UNIVERSITI PUTRA MALAYSIA

***ASSESSMENT OF INDOOR AIR QUALITY AND THE RISK OF COVID-19 INFECTION IN LECTURE HALLS AND TUTORIAL ROOMS OF A MALAYSIAN UNIVERSITY***

**SITI AISYAH BINTI MOHD AB NASIR**

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**Thesis submitted in fulfilment of the requirement for the degree of Bachelor of Science in Environmental and Occupational Health with Honours from the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia**

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## ABSTRACT

### ASSESSMENT OF INDOOR AIR QUALITY AND THE RISK OF COVID-19 INFECTION IN LECTURE HALLS AND TUTORIAL ROOMS OF A MALAYSIAN UNIVERSITY

**SITI AISYAH BINTI MOHD AB NASIR**

**Introduction:** Users and occupants of university academic buildings including lecture halls and tutorial rooms experience daily exposure of their indoor air quality (IAQ) which could affect the health of the occupants. The health concern adds up with the risk of COVID -19 infection that could be influenced by the level of indoor air quality in the academic buildings. **Objective**: This study aims to assess the indoor air quality and the risk of COVID-19 infection in Malaysian academic buildings. **Method**: Purposive sampling was used in the selection of lecture halls and tutorial rooms with mechanical ventilation at different faculties in Universiti Putra Malaysia, Serdang Campus. Four IAQ parameters ($PM_{2.5}$, $CO_2$, relative humidity and temperature) were assessed in the study. The risk of COVID-19 infection in study location was calculated using Airborne Infectious Risk Calculator (AIRC) Version 3. SOLIDWORKS was used to develop a model of lecture hall and tutorial room of academic building. **Result:** All six academic buildings selected for the study recorded acceptable indoor temperature within range between 23–26 $^oC$ while five out of six academic building were within the range of acceptable relative humidity of 40%-70%. However, five out of six academic buildings recorded $CO_2$ level of more than 1000 ppm with the highest concentration measured being recorded at 1317.0 ppm. Four academic buildings were recorded to have $PM_{2.5}$ concentration exceeding 15 µg/m³. The highest risk of COVID-19 infection calculated was 11.4% during the situation of standing and speaking with 3 hours of exposure duration, while the lowest risk calculated was 0.2% during the situation of resting and breathing with 1 hour of exposure. Temperature, relative humidity, $PM_{2.5}$ and $CO_2$ were found to have Pearson correlation coefficient, r, of 0.602, -0.487, 0.142 and 0.002 respectively. **Conclusion:** Academic buildings in the study generally have acceptable level of temperature and relative humidity. However, there was a concern on the high concentration of $PM_{2.5}$ and $CO_2$ level in the academic buildings. It was also found that the risk of COVID-19 infection in lecture halls and tutorial rooms was higher with the increasing duration of occupancy and with the activity of standing and speaking. The study suggested that there was no significant association with pattern of positive correlation between indoor temperature and $PM_{2.5}$ with the risk of COVID-19 infection. Relative humidity recorded negative correlation with no significant association with the risk of COVID-19 infection. The results indicated that indoor air quality has no significant correlation with the risk of COVID-19 infection, thus extensive studies need to be conducted to find the association between indoor air quality and the risk of COVID-19 infection.
**Keywords: indoor air quality, SARS-CoV-2 transmission, COVID-19 infection risk, university students, academic buildings**

## ABSTRAK

**PENILAIAN KUALITI UDARA DALAMAN DENGAN RISIKO JANGKITAN COVID19 DI DEWAN KULIAH DAN BILIK KULIAH DI SEBUAH UNIVERSITI DI MALAYSIA**

**SITI AISYAH BINTI MOHD AB NASIR**

**Pengenalan:** Pengguna bangunan akademik termasuk dewan dan bilik kuliah terdedah kepada kualiti udara dalaman yang boleh memberi kesan kepada kesihatan para pengguna. Kebimbangan kesihatan pengguna juga bertambah dengan risiko jangkitan COVID-19 yang boleh dipengaruhi oleh kualiti udara dalaman. **Objektif:** Kajian ini dijalankan bertujuan untuk menilai kualiti udara dalaman dengan risiko jangkitan COVID-19 di bangunan-bangunan akademik di Malaysia. **Metodologi**: Persampelan bertujuan digunapakai dalam pemilihan dewan kuliah dan bilik kuliah yang menggunakan system pengudaraan mekanikal di fakulti-fakulti Universiti Putra Malaysia, Kampus Serdang. Empat parameter kualiti udara ($PM_{2.5}$, $CO_2$, kelembapan relatif and suhu) dinilai di dalam kajian ini. Risiko jangkitan COVID-19 di lokasi kajian dikira menggunakan Kalkulator Risiko Jangkitan melalui Udara (AIRC) Versi 3. SOLIDWORKS digunakan untuk membuat model 3D bangunan-bangunan akademik. **Keputusan dan perbincangan**: Kesemua enam bangunan akademik yang terpilih untuk kajian merekodkan suhu udara dalaman di dalam julat yang boleh diterima iaitu 23–26 $^{o}$C. Satu bangunan akademik mencatatkan kelembapan relatif pada 77.04%, iaitu melebihi julat suhu relatif yang diterima. Lima daripada enam bangunan akademik mencatatkan paras $CO_2$ melebihi 1000 ppm, dan nilai $CO_2$ tertinggi yang dicatatkan adalah 1317.0 ppm. Empat bangunan akademik direkodkan melebihi paras harian $PM_{2.5}$ pada 15 µg/m³. Didapati risiko tertinggi penyebaran COVID-19 yang dikira adalah 11.4% iaitu semasa situasi berdiri dan bercakap selama 3 jam pendedahan, dan yang terendah dikira ialah 0.2% iaitu semasa situasi berehat dan bernafas selama 1 jam pendedahan. Suhu, kelembapan relatif, $PM_{2.5}$ dan $CO_2$ masingmasing mencatatkan korelasi pekali Pearson, r, 0.602, -0.487. 0.142 dan 0.002. **Kesimpulan**: Bangunan akademik dalam kajian mencatatkan suhu dan kelembapan relatif yang boleh diterima, sebaliknya terdapat kebimbangan terhadap tahap $CO_2$ dan $PM_{2.5}$ di bangunan-bangunan akademik. Kajian juga mendapati risiko jangkitan COVID-19 di dalam bangunan akademik meningkat dengan peningkatan tempoh masa pengguna berada di dalam bangunan akademik serta bersama aktiviti berdiri dan bercakap. Didapati suhu dan $PM_{2.5}$ mempunyai corak korelasi positif tanpa asosiasi dengan risiko jangkitan COVID-19. Kelembapan relatif pula didapati mempunyai korelasi negatif tanpa asosiasi dengan risiko jangkitan COVID-19 di ruang. Ini menunjukkan bahawa tiada korelasi signifikan ditemui antara kualiti udara dalaman dengan risiko jangkitan COVID-19. Maka, kajian lanjut perlu dijalankan bagi mengkaji asosiasi dan hubungan antara kualiti udara dalaman dengan risiko penyebaran SARS-CoV-2 di ruangan tertutup.


