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Effect of Heating, Ventilation, and Air Conditioning (HVAC) System on Indoor Air Quality in a Medical Facility

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Abstract

Indoor Air Quality (IAQ) refers to the stationary air within an inhabited or occupied structure. Previously, there were fewer studies on indoor air quality in medical facilities in Malaysia especially in Terengganu. Most indoor air quality issues are caused by insufficient Heating, Ventilation, and Air Conditioning (HVAC) systems, which regulate three parameters. The purpose of this study is to assess the indoor air quality of a medical facility and determine if it complies with the Industry Code of Practice 2010 (ICOP 2010) and ASHRAE 170-2017. In this investigation, a total of 3 locations namely Administration Office, Surgical Outpatient Department (SOPD) waiting area and Ophthalmology Consultation Room in Hospital Sultanah Nur Zahirah (HSNZ) were evaluated. Walkthrough inspections were done at the locations before data collection to determine the IAQ. Two IAQ meters, notably VelociCalc and Testo, were used to collect data to assess the temperature, relative humidity, and air flow of the selected locations. Samples were taken every 2 hours for each location from 8 a.m. to 5 p.m. The data then were analysed. All three locations' temperatures were lower than ICOP 2010's acceptable limit (23-26°C), but still within ASHRAE 170-207's 21-24°C range, except for the SOPD waiting room. All three locations met ICOP 2010 and ASHRAE 170-207 relative humidity standards. Meanwhile, only the SOPD waiting room had an appropriate air flow of 0.16-0.17m/s per ICOP 2010. The study also revealed that there was a correlation between the number of occupancies and the performance of HVAC system with the indoor air quality level.

Keywords: Indoor air quality, HVAC, medical facility, ICOP, ASHRAE

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1. Introduction

Indoor air quality refers to the stationary air inside a structure that has been inhabited or occupied for at least one hour by persons with varying health conditions (Rahayu et al., 2019). It is critical in all buildings, but notably in healthcare facilities such as hospitals and clinics. As a health care provider for the community, a hospital must have qualified inpatient wards, healthy air quality, and appropriate construction and facility. In an unqualified room, the disease can be spread by equipment, food and drink, health care personnel, and guests.

A hospital environment is primarily influenced by workplace design and layout, as well as operation and maintenance, and it is the site of numerous interactions between the environment and humans (Hiwar et al., 2021). Numerous studies on microbial contamination of the environment have indicated that a wide variety of factors, including IAQ parameters such as temperature, relative humidity, and ventilation, may influence the presence of microorganisms (Mata et al., 2022; Onmek et al., 2020; Mirhosseini et al., 2016). Hence, the need to assess the indoor air quality at hospitals is important as it is classified as medical facilities.

When it comes to controlling indoor air contaminants, dilution with uncontaminated outdoor air is critical. This can be accomplished through natural ventilation or mechanical ventilation. Most indoor air quality problems were caused by insufficient ventilation, which refers as follows: Heat, Ventilation, and Air Conditioning (HVAC) systems regulate three different parameters, including temperature, ventilation, and relative humidity (Aini et al., 2019). The use of HVAC system in any medical facility is crucial for several reasons. Hospitals need to maintain stringent hygiene standards to prevent the spread of infections. HVAC systems help by controlling air quality, filtering out contaminants, and ensuring proper ventilation. This is especially crucial in areas like operating rooms and isolation units. Hospitals will be able to provide a comfortable environment for patients, visitors, and staff. HVAC systems regulate temperature and humidity levels, creating a more pleasant atmosphere for healing and recovery. On top of that, hospitals often deal with airborne contaminants such as bacteria, viruses, and allergens. Advanced HVAC systems incorporate specialized filters and ventilation strategies to reduce the presence of these contaminants in the air (Nair et al., 2022).

