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Comparative Study on the Indoor Air Quality in Critical Areas of Hospitals in Malaysia

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ABSTRACT

Indoor Air Quality (IAQ) is the air quality within and around buildings and structures, particularly regarding building occupants' health and comfort. IAQ assessments were performed using an objective measurement of molecular gaseous pollutants to determine the IAQ profile in the hospital's critical areas. It also analyses the effects on patients in different environments and the sources that result in deviations from approved criteria. This comparative study is aimed to investigate the concentration of different compounds in different critical departments in the hospital and propose solutions to the related problem as an improvement in indoor air quality. The data was compared with the standards and regulations. It was found that the TVOC level in the CCU department, specifically in the fluoroscopy room, has exceeded the allowable limit. A few suggestions have been raised to lower the exceeded value. The risks and symptoms held by the occupants in the hospital buildings if they face poor indoor air quality were discussed. Further study can be conducted to relate the short and long-term health issues among medical staff to poor indoor air quality.

INTRODUCTION

The air quality within and around buildings and structures is called indoor air quality (IAQ). The primary form of concern for indoor air quality is most likely an undesired component that affects the comfort of the occupants (Kumar 2010). ASHRAE has released a report on the indoor air quality (IAQ) of Sierra Leone and Liberia's healthcare facilities. Research carried out based on the IAQ of the healthcare facilities is limited. In tropical climate countries, the study found that most people did not experience dissatisfaction with their health conditions. Indoor air quality and heat exposure are significant workplace occupational health and safety concerns. Indoor air contaminants can potentially induce temporary illness, impairment, disease, and, in extreme situations, death.

Formaldehyde (HCOH), carbon dioxide (CO_2), carbon monoxide (CO), and total volatile organic compounds (TVOCs) are the most common contaminants that are assessed for indoor air quality in buildings. There are no regulations for TVOC and microbiological contaminants among the abovementioned pollutants. Acute low-level carbon monoxide exposure may result in several neuropsychological symptoms. Without additional sources, human CO_2 emissions form a significant component of indoor carbon dioxide pollution, such as burning fuel, gases exposed from transport, and electricity (Asadi et al. 2013). The carbon dioxide exposed to people may cause various health effects, such as headaches, dizziness, and restlessness. Total volatile organic compounds are gases emitted from products or processes. VOCs in the air can irritate the eyes, nose, and throat, cause difficulties in breathing and nausea, and it may harm the central nervous system and other organs.

This comparative study aimed to analyze the sources of problems in the indoor air quality of hospitals in Malaysia. The impacts of poor indoor air quality in the healthcare building will affect the occupant's health as well as the daily activities of the workers there. Thus, the method of measurement of the compounds and the solution to control the concentration level of the compounds are also discussed in this study.

IAQ AUDIT

Indoor air quality (IAQ) in the building would be evaluated

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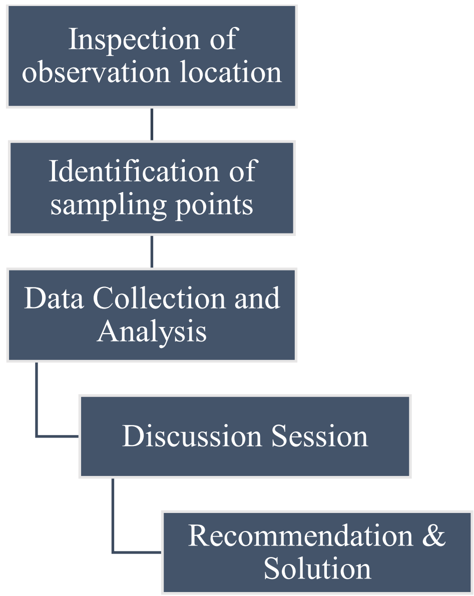

Fig. 1: IAQ audit methodology.

by following the standard of IAQ audit, which involved the physical parameters, concentration of contaminants in the air, and the measurement of biological indicators. Referring to Fig. 1, the IAQ audit methodology is distributed into five stages: the determination of sampling points, inspection of observation location, data collection, data analysis, and giving out the solutions (Sun 2012).