**Kata kunci: kualiti udara dalaman, penyebaran SARS-CoV-2, risiko jangkitan COVID-19, pelajar university, bangunan akademi**

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| | |
|---|---|
| **COVID-19** | Coronavirus disease 2019 |
| **WHO** | World Health Organization |
| **SARS-CoV-2** | Severe Acute Respiratory Syndrome Corovirus 2 |
| **$PM_{2.5}$** | Particulate matter 2.5 micron of width or less |
| **$CO_2$** | Carbon dioxide |
| **ICOP of IAQ 2010** | Industrial Code of Practice of Indoor Air Quality 2010 |
| **IAQ** | Indoor air quality |
| **AIRC V3** | Airborne Infection Risk Version 3 |
| **US EPA** | The United States Environmental Protection Agency |

# CHAPTER 1

# INTRODUCTION

## 1.0 Background study

The rise of COVID-19 pandemic due to the emergence of SARS-CoV-2 has caused dramatic changes in the human population including the aspects of economy, lifestyle, social activities as well as education. Ever since the World Health Organization (WHO) declared COVID-19 as a pandemic on 11$^{th}$ March 2020 and COVID-19 as a global outbreak in Public Health Emergency of International Concern before, specifically on 30$^{th}$ January 2020, nations across the globe have taken tremendous efforts to curb the spread of COVID-19. Similarly, Malaysia has declared series of movement control orders (MCOs) since 18$^{th}$ March 2020.

The coronavirus disease-19 (COVID-19) is a pathogenic viral infection that is highly transmissible. Its agent is Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) which is responsible in evoking a global pandemic in 2020. Earlier, the known intermediate source of origin and human transfers are limited, however, the rapid human-to-human transmission has been hugely confirmed and accepted (Shereen at al., 2020). According to WHO (2020), the three major modes of transmission of SARS-CoV-2 include contact and droplet transmission, airborne transmission as well as fomite transmission. WHO (2020) through the Report of the WHO-China Joint Mission on Coronavirus Disease 2019 has shown that 78-85% out of 75 465 COVID-19 cases that happened in China were due the transmission of COVID-19 via prolonged and close contact.

WHO (2014) defines airborne transmission as the droplet-nuclei spread, which is the dried respiratory aerosol residue with the diameter size of ≤ 5 μm from the evaporation of coughing and sneezing droplets in the atmosphere by the infective material aerosolization. This is also a major concern when human respiratory characteristics are considered. During respiration, human beings inhale fresh air composed of 78% nitrogen, 21% oxygen, 0.04% carbon dioxide as well as other minor gases and pollutants, which includes particles that are suspended in the air as well as microdroplets, which are the possible mode of transmission of SARS-CoV-2 viruses into human beings (Rowe et al., 2021). Small aerosol droplets with infective materials exhaled by an infected person are able to be inhaled by other individuals located meters away (Zhao et al., 2022). The study also mentioned that small aerosol droplets of ≤ 5 μm have the ability to survive in the air for a duration of 3 hours to 3 days with longer travel distance.

As Malaysia has gradually loosen the restrictions of mobility, people are beginning to return to the initial work, education and social norms, in which this is raising concerns of the risk of COVID19 transmission indoors. Several studies have suggested that indoor air quality, including particulate matter, carbon dioxide, relative humidity and indoor temperature, play a significant role in the transmission of COVID-19 indoors (Nair et al., 2022). This raises a concern on the risk of COVID-19 infection among university students especially when physical lectures are now allowed as per norm, as it is found from several studies that university indoor spaces including lecture halls, libraries and tutorial rooms are found to have indoor air quality issues especially on the exceeding concentration of carbon dioxide (Ismail et al., 2020). The review also mentions that poor indoor air quality in universities affects the health of students.

Although the World Health Organisation has recommended the social distance of 1 metre as one of the measures to prevent the spread of COVID -19, several studies indicate that small particles carrying viruses can be spread up to 10 metres indoors (Zhao et al., 2020). This alone increases the risk of SARS-CoV-2 transmission in enclosed spaces such as university classrooms, schools and workplaces, as students are in close proximity and spend on average more than 5 hours in learning facilities (Ismail et al., 2020). Sarhan, Naser & Naser (2021) also found that the current implementation of indoor protective measures, e.g. a social distance of 1.5 m, to reduce the risk of transmission of COVID -19 is inadequate, especially when the indoor residence time is longer. This is because the amount of inhaled aerosol droplets among indoor residents is still high despite compliance with the 1.5 m social distance. Their findings raised concerns about the influence of indoor air quality and transmission of SARS-CoV-2, especially among university students, as physical lectures are gradually allowed for classes, increasing the risk for students and faculty to be exposed to COVID -19 infection (Rodriguez, 2022).

Therefore, our study aimed to assess the indoor air quality and investigate the rate of COVID-19 infection risk in academic buildings.