There is still insufficient research work being done at any medical facility specifically on physical parameters. Therefore, this study will present an analysis of physical parameters namely temperature, relative humidity, and airflow of HVAC systems in Hospital Sultanah Nur Zahirah, Kuala Terengganu. The objectives were to observe the surroundings of selected locations with Heating, Ventilating and Conditioning (HVAC) system, to determine the temperature, relative humidity, and air flow of the selected locations and compare with the Industry Code of Practice on Indoor Air Quality (ICOP 2010) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 170-2017 and to analyze the average IAQ level from sampling locations and analyse the peak time of indoor air contaminants.

1.1. Health Effects Due to Poor IAQ

Several effects could occur due to poor IAQ. The first scenario is called Sick Building Syndrome (SBS). SBS develops when building occupants exhibit symptoms that cannot be linked to a specific exposure inside the building (Aziz et al, 2023). Building occupants frequently experience symptoms that do not match any known disease and are difficult to trace (Licina & Yildrim, 2019). The symptoms usually disappear or lessen in intensity when occupants leave the building.

Additionally, Bozic et al. (2021) indicated that dust and moisture deposition within the HVAC system increases the danger of fungus and bacteria spreading. Fungi typically enter a structure via the external air intakes of the heating, ventilation, and air conditioning system, where they can aggravate allergies and SBS symptoms. To ensure proper IAQ, each parameter's limit must be maintained. SBS is more common in buildings with mechanical ventilation systems than regular ventilation systems (Syazwan Aizat et al, 2009). Healthy indoor air quality features include proper ventilation, airborne pollutant regulation, and temperature and relative humidity control.

The next effect is called Building Related Illness (BRI). Indoor air pollution is a significant contributor to BRI. BRI is a term referring to a circumstance in which residents of a building become ill as a result of being exposed to something inside the building (Tran et al., 2020; Joshi, 2008). Legionella disease, asthma, Pontiac fever, and hypersensitivity pneumonitis are all examples of such diseases. Legionnaires' disease manifests as pneumonia as a result of infection with Legionella pneumophila, a bacterial microbe common in moist environments and capable of colonizing cooling towers and hot water systems in hospitals (Nag, 2019). Even after leaving the building, the tenants continue to suffer from the ailment. While the majority of these conditions are curable, others face grave hazards. Those in inadequately ventilated buildings are more susceptible to experiencing SBS symptoms than residents who are not suffering from such diseases.

1.2. Airborne Transmission

When aerosol droplets containing viruses and other fluids are released into the air under dry indoor settings, they evaporate to the point where the water vapor pressure at the aerosol surface equalizes with the ambient conditions. After water evaporation, the microdroplets grow quite small and remain suspended in the air for prolonged periods. Ahlawat et al. (2020) found that after some time, the suspended virus particle concentration increases due to stagnant air and inadequate ventilation, increasing the risk of infection in public locations such as hospitals. As inhaled droplets leave an infected person, they either evaporate or undergo some droplet development. Both of these possibilities are reliant on relative humidity (Feng et al., 2020).

1.3. Influence of Heating, Ventilation and Air Conditioning System (HVAC) on IAQ

Given the fact that ventilation has a significant impact on particle deposition rates indoors, the hospital is air-conditioned for the rest of the year. Saran et al. (2020) emphasized that HVAC has a critical influence in influencing infection rates in the intensive care unit (ICU). It is also critical to implement a heating, ventilation, and air-conditioning system that meets particular specifications to maintain adequate indoor air quality in dentistry clinics. Ventilation systems have a substantial effect on the interior levels of airborne fungi, with air-handling units (AHU) reducing the indoor concentration of airborne fungi while natural ventilation and fan-coil units (FCU) increase it (Tzoutzas et al., 2021).