Inspection of Observation Location

The first stage of the IAQ assessment is to investigate the observation location, the critical area in the hospital. At the initial stage, much information should be collected before identifying the sampling points, such as occupants' conditions, feedback, layout and architectural information of the target buildings, locations stored or placed of the potential sources, and the HVAC system in the buildings. At the same time, the possible location where suspected as the possible bad air quality room is investigated. Some potential sampling points which have bad indoor air quality are critical areas like the Intensive Care Unit (ICU), Coronary Care Unit (CCU), and Operating Theatres (OPT) is investigated. The primary information like working area (m^2) and location information (hygiene, air intake location, source of contaminants) of the critical area are recorded to ensure high accuracy of IAQ assessment results.

Identifications of Sampling Points

The sampling points in the critical area of the hospital are determined after an investigation of the location. The sampling points are distributed to the points suspected of bad air quality by considering the HVAC system of the location and the potential source of material used in that area. Based on the standard developed by the department of occupational safety and health (DOSH), the sampling positions should be measured for at least 8 h. The testing period should occur at four intervals or in different situations. For example, day shift, night shift, high peak situation, and loosened situation. Based on the standard industry code of practice on indoor air quality developed by DOSH, the minimum number of sampling points depends on the area of the building area (Table 1). There are some criteria considered when choosing the sampling points. For example, the sampling points should be located at a primary workstation and should not disturb the daily work activities in the study area. Next, the sampling points should not be set directly in front of the HVAC system and direct sunlight. The sampling points are also not suggested in hallways or passageways. The sampling points should not directly attach to the corner, windows, walls, and other vertical surfaces (minimum 0.5-meter distances). The

Table 1: Minimum Number of Sampling Points.

Total Floor Area (served by MVAC) [m^2]	Minimum Number of Sampling
< 3,000	1 per 500 m^2
3,000 - < 5,000	8
5,000 - < 10,000	12
10,000 - < 15,000	15
15,000 - < 20,000	15
20,000 - < 30,000	21
≥30,000	1 per 1,200 m^2

Table 2: Results of measurement for critical areas in Malaysia's hospitals.

Sampling Location Information			Chemical Gaseous Pollutants			
Department	Room	Sampling Location	TVOC [ppm]	CO [ppm]	CO_2 [ppm]	HCOH [ppm]
Threshold Limit			3	0.2	1000	0.1
CCU	Cubicle 5	A1	0.2	0.0	422	0.00
	Isolation Room 1	A2	0.5	0.0	490	0.09
	Fluoroscopy	A3	9.3	0.2	389	0.05
ICU	Isolation Room 1	B1	1.2	0.0	361	0.00
	Isolation Room 2	B2	2.8	0.0	350	0.08
	In front of Bay 5	B3	0.1	0.0	304	0.00
Operating Theatre	Pre-Op Holding 2	C1	0.8	0.0	472	0.00
	Post-Anaesthesia Recovery 3	C2	0.0	0.0	385	0.00
	In front of Anaes. Work Room	C3	1.3	0.0	498	0.00
	To OT's Corridor	C4	1.8	0.0	472	0.00
	Operating Room 1 (General)	C5	0.0	0.0	418	0.00
		C6	0.0	0.0	390	0.00
	Operating Room 2 (General)	C7	0.1	0.0	413	0.00
		C8	0.0	0.0	338	0.00
	Operating Room 3 (Neurology)	C9	0.0	0.0	444	0.00
		C10	0.0	0.0	471	0.00
	Operating Room 4 (General)	C11	0.5	0.0	399	0.00
		C12	0.2	0.0	422	0.00
	Operating Room 5 (Cardiac)	C13	0.0	0.0	442	0.00
		C14	0.0	0.0	414	0.00
	Operating Room 6 (Orthopaedic)	C15	0.0	0.0	364	0.00
		C16	0.1	0.0	371	0.00

sampling positions should not prevent the staff from leaving the study area. Lastly, the inlet of samplers should be placed between 75 and 120 cm, preferably 110 cm from the floor.

Data Collection and Analysis (Chemical Indicator)

Different types of indicators are used to obtain the concentration of different compounds. The chemical indicators measure the concentration of carbon dioxide, carbon monoxide, formaldehyde, and total volatile organic compounds (TVOC). After that, the concentration of the chemical compounds is compared with the standards of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and DOSH. The solution is proposed when certain chemical compounds' concentration exceeds the threshold limit listed in the standard. The measurement tools used for the related chemical compounds and the hospital's potential sources are ANLOR Compu Flow IAQ Meters Model CF930, PPM Formal Demeter htv and the-M, and Mini RAE 2000 Portable VOC Monitor (model PGM 7600).