## 1.1 Problem statement

A study has shown that ventilation, temperature and relative humidity problems are common in academic buildings (Ahmad & Hassim, 2015). These problems are primarily caused by inefficient classroom ventilation systems and improper window placement, resulting in insufficient circulation of indoor air and fresh outdoor air, and failure to properly control classroom temperature and relative humidity (Aliakbari, Moghadam & Lombardi, 2022). Considering that poor indoor ventilation has been associated with transmission of other respiratory viruses such as influenza viruses and parainfluenza viruses, this raises concerns about an increased risk of transmission of SARS-CoV-2 in academic buildings of higher educational institutions especially academic buildings with poor indoor air quality (Wang et al., 2021). Other than that, it is also identified that air pollutants pose a considerable influence over the infectious period of virus in the air (Nair et al., 2022). Through the study, it is suggested that air pollutants including particulate matter ($PM_{10}$ and $PM_{2.5}$), nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone, carbon dioxide, TVOCs and other pollutants as well as environmental quality parameters including relative humidity and temperature can expand the infectious duration of virus in the atmosphere, and increase the incidence, transmission, and mortality rates of viral disease. However, the study also finds that the relationship between the studied meteorological variables with the spread of COVID-19 is ambiguous, thus suggesting to direct further studies to risk prediction models to enable further understanding and making prediction of viral transmission risk indoors. Another study that highlights the concern of indoor air parameters such as particulate matters, temperature, relative humidity and temperature being a contributing factor in increasing the distance of spread of SARS-CoV-2 indoors suggest that extensive study is needed as the understanding is limited

(Wang et al., 2021). It is mentioned that although it is suggested that higher temperature and lower relative humidity are optimum for the stability of SARS-CoV-2, several studies however show contradicting results, where the potential role of temperature and relative humidity alone on the reproductive number and transmission of SARS-CoV-2 are not compelling enough to contribute to the global pandemic.

The risk of COVID-19 is also found to be a concern in academic facilities as several studies found universities as a place where outbreaks could happen at a large scale. 15% of of confirmed cases in Wisconsin in 2021 happened at universities with 18% of the cases are linked with outbreak cases (Pray et al., 2021). Indiana University also experienced a surge of cases to 371 COVID-19 positive cases at the first few weeks of phased student return to the university campus even with various public health measures being implemented such as isolations and hybrid learning mode (Fox et al., 2021). In local context, the risk of COVID-19 has been more focused on self-risk assessment such as mySejahtera application and the Health-Risk Assessment and Self-Evaluation (CHaSe) developed by Ismail et al. (2022) which lacks in the involvement of environmental factors that could contribute to the level of COVID-19 infection risk. Other than that, self-risk assessments are also not adequate to help understand the pattern of SARS-CoV-2 virus transmission and dispersion in different situations and buildings.

Thus, the proposed study is to fill in the gap of limited knowledge by studying the association between indoor air quality and the risk of COVID-19 airborne transmission in main university lecture halls.

## 1.2 Study justification

The period of lockdown had significantly changed the movement and activities of the people, which contributed to a major reduction of commercial activities worldwide, including academic activities. Thus, university campuses had been emptied because of the transition of education mode into distance learning mode (Bhat et al., 2022). This is a concern as it has been commonly found that inadequate ventilation, which could be due to rarely occupied spaces and poor ventilation system, can lead to the accumulation of pollutants to levels that can pose health problems towards the occupants (EPA, 2021). In line with the statement, the study conducted by Bhat et al (2022) also found that university campuses are experiencing deteriorating indoor air quality during COVID-19 emergence especially particulate matters in emptied and rarely occupied buildings. Thus, it is suggested that there is a need to conduct the study of the indoor air quality in university buildings in relation to its impact towards the transmission of viral infection, especially COVID-19.

Another justification of conducting this study is that the understanding on the extent of influence of indoor air parameters towards the spread of SARS-CoV-2 is limited up until now (Wang et al., 2021). Study conducted showed a significant negative correlation between recorded temperature and relative humidity with the effective reproductive number of SARS-CoV-2 in China and USA, suggesting that temperature and relative humidity higher than optimum level could potentially suppress the transmission of COVID-19. However, contradicting the statement, several other studies including the study conducted by Merow and Urban found no association between temperature and COVID-19 transmissibility (Wang et al., 2021). To further understand the risk of COVID-19 infection under different indoor air quality level and circumstances or situations, an online calculator named Airborne Infection Risk Calculator V3 developed by The City University of New York, University of Cassino and Southern Lazio, Queensland University of Technology and International Laboratory for Air Quality and Heath (ILAQH) was utilised to calculate the estimation of COVID-19 infection in indoor spaces. The choice of tool is particularly justified via the integrated features which include updated SARS-CoV-2 ERq distributions and SARS-CoV-2 variant multiplier (Mikszewski et al., 2021).

Another major gap of the current findings on the association between indoor air quality and the transmission of SARS-CoV-2 is the limited examples of data and analysis on the COVID-19 infection patterns as well as the specific indoor characteristics that have influenced the occurrence of infections (Morawska & Cao, 2020). However, the reason for concern is that the study also notes that the initial pattern of spread of COVID -19 was studied and suggests that many cases of COVID -19 are transmitted without contact, suggesting that the ventilation system and indoor air quality could be a possible major route for the spread of the virus through the air. Thus, more extensive studies need to be conducted to provide further evidence and insight into the impact of indoor air quality on the transmission of SARS-CoV-2.

## 1.3 Research question:

- Research question 1 : What is the state of indoor air quality in lecture halls and tutorial rooms of university academic buildings?

- Research question 2: What is the risk of COVID-19 infection in lecture halls and tutorial rooms at university academic buildings?

- Research question 3: Is there a correlation between the risk of COVID-19 infection and indoor air quality parameters in lecture halls and tutorial rooms at university academic buildings?

- Research question 4: What is the pattern of SARS-CoV-2 transmission in lecture halls and tutorial rooms at university academic buildings?

## 1.4 General objective

To assess the indoor air quality of academic buildings and the risk of COVID-19 infection in lecture halls and tutorial rooms of university academic buildings.

## 1.5 Specific objectives

Objective 1: To determine the levels of indoor air quality factors ($CO_2$, $PM_{2.5}$, temperature and relative humidity) in lecture halls and tutorial rooms at university academic buildings

Objective 2: To derive the risk of COVID-19 infection in lecture halls and tutorial rooms at university academic buildings

Objective 3: To determine the correlation between the risk of COVID-19 infection and indoor air quality parameters ($CO_2$, $PM_{2.5}$, temperature, and relative humidity) in lecture halls and tutorial rooms at university academic buildings

## 1.6 Hypothesis

$N_0$ hypothesis: There is correlation between indoor air quality with the risk of COVID-19 infection in lecture halls and tutorial rooms of academic buildings.

$N_a$ hypothesis: There is a no correlation between indoor air quality with the risk of COVID-19 infection in lecture halls and tutorial rooms of academic buildings

## 1.7 Definition

### 1.7.1 Indoor air quality

According to the official website of the Department of Occupational Safety and Health Malaysia (2019), indoor air quality portrays the quality of air inside an enclosed space, which can affect an individual's health, comfort and ability to carry out work. Indoor air quality can include but is not only limited to indoor temperature, humidity level, presence of mould and bacteria, ventilation as well as chemical exposure. DOSH also states that poor indoor air quality is able to cause discomfort and illness, as well as low productivity and absenteeism in work setting. Good indoor air quality on the other hand enables the health of enclosed building occupants to be protected. The United States Environmental Protection Agency (2021) defines indoor air quality as the quality of air in and around buildings as well as structures, particularly due to its relation to the state of health and comfort of building occupants.