HVAC systems in hospitals were meant to regulate the temperature and humidity of the indoor air, remove contaminated air, and reduce the risk of transmission of airborne infections to safeguard both personnel and patients. HVAC systems, on the other hand, might provide an excellent habitat for microbial development (Sibanda et al., 2021). Microorganisms are frequently found in humid, organic settings, although some may survive in dry circumstances as well. Dust and moisture collection within HVAC systems raises the likelihood of fungus and bacteria spreading. Poorly operating HVAC systems have been connected to airborne infections (Wu et al., 2016; Schmidt et al., 2012). Therefore, excessive humidity and moisture in HVAC systems must be limited to prevent fungal spores and waterborne germs from proliferating and dispersing throughout the indoor air (Moritz et al., 2001).

2. Methods

In this study, the sampling was carried out in indoor places where the HVAC systems are available in the Hospital Sultanah Nur Zahirah (HSNZ) establishment. The sampling period was divided into four parts: morning, noon, afternoon, and evening. The sampling locations were selected according to the function of the area and the number of populations of the area which were Administration office, Surgical Outpatient Department (SOPD) waiting area, and Ophthalmology Consultation Room. The methodology process consisted of walkthrough inspection and on-site data collection at sampling locations via direct reading measurement and monitoring. Hence, the detail of the procedure is as follows.

2.1. Walkthrough Inspection

The goal of the IAQ walkthrough inspection was to determine the current state of the IAQ at the selected location. The task was completed through observation, addressing issues by providing a qualitative estimate of the IAQ influence by comparing it to general objectives and available references. Figure 1 shows the Administration office layout which it is one of the divisions under the HSNZ Management Department. There are 6 units under this division where they manage matters such as correspondence, file system, rental of premises, management of events and meetings, reservation of common areas, affairs and facilities of officers. The number of staffs in the office was fixed or constant as the office is restricted to staffs only.

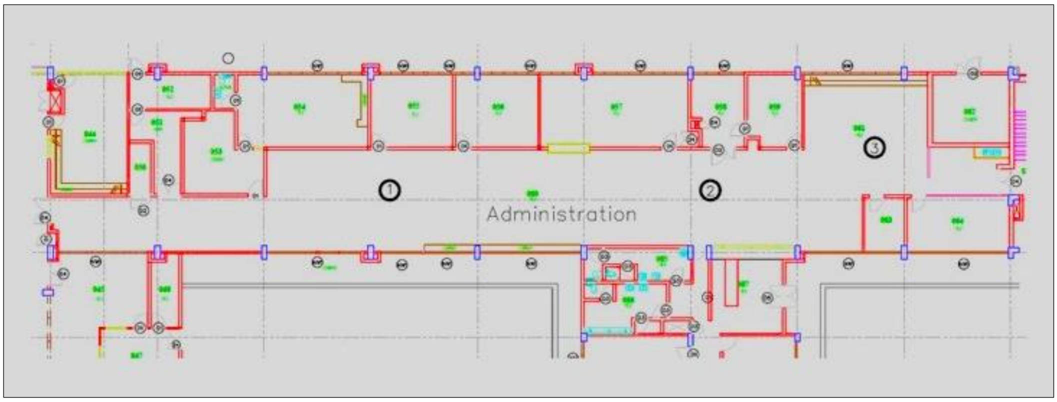

Figure 1. Drawing Plan of Administration Office of HSNZ

Figure 2 illustrates the drawing plan for the waiting area of SOPD and Orthopaedic Department. As the waiting areas were at the same space without partition, it will be mentioned as SOPD sampling locations. The number of patients and visitors who came for appointments and treatments varies throughout the day every day but it most likely to be packed since early in the morning.