IAQ DATA FOR CRITICAL AREAS IN THE HOSPITAL

In this study, the results for measuring the chemical gaseous pollutants are illustrated and thus compared with the threshold limit, which refers to the standard DOSH (2005), ASHRAE (2019), and Guidelines for Good Indoor Air Quality in Office Premises Singapore, ENV (1996). Then, the action to reduce the chemical pollutants is discussed. The measurements for critical areas are illustrated in Table 2, while the threshold limit of each chemical gaseous pollutant is summarized as well.

Once the source of VOC is found indoors, the VOC level could be increased significantly to ten times higher than the outdoor VOC level and can result in chronic diseases. The TVOC level should not be exceeded 3ppm, which refers to DOSH and ENV. All the sampling locations are within the threshold limit except in CCU, A3, and the Fluoroscopy room, which contains an exceeded value of 9.3 ppm. VOC can be found in several sources, including paints, furniture, cleaning agents, fire suppression coatings, and other solvents. Since there is a close space without any air-conditioning system, it has caused poor ventilation conditions while there is not contain any office equipment. Fresh air is encouraged to introduce to improve ventilation, and the TVOC level could be reduced. After completing the renovation work and design development, the measurement was conducted repeatedly since the fresh air was recirculated, and 0.8 ppm was achieved, which is not exceeded the threshold limit.

According to ASHRAE, a substantial amount of carbon monoxide can cause symptoms like nausea and unconsciousness or, in extreme circumstances, even fatal. The standard has a threshold limit of 10 ppm. The carbon monoxide level in the critical area is within the threshold limit, ranging from 0 to 0.2 ppm. The possible source of 0.2 ppm of carbon monoxide probably comes from the operating medical instrument in the fluoroscopy room in CCU.

The respiration of occupants in critical areas is the possible primary source of carbon dioxide. By referring to the ASHRAE Standard and Malaysian Code of Practice on Indoor Air Quality, the threshold limit of carbon dioxide is 1000 ppm, while the carbon dioxide level measured in the critical area in the hospital is within the range of 304 to 498 ppm, which is not exceeded the threshold limit of the standard mentioned above. Therefore, there is no need to renovate to improve indoor air quality based on carbon dioxide levels in this critical area. According to the ASHRAE Standard, formaldehyde is a colorless, pungent gas that serves as a preservative in healthcare facilities, such as mortuaries and medical laboratories. Some possible sources of formaldehyde are paper product coating, fiberboards, glue, and others. Individuals exposed to formaldehyde should not exceed the limit of 0.1 ppm for 8 h ENV (1996). The measured formaldehyde level for all sampling locations in the hospital's critical area is 0 to 0.09 ppm.

POTENTIAL SOURCES FOR DIFFERENT KINDS OF COMPOUNDS

Total Volatile Organic Compounds

TVOC was adopted to measure the overall VOCs in a given hospital space. By referring to Table 2, all the locations are within the threshold limit by ASHRAE Standard except for one location, the fluoroscopy room. VOCs' concentration levels, such as aromatic and halogenated hydrocarbons, ketones, aldehydes, and limonene, were widely variable between hospitals due to building age and product type used according to health activities conducted in each department. High temporal variability was observed in concentrations of alcohol, probably due to the intensive use of alcohol-based hand rubs in all hospital places. In addition, some specificity of hospital activities, such as the healthcare of patients and staff, may be exposed to a wide range of VOCs emitted from the products of disinfectants and sterilants (Bessonneau et al. 2013). Most studies have assessed that hospital activities and healthcare workers are only exposed to a few compounds, such as anesthetic gases, primarily found in operating rooms, glutaraldehyde, and ethylene oxide, usually found in disinfection units. In other sites, such as operating rooms investigated in other studies, indoor air was contaminated mainly by anesthetic gases, aldehydes, oxides, and alcohols (Glumbakaitė et al. 2003). The highest VOC concentrations were observed in rooms with natural ventilation, while the HVAC system will significantly decrease the VOC concentration levels (Sidheswaran et al. 2013).