The proposed study will be looking at 4 parameters of indoor air quality; particulate matter ($PM_{2.5}$), carbon dioxide ($CO_2$), relative humidity, and temperature inside observed lecture halls. All of the mentioned parameters will be measured via real-time monitoring; $CO_2$ (in ppm), relative humidity (%) and temperature (°C) will be measured using HOBO CO2 Logger (MX1102), $PM_{2.5}$ with TSI DustTrak II Aerosol Monitor 8532, USA in ppm.

### 1.7.2 COVID-19 transmission

COVID-19 transmission refers to the mode of transmission of SARS-CoV-2 from infected human to another human. According to WHO (2020), the possible SARS-CoV-2 routes of transmission include contact and droplet transmission, in which the virus can be transmitted via direct, indirect or close contact with infected individuals' secretions, for instance, saliva and respiratory droplets from coughing, sneezing, talking or singing. Another route of transmission is through air (airborne transmission), which is described as the infectious agent spread through the dispersion of aerosol droplet nuclei, which remain infectious even when being suspended in the air over a long duration of time and distance. The third mode of transmission mentioned by WHO is fomite transmission, which refers to the secretion of respiratory droplets from infected persons that is able to contaminate object surfaces.

Risk of COVID-19 transmission can be obtained by using Airborne Infection Risk Calculator (AIRC) that enables users to address two main concerns on the risks of COVID-19 transmission indoors; the potential risk of infection that is associated with the duration of stay in the indoor space, and the number of occupants in the space that could help in preventing further spread of disease in the space. The parameters and information needed for the input of calculation are as listed:

a. Room dimension
b. Infectious Viral Removal Rate
c. Number of infectious occupants
d. Initial quanta concentration
e. Exposure time

f. Susceptible inhalation rate

g. Infections occupants' activities

h. AER sensitivity analysis

Computational fluid dynamics (CFD) is also utilised as a tool to have a better understanding of the airborne transmission and dispersion of SARS-CoV-2 in different situations and buildings. The difference of ventilation will also be analysed via CFD modelling to find the effect of it towards the dispersion of SARS-CoV-2 (Mohamadi & Fazeli, 2022).

## 1.8 Conceptual Framework

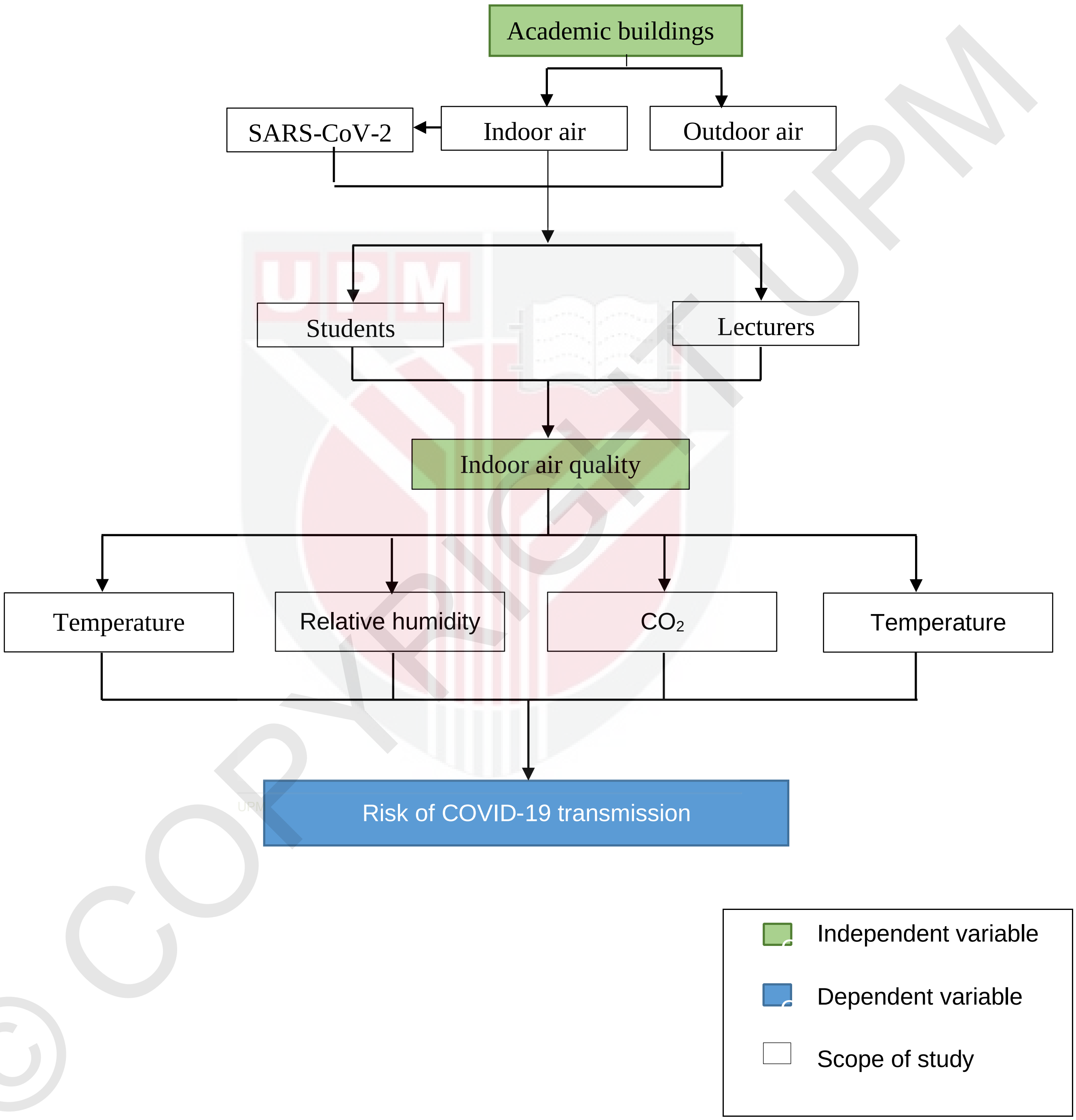



Figure 1.1 The conceptual framework of the study

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Indoor air quality in Malaysia

Indoor air quality has previously been conducted especially in homes, workplaces and education institutions including universities, schools and kindergartens to gain more insights on the impact of indoor air quality towards occupants' respiratory health conditions (Choo & Juliana, 2015). Understanding the importance of good air quality in academic buildings, several indoor air quality monitoring were conducted in universities around Malaysia which found varying results of indoor air quality in Malaysian academic buildings. A study in Universiti Teknologi Malaysia (UTM) found that the indoor air temperature of the monitored classrooms complied with the MS 1525:2014 standard, 85% of classrooms have suitable relative humidity, with most monitored classrooms have issues with air velocity (Zuhari et al., 2019).