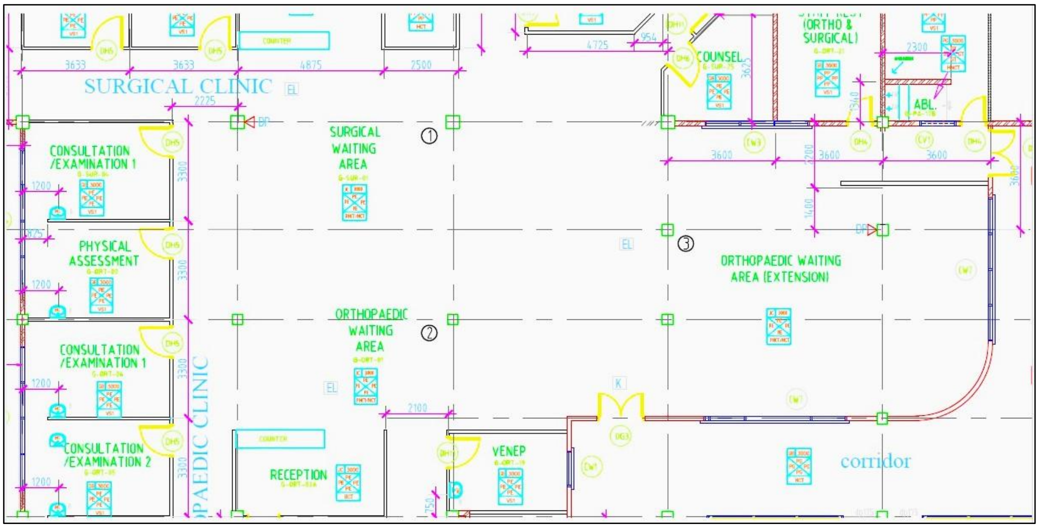

Figure 2. Drawing Plan of Surgical Outpatient Department (SOPD) waiting area of HSNZ

Due to restricted access in treatment rooms at SOPD, the next sampling locations were taken in treatment rooms or consultation rooms of Ophthalmology Clinic. This unit admit external and internal patients to the ward and provide them with skilled treatment such as provide emergency eye care services to reduce the risk of blindness for all patients. The consultation rooms were located at the Level 1 of the Daily Treatment Complex of HSNZ, and the layout drawing as shown in Figure 3. The room space was sufficient for 4 to 5 people at a time.

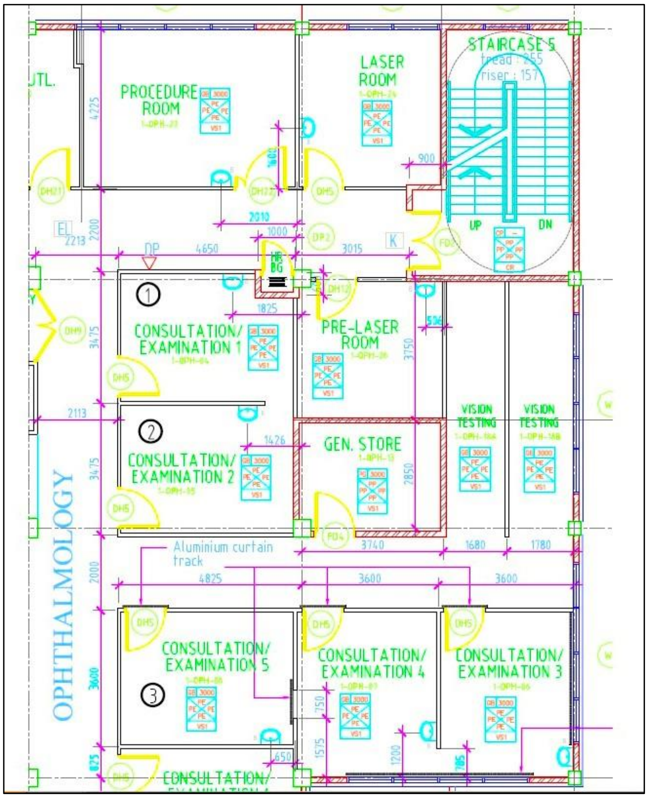

Figure 3. Drawing Plan of Ophthalmology Consultation Room of HSNZ

2.2. On-site Data Collection

The physical parameters of indoor air quality were assessed using direct reading instrument which is the IAQ Meter. The IAQ Meter is a small, handheld, multi-function ventilation test instrument that features a user interface that is driven by menus to make operation as simple as possible. The IAQ meter was created to function fast and effectively, without the requirement of laboriously programmed settings. The function of IAQ meters in the study were to check temperature, relative humidity and air flow.

