden in the middle of ACC. The soil is not covered fully with grass. Mould is found growing around the garden. The porous sand is frequently dry and is unsuitable for plant growth.

Subjective Assessment (questionnaires)

Staff from the MDC unit have symptoms such as asthma, sinusitis and eczema. Some of the staff wear contact lenses. Fifty percent of staff from the MDC have sinusitis, and 17% have asthma and eczema. The contact lens users represent 17% of the staff. Staff from the EU responded that they do not have any of these symptoms. The author feels that staff from the EU would not disclose these particulars as they worry the diclosure may affect their career life.

Thirty-three percent of the EU staff have dry throat, headaches and noise irritation. From the MDC unit, 23% of staff have dry skin or rash, 23% have breathing difficulty, and 15% of staff have sleepiness, while 8% have difficulty in concentrating, noise irritation, headaches, dry throat and dry eyes. From measurement of relative humidity using a thermo hydrometer, the relative humidity is found to be high, but the respondents claim that they have dry eyes and dry throats. This is probably due to staff working in rooms or stores that are not equipped with HVAC systems or in dry areas that were not included in this walk-through audit. The research focused on spaces with occupants most of the time, such as the wards and patients counter. 100% of the staff in the EU responded that they could smell something in their working space, while only 11% of MDC staff could smell some odour in their working space. 60% of the EU staff said the cause is odour from medical stationaries, while 40% of staff from the department claimed that odour is from elsewhere. The main sources of odour are probably formaldehyde and other chemical substances in antiseptic fluids used in sterilisation of medical tools during endoscopy, medication on the patients, and surgical scrubs. Other sources of odour might be caused by combinations of outdoor activities which bring odours from outdoors through the AHU. In the EU, 75% of occupants claim to be too warm, while the rest claim to be comfortable. In the MDC unit, 56% of the occupants claim to be comfortable, 33% claim to be too warm, and 11% claimed to be slightly warm. A number of staff that claimed to be warm are staff that are busy managing the department and patients, mainly the younger and newer staff. Staff that claimed to be comfortable are the ones that are involved in sedentary activity, like the senior staff in the management level. The ducting in the counter and ward areas is the smallest branch in

comparison to the main branch from the AHU, resulting in a pressure drop, due to the long distance, that causes insufficient supply air.

In the EU, the staff that reported mild, normal, and feeling breeze are 50%, 33% and 17%, respectively. The staff in the EU that report normal breathing air and normal to odour are at 83% for both cases, as shown in Figure 1, probably due to odour just mentioned. Note that 71% of the staff in the EU also reported nearly clean air (again, shown in Figure 1). In the MDC unit, 40% of staff claim the air is nearly clean, 50% report a slight odour detected, and 50% report the air is quite clean. Lastly, 42% of EU claimed that HVAC noise is at a normal level, while 8% claimed it is very noisy. For other sources of noise, 50% report noise, and the rest are unknown. For MDC unit, 26% reports major noise from ventilation, 16% reports normal noise, and 11% reports minor noise. For other sources of noise, 37% reports normal noise, 5% reports minor noise, and 5% reports no noise at all.

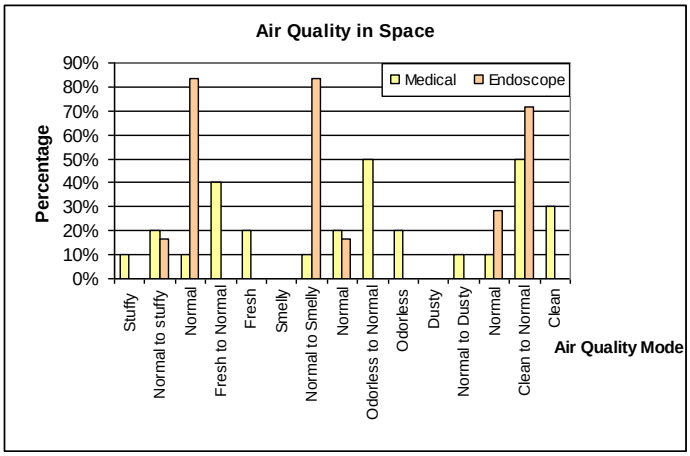

Figure 1. Air quality in the space

CONCLUSIONS

The following conclusions can be drawn from the present research as follows:

(a) Chemical contaminants in both wards are below the threshold levels recommended by the standards.

(b) Average air temperature for the EU and MDC wards are 20.7°C and 22.2°C, respectively. These are slightly lower than the ASHRAE standard (22.5-26.0°C).

(c) Relative humidity levels for both wards are high. The RH levels are 75% and 71%, respectively, for EU and MDC. The high RH leads to the condensation problem in the hospital. High levesl of humidity can also cause fungus and mold growth.

(d) The occupants for both places are not expected to experience much air draft, since the air velocity is far below than the standard's maximum level.

(e) Particle counts for both places are within the threshold levels.

(f) Only 75% of the EU occupants and 56% of the MDC occupants are feeling comfort. The remaining occupants claim that the environment is too warm. The results indicate that the active staff who are managing patients are those who are feeling warm.

(g) The results strongly suggested that a further research on the adaptive thermal comfort model in hospitals in the tropics must be conducted.

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