Carbon Monoxide

From the data obtained, the carbon monoxide concentration in the hospital is very close to zero and only showed an insignificant value in the Fluoroscopy department. Therefore, the emission of carbon dioxide exposure in the indoor environment of the hospital is minimal. Carbon monoxide is produced from the incomplete combustion of hydrocarbons containing fuels such as wood, gasoline, coal, natural gas, and oil. The fluoroscopy department may release very little carbon monoxide during x-ray radiation. In addition, other sources of carbon monoxide in the hospitals are from the vehicles' exhausts, including cars, motors, and ambulances outdoors in hospitals. The department near the drop-off or parking area is exposed to vehicle carbon monoxide emissions. Various fuel-burning appliances will produce certain concentration levels of carbon monoxide. However, these appliances should handle or use in an open area to avoid excess inhaling of carbon monoxide.

Carbon Dioxide

All humans, animals, plants, fungi, and microorganisms can produce carbon dioxide gas. From Table 2, the CO_2 concentration of hospitals is within the standard or guideline established by ASHRAE or DOSH. Many factors, such as human behavior, patient and staff density, and the performance of ventilation systems, influence the indoor concentration of carbon monoxide in hospitals. The occupant density in hospitals is the primary source of carbon dioxide because, through respiration or breathing, the human body uses inhaled oxygen and produces carbon dioxide. The air that humans exhale has a much higher carbon dioxide concentration than the surrounding air. During human exhalations, the carbon dioxide will mix with the air in a closed room, and the overall carbon dioxide concentration will rise. Therefore, carbon dioxide concentration will increase in a small room with multiple occupants for a long time. This situation will occur in the isolation room for patients, which is enclosed. In addition, improper heating, ventilation, and air conditioning system (HVAC) can cause a rise in the concentration of carbon dioxide levels. The air-conditioning, which is not functioning, will elevate the level of carbon dioxide in the hospital. Smoking also can release smoke and chemicals into the air as smoking involves a complete combustion reaction. This will also produce a small amount of carbon dioxide. However, in a small, closed space, smoking can reduce the oxygen concentration level of the air around. Alongside this process, releasing carbon dioxide will further change the air's composition and make occupant challenging to breathe.

Formaldehyde

The formaldehyde concentration is relatively low in the hospital. Some potential sources cause the emission of formaldehyde. Air cleaning is broadly applied to reduce contaminant concentrations in many buildings. The HVAC systems usually have filters to remove airborne particles from incoming outdoor air and recirculated indoor air. A study showed that some filters release specific amounts of formaldehyde by increasing the humidity. In addition, formaldehyde-based product such as personal care and consumer items is commonly used by people. The products usually contain formaldehyde emission elements. They act like a preservative to kill bacteria or microorganisms and prevent the growth of viruses or pathogens, extending the product storage life. This kind of product is commonly used in hospitals for cleaning purposes.

Furthermore, the surface coatings such as latex paint will contain low formaldehyde emissions. Many studies have been conducted previously, showing that cigarette smoking significantly contributes to the high formaldehyde concentrations indoors. Although the hospital area is prohibited smoking, some smokers may have their cigarettes in the staircase area.

TYPICAL SYMPTOMS AND RISKS OF EXPOSURE

Total Volatile Organic Compounds

Total volatile organic compounds are the primary sources that cause poor indoor air quality and harm human health. Some key symptoms are linked with total volatile organic compounds exposure, for instance, nose and throat discomfort, headache, dizziness, tiredness, vomiting, allergic skin reaction, shortness of breath, and also impact on the nasal cavity. The early signs or immediate symptoms of people after exposure to volatile organic compounds are irritation of the eyes and nose, dizziness, headache, amnesia, and blurred vision (Rumchev et al. 2007, Alford & Kumar 2021). Long-term exposure to volatile organic compounds or exposure to a high concentration and large quantity of total volatile organic compounds can trigger adverse health concerns such as irritation of the eyes, nose, and throat, dull headaches, or nausea, as well as permanent damage to the body organ including liver, kidney, lungs, and central nervous system in extreme cases. Furthermore, some volatile organic compounds are suspected of leading to cancer. Volatile Organic compounds exposure could be very harmful to young children, older adults, people with respiratory problems, and people hypersensitive to the chemical compounds.