Samples were taken for 8 hours with 2 hours interval at each location as the selected locations operate during normal business hours. The sample was divided into two periods, one in the morning and one in the afternoon. Sampling from the first to the third sampling point were repeated in the same order for the afternoon and evening sampling sessions. The monitoring periods were summarized in the Table 1.

Table 1. Sampling Time

Sampling Slot	Time Interval
Slot 1	8 am to 10 am
Slot 2	10 am to 12 pm
Slot 3	1 pm to 3 pm
Slot 4	3 pm to 5 pm

The instruments were set at the same height as breathing area in sitting position, approximately 1 meter height from floor level. The data will be tabulated in a spreadsheet and then analyzed in Microsoft Excel. The final IAQ data were compared with ICOP 2010 and ASHRAE 170-2017.

3. Results and Discussion

3.1. Walkthrough Inspection

The result from walkthrough inspection is summarized into a simple diagnosis checklist. Three physical parameters, namely temperature, relative humidity, and airflow, were also analysed and discussed for the results and discussion.

The goal of the IAQ walkthrough inspection was to determine the current state of the IAQ at the selected locations. The results are shown in Table 2.

Table 2. Findings of Walkthrough Inspection at Selected Locations in HSNZ

Selected Areas	Observation
Administration Office	Workstation was occupied with common office stationeries and personal computers. This area was served with a centralized air-conditioned system with supply diffusers and free return grills. Mold stains were noted on walls in certain areas. Water stains were also sighted below the split unit, ceiling board and walls during inspection. Stand fans were sighted during inspection. This may indicate possible thermal discomfort in the office.
Surgical Outpatient Department (SOPD)	Open waiting area combine with Orthopedics' waiting area. High occupancy was noted during assessment. This area was served with a centralized air-conditioned system with supply diffusers and free return grills. Flaking paint was sighted on the ceiling, indicating moist ceiling. Mold stains and growth were noted on the ceiling surrounding the supply diffusers.
Ophthalmology Consultation Room	This area was served with a centralized air-conditioned system with supply diffusers and free return grills. Low temperature and air movement were recorded in this area. Signs of mold stain and growth on the ceiling board and wall at the walkway. There were signs of condensation occurred on the supply diffuser grill.

Table 2 shows that all three selected locations were equipped with centralized air-conditioned system with supply diffusers and free return grills. A system of supply diffusers and free return grills was utilised by central air conditioners to circulate cool air (Gholamzadehmir et al., 2020). In addition, it should be emphasised that mold stains and growth were present on the walls and ceilings of all selected locations. Mold growth on the wall does indicate that the level of air quality warrant additional inspection. Inadequate indoor air quality may pose a health risk, such as the presence of fungal contamination, and may also lead to allergic reactions and infections (Rogawansamy et al., 2015). Therefore, it was needed to perform office bio-decontamination to eliminate and restrict the accumulation of potential air contaminants in sampling areas.

3.2. Temperature

For physical parameters, the Industry Code of Practice for Indoor Air Quality 2010 and ASHRAE Standard 170-2017 specify a temperature range of 20-26°C and 21-24°C, respectively as an acceptable range for satisfactory performance. In accordance with ASHRAE 55(2004), thermal comfort is defined as "that condition of mind that indicates contentment with the thermal comfort environment." The impression of thermal comfort is controlled by the temperature of the body, which is in turn influenced by human activity, clothing, and environmental elements such as air temperature, air movement, and relative humidity.