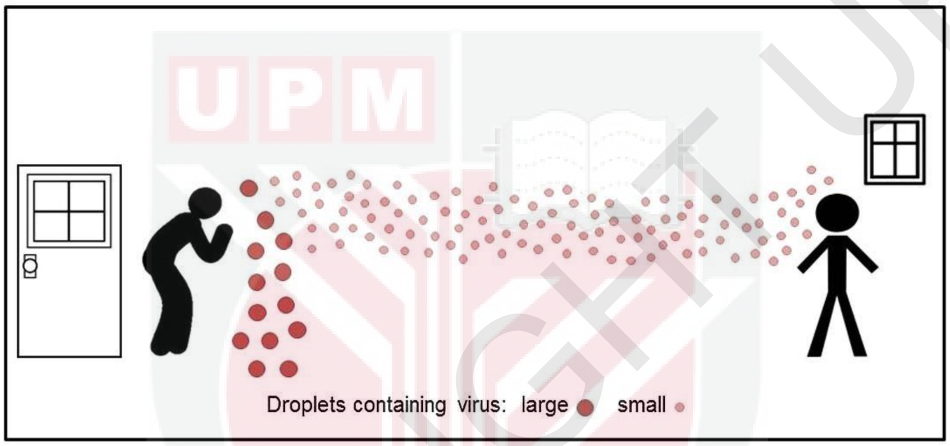
Previous study by Yusoff & Azwan (2014) also found that only three out of 20 selected Malaysian universities had an average temperature reading within the standards set by ICOP of IAQ 2010. The study also found that 35% of the involved universities had recorded relative humidity exceeding the acceptable range set by ICOP of IAQ 2010, and 45% of them recorded air movement below the standard. Their study indicated that there might be problems with the indoor air quality in Malaysian academic buildings, which posed a concern with the risk of indoor infection of COVID-19 among occupants, mainly students and teacher. Another study on indoor air quality of different buildings in higher institution, including the university classroom, laboratory, office, library, mosque, anatomy dissection hall and cafeteria found that the level of biological pollutants in the monitored locations do not exceed the acceptable limit by the Industrial Code of Practice for Indoor Air Quality (ICOP of IAQ) (Azlan et al., 2022) However, it was found that the university classroom, office and anatomy dissection laboratory experience high concentration of carbon dioxide exceeding the acceptable range from ICOP of IAQ.

## 2.2 Indoor COVID-19 transmission

As of 10.14p.m., 20 May 2022, 521 920 560 COVID-19 confirmed cases were reported to the World Health Organization (WHO) with 6 274 323 death cases reported (WHO, 2022). Karia et al. (2020), states that there are generally two major modes of SARS-CoV-2 transmission: direct and indirect. Direct mode of transmission includes transmission via aerosols as well as body fluids, while the indirect mode includes transmission via fomites and objects that are used by infected persons. However, this mode is typically underestimated and needs further study to emphasise on its role in transmitting and spreading SARS-CoV-2. Karia et al. (2020) also mentioned that respiratory droplets that are formed through activities such as talking, sneezing as well as coughing of an infected person is a common mode of SARS-CoV-2 transmission. Thus, the risk of transmission has a possibility to increase if the infected and susceptible are present within one metre apart. Karia et al. (2020) also suggested that airborne transmission of SARS-CoV-2 through the formation of aerosols of particles sized less than 100μm in diameter is the main mode of transmission. This raises the concerns of the risk of COVID-19 transmission indoors, considering the factors of ventilation and circulation of air within the indoor spaces.

With the concern on public health due to the COVID-19 pandemic, previous studies on COVID19 and indoor transmission were also conducted to better understand the interaction and relationship between the two aspects; COVID-19 transmission and indoor air quality. According to a study by Rodriguez et al. (2022), mechanical ventilation in university classrooms reduces the time occupants are exposed to heat stress by providing control over thermal variables such as relative humidity and temperature and maintaining an acceptable risk of SARS-CoV-2 transmission among indoor occupants, taking into account mask-wearing habits. Their research found that the transmission of COVID -19 can be influenced by the parameters of thermal comfort, i.e. relative humidity (RH) and room temperature, as the likelihood of airborne transmission of the virus is higher in dry indoor environments than in humid ones. The results showed that there is a higher risk of SARS-CoV-2 airborne transmission when RH is lower.

With increasing efforts and research to better understand COVID -19, airborne transmission is now recognised globally as one of the modes of transmission, leading to public prevention measures such as mandatory wearing of masks in public, especially indoors (Rowe et al., 2021). The important component leading to the conclusion that airborne transmission is a major route of infection for COVID -19 was observations and reports of the continuous pattern of transmission of COVID -19 and the clustering of cases in certain environments, e.g. clusters associated with indoor activities. In support of this, it has been observed that there are a consistently large number of COVID -19 cases where high transmission rates and spread occur in specific locations, known as 'super-spreader' cases or cluster events, with a large proportion of these cases occurring indoors, consistently associated with airborne transmission. In addition, Habeebullah et al. (2021) found that the rate of SARS-CoV-2 infection was higher amongst household close contacts compared to casual contacts. Studies by Leclerc et al. (2020) also agrees  that the spread of COVID-19 was contributed by large indoor gatherings, which are frequently associated with the start of cluster COVID-19 cases. Other than that, contaminated air and air pollution are also found to be a major drive that increases the diffusion and acceleration of COVID-19 infection (Coccia, 2020). The study suggests that contaminated air aids in the increase of SARS-CoV-2 transmission to humans compared to human-to-human transmission.




(Morawkska & Cao, 2020)

**Figure 2.1** The distance of droplet dispersion in indoor space which is influenced by the size of the droplets

Figure 2.1 illustrates how the size of droplets that contains virus could travel through air, and that the distance of travel is dependent on the size of droplets, in which smaller droplets are able to travel further compared to larger ones.