Carbon Monoxide

A large amount of carbon monoxide is hazardous to the human body as the inhaled carbon monoxide would displace oxygen in the body cells and result in a shortage of oxygen in the body organ, including the heart, lungs, brain, and other crucial body organs. Exposure to a high concentration of carbon monoxide or continued exposure to carbon monoxide can lead to permanent brain and heart damage and even death. Common signs of carbon monoxide poisoning include dizziness, blurred vision, confusion, dull headache, muscle weakness, breathing difficulty, confusion, vomiting, and heart irregularity (Harper & Croft-Baker 2004). Carbon monoxide poisoning could be very harmful to unborn babies, children, older adults, and people with coronary heart disease. Properly controlling the amount and concentration of carbon monoxide is crucial to preserve high indoor air quality in the hospital, as many patients and staff have different age levels and health conditions. For pregnant patients or staff, carbon monoxide exposure might cause miscarriage, premature birth, congenital disability, fetal brain damage, and fetal death, as fetal hemoglobin is more likely to absorb carbon monoxide than adult hemoglobin.

Moreover, children usually take more breaths per minute than adults. They tend to inhale more carbon monoxide in the air, which causes them as one of the high-risk groups for carbon monoxide toxicity. Lastly, exposure to carbon monoxide may increase the risk of developing brain damage in the elderly, who are more prone to become ill in those with health concerns, such as respiratory problems and memory impairment.

Carbon Dioxide

Carbon dioxide does not show any toxic effect at lower dosages. At the same time, it may cause a rapid respiratory rate, irregular heart rate, drowsiness, dizziness, and impaired consciousness as the concentration of carbon dioxides increases. In severe cases, exposure to an extremely high concentration of carbon dioxide may lead to convulsions, coma, permanent brain and organ damage, and even death (Langford 2005, Bierwirth 2017). Maintaining a low and minimum amount of indoor air in the hospital is crucial for the psychomotor performance of staff, especially nurses and doctors in critical areas such as CCU, ICU, and operating theatre. This is because a high level of carbon dioxide above 1000 ppm has significant adverse influences on people's cognitive performance, such as decision-making, problem-solving, and speed of individual movement (Azuma et al. 2018). In addition, carbon dioxide poisoning would lead to confusion or unusual thinking, panic attack, and the ability of the individual to communicate effectively with others. The medical team in the hospital needs to deliver effective patient care and perform well in their task to avoid misdiagnosis and wrong judgments, which might result in negative patient outcomes.

Formaldehyde

High levels of formaldehyde significantly affect human health, commonly correlated to eye, nose, and throat complaints and fatigue (Asare-Donkor et al. 2020). Negative health effects from exposure to formaldehyde may happen from inhalation or direct contact with formaldehyde, such as eyes, mouth, and skin. The main hazardous effects of acute formaldehyde inhalation are irritation of the eyes, nose, throat, and lungs and the adverse impact on the nasal cavity. Coughing, sneezing, muscle aches, and bronchitis are other side effects of formaldehyde exposure in the human body. These health effects could have occurred in people of different ages and health conditions. However, these health effects are more common in young children, the elderly, and people with breathing problems. The low level of formaldehyde exposure could result in an itchy and burning sensation in the eyes, nose, and skin, sore throat, and respiratory problems (Zain et al. 2019).

Nevertheless, hypersensitive people might have a severe allergic reaction when exposed to a low dose of formaldehyde. People exposed to chronic formaldehyde are more liable to become hypersensitive to formaldehyde and have a high risk of developing cancer. Statistics show an increase in cases of female workers handling formaldehyde resins for long periods having menstrual disorders. However, no evidence suggests any correlation between formaldehyde and miscarriage and a congenital disability.

CONCLUSION

This study aims to investigate the concentration of different compounds in the different critical departments in the hospital. The study was conducted before and after the renovation. From the comparison made at all sampling locations in the critical area of the hospital, the data was under the threshold limit after completing the renovation to reduce the chemical gaseous pollutants. Indoor air quality is vital to improving indoor air pollution. Indoor air pollution contributes to various respiratory and cardiovascular health effects, from simple symptoms to severe illnesses. Due to its high-level chemical contaminant, formaldehyde is not feasible to remove or isolate. Therefore, the building must be clean and sterile well based on the guideline in Malaysia so that the contaminant can be reduced. The source of formaldehyde could be sealed well or enclosed to reduce the emission of formaldehyde. Moreover, outdoor air is crucial to promote good air quality through natural ventilation, such as opening windows and doors. Future research can be conducted to investigate the short and long-term health risks of medical staff and their relation with IAQ.

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