Table 3. Average temperature at sampling locations

	Temperature (°C)			
Sampling Locations/ Time	**8 am to 10 am**	**10 am to 12 pm**	**1 pm to 3 pm**	**3 pm to 5 pm**
Administration Office	23.5	22.8	21.9	22.8
SOPD	21.0	20.8	20.6	20.4
Ophthalmology	22.3	22.6	22.7	22.5
ICOP 2010	23-26 (°C)			
ASHRAE 170-2017	21-24 (°C)			

Most of average temperature readings at all three selected locations were below the acceptable range (23-26°C) of ICOP 2010 as shown in Table 3. Although the number of occupancies sharing the area during normal hours were high, average temperature readings of SOPD displays the area with the lowest temperature throughout the day. It was also both below the acceptable limit of ICOP 2010 and ASHRAE 170-2017.

Meanwhile, the temperature in the administration office was within acceptable value with 23.5°C from 8 am to 10 am. This can be due to administration office is a workspace station area where the amount of people is almost fixed daily. Moreover, as a healthcare treatment space with few numbers of occupants at a time, Ophthalmology Consultation Room were noted within the range of ASHRAE 170-2017.If the temperature was not in compliance with the limit set by ICOP 2010, tendency to impede the workers' productivity increases. This can lead to delay of daily operation within the hospital as all departments were related to one another. From the graph illustrates in Figure 4, SOPD did not meet the limit range by both standards.

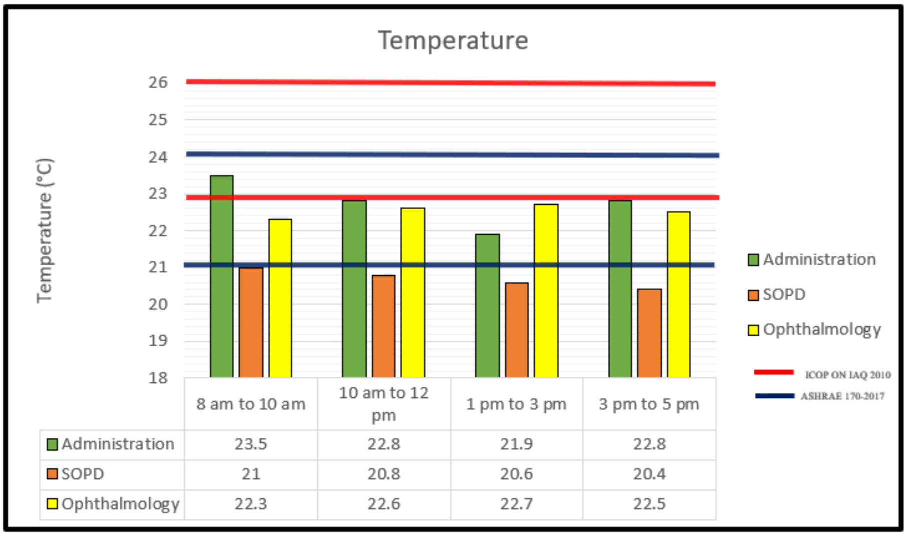

Figure 4. Temperature at all Selected Locations

3.3. Relative Humidity (RH)

The amount of water vapor present in the air is referred to as relative humidity. According to the Malaysian Industry Code of Practice on Indoor Air Quality 2010, the optimum comfort range for relative humidity is 40% to 70%, with 40 being the most comfortable. It is recommended by ASHRAE 170-2017 that the relative humidity be kept below 60% at all times. In order to comply with the Industry Code of Practice for Indoor Air Quality, the relative humidity level in a building should be maintained between 40-70%. This reduces the formation of mold and other biological contaminants. According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), relative humidity readings that are slightly higher than 60% create a potential risk of microbiological growth, including mold, yeast, and dust mites, if there is sufficient moisture, warmth, still air, and a food source.