One of the SARS-CoV-2 transmission routes mentioned is the transmission of virus-laden particles through the air. The study also indicates that once droplets have expired from their hosts, the liquid content begins to evaporate, shrinking the size of the droplets to the point that air current affects the droplets' travel distance in comparison to gravitational influence. This allows viral contents in microscopic droplets to be transmitted and propagate metres away from the source. (Morawska & Cao, 2020).

## 2.3 Carbon dioxide as indicator of indoor ventilation and the risk of COVID-19 infection

Ventilation, including natural and mechanical ventilation, consists of two main modes; mixing ventilation in which the design of inlets and outlets allows flow generation that keeps an indoor space well-mixed to ensure that the temperature and components in the air (including contaminants) are uniform and evenly dispersed throughout the space. This is common in airconditioned buildings. Another mode of ventilation is known as displacement ventilation, where the arrangement of vents is to establish an interior stratification (warm upper zone and cool lower zone). The design of this mode is to ensure that occupants occupy the cool lower zone, and that extractors are put in the upper part of the enclosed space (Bhagat et al., 2020).

To evaluate the effectiveness of ventilation, Poirier et al. (2021) finds that several studies conducted agree on $CO_2$ being a good indicator for occupant emissions as the concentration of indoor $CO_2$ could measure the ventilation rate, thus being able to evaluate the effectiveness of the ventilation in an indoor space. The study also mentions that $CO_2$ is recommended to be used as an indicator and monitored to observe and reduce the virus transmission risk during the COVID-19 pandemic. This statement is also supported by Dominguez-Amarillo et al. (2020), which suggests $CO_2$ can act as a tool to evaluate the effectiveness of ventilation, thus making it suitable to be an index of indoor air quality as well. It is stated in the study that the concentration of $CO_2$ is considered to exceed the standard when the measurement is above 1000 ppm, thus indicating poor ventilation.

To add, it is stated by Pettenkofer et al (1858), Zhang et al (2016), Cain et al (1979), Cain et al (1967) and Fanger (1988) concur that carbon dioxide ($CO_2$) makes a good marker for emissions of occupant, which includes bio-emmisions, odours, volatile organic compounds (VOCs) as well as particle emission from equipment indoors that are used by the occupants (Poirier et al., 2021). It is also justified by Emmerich and Persily (2011) that $CO_2$ could be an indicator for ventilation rate. Their study mentions that the relationship between indoor carbon dioxide concentration and ventilation rate is understood, where CO2 can be an indicator of a space's acceptability for human use, a tool for estimating a building's air exchange rate, and the percentage of outdoor air intake. This can be done by measuring the decay rate of CO2 concentration after occupants have been absent from the building, by measuring CO2 concentration in real time, and by analysing the data to determine the air exchange rate to determine the effectiveness of ventilation. Thus, CO2 is a relevant parameter for ventilation via a performance-based approach (Poirier et al., 2021).

Fadaei (2021) found that ensuring effectiveness of the ventilation system has been a key strategy implemented in facilities, especially health facilities such as hospitals, to control infectious diseases as ventilation systems has been studied to be capable of being a route to transmit communicable diseases including SARS, measles, tuberculosis, influenza and so on. Thus, one of the factors being considered with the risk of COVID-19 transmission indoors is ventilation. Bhagat et al. (2020) states that there is an increase of evidence indicating that airflow is a crucial factor to be understood and considered to estimate the risk of COVID-19 infection. It is also mentioned that the current available data suggests that indoor transmission of SARS-CoV-2 exceeds the risk of outdoor transmission, possibly because of longer exposure duration and the decrease of turbulence levels, that also affects dispersion, indoors.

## 2.4 $PM_{2.5}$ and its role in transmitting SARS-CoV-2

Air quality, both indoor and outdoor, pose a notable factor that could cause health problems. Individuals who are exposed to poor air quality could be more susceptible to viruses, especially viruses with high contaminating nature such as COVID-19 (Kasioumi & Stangos, 2022). Particulate matter, which is one of the parameters of indoor air quality, with the size of 5μm and lesser is able to remain in the atmosphere for an extended duration of time and can be transmitted to distance more than 6m (Nor et al., 2021). One of the primary viral transmissions of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which is the agent of COVID-19, is found to be through respiratory droplets of various particulate size (Nor et al., 2021). Thus, particulate matter 2.5μm ($PM_{2.5}$) is one of the indoor parameters concerned with the transmission of SARSCoV-2 virus in enclosed space.

Particulate matters are a type of air pollutants that are able to bind to virus droplets and this will facilitate the spread of SARS-CoV-2 through the air. This could aid in the increase of the virus diffusion range as well as enabling direct transport of virus deeper into the pulmonary region (Qu et al., 2020). Findings also supported the suggestion of $PM_{2.5}$ being a factor that could increase the spread of SARS-CoV-2 by being a carrier for droplet nuclei emitted by exhalations which are then being stabilised in the air via coalescence of aerosols with highly concentrated particulate matter (Setti et al., 2020).

Milicevic (2021) in their measurements found that $PM_{2.5}$ is constantly found to be the main factor of SARS-CoV-2 transmission indoors in USA compared to other size of particulate matters, carbon monoxide and nitrogen dioxide, which are also found to be indoor SARS-CoV-2 transmitters. Apart from the ability of particulate matter to facilitate the spread of virus, the fine size of $PM_{2.5}$ also poses concerns of its effect on health if inhaled, as the small size allows the particles to travel deeper into respiratory tract, thus damaging the tract and enter the bloodstream, causing possible health problems (Kasioumi & Stangos, 2022). However, it is also stated that studies on the role of $PM_{2.5}$ in transmitting SARS-CoV-2 indoors should be more extensively studied and explored as extensive evidence is required to strengthen the claims of the $PM_{2.5}$ to be a factor of indoor SARS-CoV-2 transmitter (Milicevic, 2021). This statement can also be supported by findings from Nor et al., (2021) where the conducted study was not able to suggest an association between $PM_{2.5}$ concentration SARS-CoV-2 transmission in the location sampled.

## 2.5 Indoor temperature and relative humidity, and their roles in SARS-CoV-2 transmission indoors

According to Graphical Weather (2022), relative humidity is defined as a type of ratio expressed in percentage, to numerise the presence of atmospheric moisture relative to the amount that would be present when the atmosphere is saturated. The amount of atmospheric moisture level when the air is saturated depends on the temperature. Relative humidity is acquired from the temperature and dew point for the specifically indicated hour. It is a common knowledge that indoor relative humidity could affect the health of individuals as it could contribute to the incidence of respiratory infections as well.

Feng et al. (2020) states that exhaled droplets formed from an infected individual would either start to evaporate or undergo some growth, in which both are dependant of relative humidity. Several experimental studies have also been done to understand more on airborne-transmitted infectious viruses which have suggested that the survival and infectivity of pathogens including viruses could be minimised to relative humidity in the range of 40% to 70%. Ahlawat et al. (2020) also mentions that the optimal relative humidity for human health in indoor spaces is in a range of 40% to 60%.

Study by Ahlawat et al. (2020) stated that SARS-CoV-2 have higher surface stability than SARSCoV-1. It was also suggested that there is a possibility of the emission of tiny viral particles in indoor spaces through several factors including relative humidity, temperature, and wind speed. It is also suggested that SARS-CoV-2 transmission is higher in dry indoor places with less humidity; <40% RH, compared to indoor spaces with high relative humidity; >90% RH (Ahlawat et al., 2020). Aerosol droplets containing liquids and viruses evaporate in dry air, causing the water vapour pressure on their surface to equilibrate with the surrounding atmosphere. This leads to a loss of water, which influences other factors such as the pH value and the concentration of dissolved substances. The microdroplets become smaller and can remain suspended in the air for longer, which helps to increase the concentration of virus particles in suspension. Relative humidity and indoor ventilation both play a role. Stagnant air and inadequate ventilation increase the likelihood of an accumulation of airborne virus concentrations.

Other than relative humidity, another closely related meteorological factors that affect the stability of virus is temperature. Virus viability is mentioned to be able to retain for more than 5 days at the range of temperature between 22-25°C and relative humidity of 40-50%, which is also a typical air-conditioned environment. However, the viability of virus will rapidly decrease (>3 log(10)) at higher temperatures and higher relative humidity; i.e 38°C, with relative humidity of >95%. Thus, it is suggested that SARS coronavirus has better state of stability in environments with low temperature and low humidity, as these conditions of parameters would be able to facilitate the transmission of virus, especially in air-conditioned spaces (Chan, 2011).

## 2.6 COVID-19 Risk Infection Calculation

Throughout the COVID-19 pandemic, there are numerous efforts in developing tools to determine the risk of COVID-19 infection, including online calculators and softwares, that range between simple and easy to complicated, mostly depending on the objective of the tool usage. For instance, CovidRiskCalc is an online application that helps in calculating the estimated risk of a person to be infected with COVID-19 when coming into contact with a group of people during a specific event, where some of the group may be COVID-19 infected (Artzrouni, 2020). A calculator tool, Covid Risk Calculator (CORAL) was also used to conduct a study in being a guide for frontline clinicians in handling persons under investigation (PUI). The result suggests that CORAL is efficient and effective as a tool in guiding frontline clinicians for the diagnostic evaluation of persons under investigation as well as safe discontinuation of precautions (Dugdale et al, 2021).

Another COVID-19 infection risk calculator is Airborne Infection Rate Calculator (AIRC) version 3 which is an updated AIRC tool developed by personnel from The City University of New York, University of Cassino and Southern Lazio, Queensland University of Technology School of Earth and And Atmospheric Sciences, International Laboratory for Air Quality and Heath (ILAQH). The tool acts as a preliminary decision-support aid for facility managers, building engineers, as well as public and occupational health professionals which will be continuously studied and revised throughout the advances of SARS-CoV-2 and other airborne pathogens (Mikszewski, 2021). The tool is chosen to be utilised to calculate the risk of COVID-19 transmission in indoor environments, in order to fulfil the proposed research project. AIRC also enables researcher to highlight two main concerns on the risk of COVID-19 transmission indoors — the potential risk of infection that is associated with the duration of stay in the indoor space, and the number of occupants in the space.

# CHAPTER 3

# METHODOLOGY

## 3.1 Research Design

The research was a quantitative cross-sectional study to assess indoor air quality and the risk of COVID-19 infection in academic buildings. Purposive sampling was used in the selection of academic buildings in regards of the listed inclusion and exclusion criteria. The researcher performed real-life 10-hour continous monitoring of parameters of interest (indoor temperature, relative humidity, carbon dioxide and $PM_{2.5}$), in lecture halls and tutorial rooms of different faculties of University Putra Malaysia Serdang Campus, each at a specific duration of time between 7:30 a.m. to 5:30 p.m.

## 3.2 Background and Study Location

Universiti Putra Malaysia is the largest university in Malaysia covering 1822.8 hectares of land, with a total of 29 703 students in 16 faculties as of 2021 enrolment. Universiti Putra Malaysia was chosen as the academic buildings differ in the year built, occupancy and ventilation system used, allowing the quality of indoor air and the risk of COVID-19 infection indoors to be studied in different types of conditions. Three lecture halls and three tutorial rooms from three faculties were selected as sampling locations using purposive sampling based on the inclusion and exclusion criteria. The locations selected were as such; Faculty of Medicine and Health Sciences lecture hall, LH(a) and tutorial room, TR(a), and Faculty of Veterinary Medicine lecture hall, LH(b) and tutorial room, TR(b) and Faculty of Biotechnology and Biomolecule Science lecture hall, LH(c) and tutorial room, TR(c). Figure 3.1 shows the location of Faculty A, Faculty B and Faculty C and Table 3.1 contains the description of location and characteristics of academic buildings selected for the study. The general floor plan of lecture halls and tutorial rooms were tabulated in Figure 3.2.