Table 4. Average relative humidity at sampling locations

Sampling Locations/ Time	**Relative Humidity (%)**			
	8 am to 10 am	**10 am to 12 pm**	**1 pm to 3 pm**	**3 pm to 5 pm**
Administration Office	60.8	58.1	58.9	60.0
SOPD	62.5	61.3	61.4	62.7
Ophthalmology	57.2	59.0	59.8	59.9
ICOP 2010	40-70 (%)			
ASHRAE 170-2017	20-65 (%)			

Table 4 also shows average relative humidity measured at all sampling points were within the acceptable range of 40-70% of ICOP on Indoor Air Quality 2010 by Department of Occupational Safety Health (DOSH). Based on the chart shown in Figure 5, all sampling areas recorded relative humidity level almost reaching the design range of ASHRAE 170-2017 of 65% relative humidity. This prove the reason why mold stains and growth were located at all selected locations. As per ASHRAE standard, occupies spaces should be maintained below 65% relative humidity to minimize the growth of allergenic or pathogenic organisms. Molds can cause inflammation of the upper and lower airways by secreting a variety of metabolites, such as glucans or mycotoxins. Therefore, the quality of the air within has a significant influence in the health of the respiratory system.

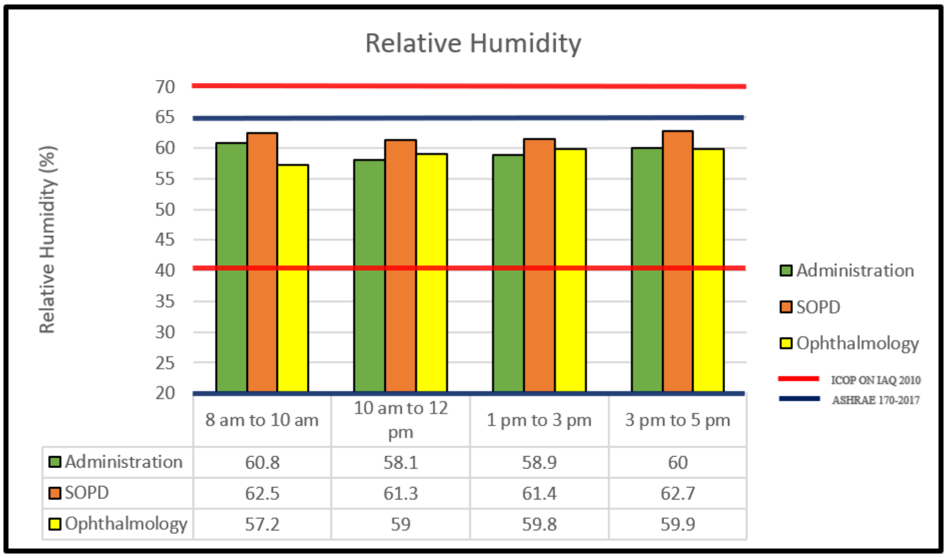

Figure 5. Relative Humidity at all Selected Locations

3.4. Air Flow (AF)

The optimal range for air movement in Indoor Air Quality standards is 0.15-0.50 m/s. Thermal comfort is enhanced by air movement. In the absence of air movement, a sense of hot/stuffy air may occur. Additionally, reduced air flow contributes to elevated levels of indoor pollutants such as PM10, TVOC, and formaldehyde. Meanwhile, if the air flow exceeds the limit, it facilitates the spread of contaminants, particularly microorganisms, throughout the structure.

Table 4. Average Air Flow at Sampling Locations

	Air Flow (m/s))			
Sampling Locations/ Time	**8 am to 10 am**	**10 am to 12 pm**	**1 pm to 3 pm**	**3 pm to 5 pm**
Administration Office	0.08	0.07	0.06	0.09
SOPD	0.17	0.17	0.16	0.16
Ophthalmology	0.12	0.13	0.14	0.15
ICOP 2010	0.15 – 0.5 (m/s)			
ASHRAE 170-2017	NA			

The average air flow readings from all three selected locations. As illustrated in Table 4, Surgical Outpatient Department (SOPD) recorded the highest airflow between all selected locations with average air flow readings within the acceptable range as per ICOP on Indoor Air Quality 2010 by Department of Occupational Safety Health (DOSH) throughout the day. This was necessary as SOPD was the highest number of occupancies with patients coming for appointments and treatment for their sickness, thus, the HVAC system need to regulate and remove the contaminated air. Meanwhile, as shown in Figure 6, Administration Office measured average air flow readings below the acceptable readings throughout the day. Lastly, Ophthalmology Consultation Room measured average air flow readings below the acceptable readings except during 3 pm to 5 pm with 0.15 m/s.

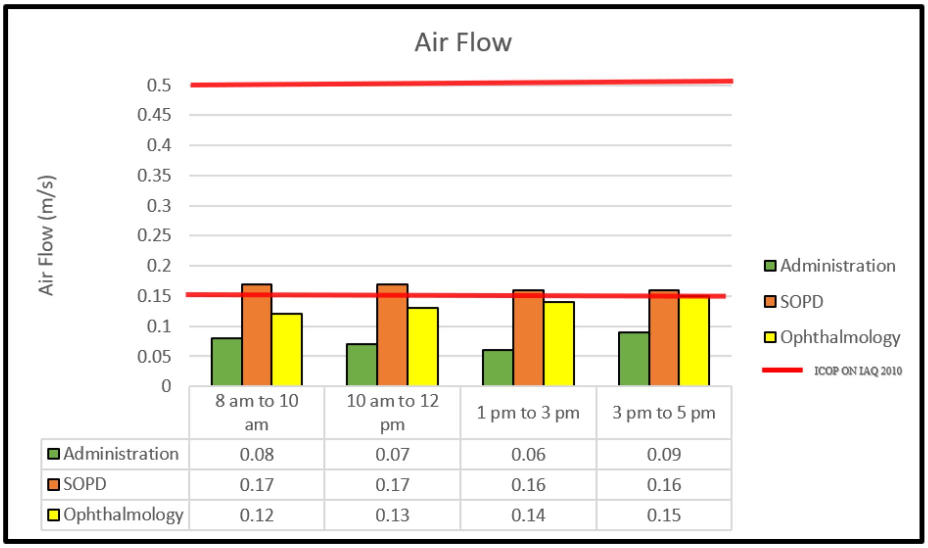

Figure 6. Air Flow at all Locations

3.5. Remediation of Mold Growth

Mold is allergic whether it is alive or dead, and some mold may be toxic. The remediation strategy should include efforts to resolve the water or moisture issue; otherwise, the issue may resurface. Mold may typically be eliminated from nonporous surfaces by wiping or washing with water or water and detergent. It is crucial to dry these surfaces thoroughly and soon to prevent mold growth. Some biocides are classified as pesticides, and some states mandate that only registered pesticide applicators use to clean up mold growth. However, mold and humans are both susceptible to the toxicity of biocides. Hence, the need to wear a PPE when cleaning up the contaminated area. Lastly, the materials and furnishings which have been infected with mold growth but cannot be saved should be double-bagged using polyethylene sheeting that is 6 mil thick. After that, the materials can typically be dumped like regular garbage from building sites.

4. Conclusion

Based on the study, the indoor air quality level of selected locations in Hospital Sultanah Nur Zahirah were assessed successfully. Therefore, from this study, it can be concluded that there were mold stain and growth sighted at all selected locations indicates poor IAQ and require additional inspection. All three selected locations' temperature were lower than acceptable limit (23-26°C) of ICOP 2010 but were still in range of 21-24°C of ASHRAE 170-207: except for SOPD waiting area. Next, relative humidity for all three selected locations were in the acceptable limit of ICOP 2010 and ASHRAE 170-207. Only Surgical Outpatient Department (SOPD) waiting area recorded average air flow readings within the acceptable range (0.15-0.50 m/s) as per ICOP 2010. Finally, there was correlation between the number of occupancies and performance of HVAC system with the indoor air quality level. The findings gained will be used as baseline information to further improve and implement any necessary rectification in the air-conditioning building on an ongoing and sustainable basis.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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