**Figure 3.1** Location of Faculty A (Faculty of Medicine and Health Sciences), B (Faculty of Veterinary Medicine), and C (Faculty of Biotechnology and Science Biomolecule) located at Universiti Putra Malaysia, Serdang Campus, Selangor, Malaysia

(a) (b)

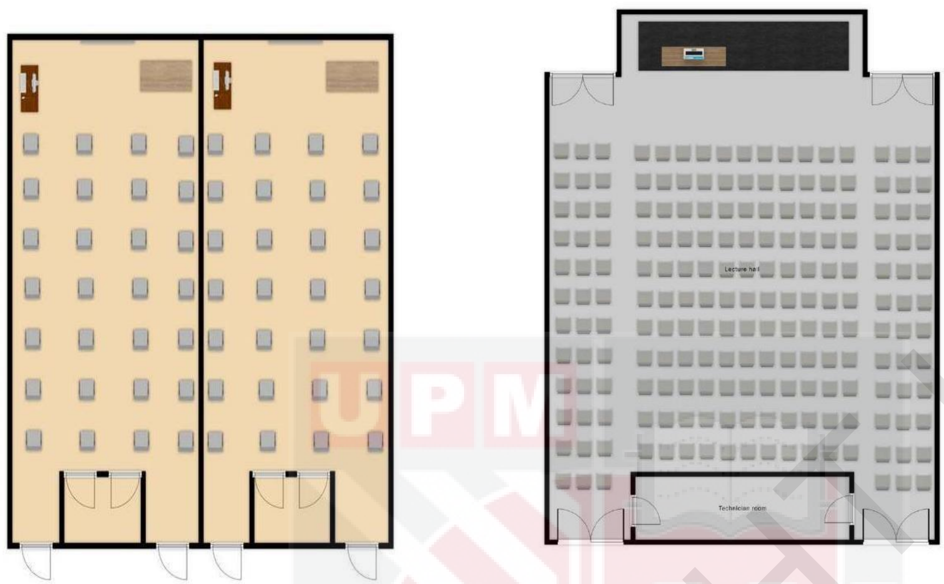


**Figure 3.2** The general floor plan of academic buildings selected in the study. (a) is tutorial room. (b) is lecture hall

**Table 3.1** Description of academic buildings selected for the study.

| Faculty | Academic building | Description |
|---|---|---|
| A | LH(a)<br>TR(a) | • The faculty complex was built in August 1996 and is located 2895.1m southeast of Sultan Abdul Samad Library, University Putra Malaysia, and 266.7m west of Serdang Hospital.<br>• The academic buildings of the faculty including tutorial rooms, lecture halls, exam halls and laboratories, are mechanically ventilated using centralised air |

| | | |
|---|---|---|
| | | conditioning system, in which the air handling unit (AHU) uses mesh filter as the air filter. |
| B | LH(b)<br>TR(b) | • The new faculty complex was built in 2010 and is located 2757.6m southeast of Sultan Abdul Samad Library University Putra Malaysia.<br>• The academic buildings of the faculty including lecture halls, tutorial and seminar rooms, laboratories, office and research area are mechanically ventilated with centralised air conditioning system. |
| C | LH(c)<br>TR(c) | • The faculty was built in 2004 and is located 270.8m north of Sultan Abdul Samad Library, Universiti Putra Malaysia.<br>• The academic buildings including the laboratories, office, lecture halls and seminar rooms are mechanically ventilated with split-unit air conditioning. |

## 3.3 Selection Criteria

### 3.3.1 Selection Criteria of Faculty

Faculties were selected based on the variety of year the building was built and the type of mechanical ventilation used in buildings.

### 3.3.2 Selection Criteria of Lecture Halls and Tutorial Rooms

Inclusive criteria

1.Lecture halls and tutorial rooms with scheduled occupancy of students and lecturers.

2.Lecture halls and tutorials that use mechanical ventilation.

Exclusion criteria

1.Lecture halls and tutorial rooms located at the basement floor of the building.

2.Lecture halls and tutorial rooms that use natural ventilation and fans.

## 3.4 Duration of Study

The study took a maximum duration of 12 weeks of data collection starting from 1st of October 2022 to December 2022, in which a maximum duration of two weeks was allocated for data collection at one faculty. Each location took a 10-hour continuous measurement of the parameter of interest (relative humidity, temperature, $PM_{2.5}$ and $CO_2$.) from 7:30 a.m. to 5:30 p.m. The volume and air flow of each sampling location was also taken throughout the sampling period using a balometer.

## 3.5 Data Collection and Instrumentation

### 3.5.1 Building Characteristics

A walkthrough assessment was conducted to determine the general conditions of study locations, potential sources of contaminants as well as the ventilation and air-conditioning system used. The walkthrough assessment was conducted by adopting checklist for walkthrough inspection of Industrial Code of Practice of Indoor Air Quality, 2010 (ICOP of IAQ 2010) Department of Safety and Health (DOSH) as attached at Appendix A.

MILESEEY Laser Distance Meter, as shown in Figure 3.3, was used to measure the length, height and width of the space to enable researchers to find the volume of the indoor space being measured. The instrument, which is a laser 2 class product, uses laser beam with the wavelength of 630670nm and power <1mW, beam divergence of 0.16x0.6mrad and pulse duration of 0.25s. MILESEEY Laser Distance Meter is able to measure to a maximum distance of 40 m, with the accuracy of ± 0.5 mm. The instrument was placed onto a flat surface and the bubble indicator was adjusted to be within the indicated space to ensure a linear surface for accurate measurement.

a. MILESEEY Laser Distance Meter


**Figure 3.3.** MILESEEY Laser Distance Meter

### 3.5.2 Indoor Air Quality Monitoring

Static indoor measurements for $CO_2$, temperature and relative humidity were conducted using HOBO CO2 Logger MX1102 (USA), and TSI DustTrak II Aerosol Monitor 8532 (Shoreview, MN) was used to measure $PM_{2.5}$.. All measurements were set to record a 5-minute average of concentrations for 10 hours (7:30 a.m. until 5:30 p.m.). To record the difference of each indoor air parameter concentration between zero occupancy and presence of occupants, the monitoring was conducted 30 minutes before the start of the first class and 30 minutes after the last class period.

a. HOBO $CO_2$ Logger (MX1102), USA

HOBO $CO_2$ Logger (MX1102), as shown in Figure 3.4, was used to measure real-time temperature, relative humidity and $CO_2$ of the indoor environment in which the study took place. The logger can sense temperature within the range of 0° to 50°C with the accuracy of ±0.21°C.

The range of detected relative humidity by the sensor is 1% to 70% when $CO_2$ sensor is enabled (non-condensing environment) and 1% to 90% when the $CO_2$ sensor is disabled (condensing environment). The response time for temperature is 12 minutes to 90% in airflow of 1 m/s. The sensor can detect relative humidity with the accuracy of ±2% for relative humidity from 20% to 80% to a maximum of ±4.5% which includes hysteresis at 25°C, while relative humidity that is below 20% and above 80% has an accuracy of ±6% typical. The response time for relative humidity is 1 minute to 90% in airflow of 1 m/s. The logger also senses $CO_2$ within the range of 0 to 5000ppm with the accuracy of ±50 ppm, ±5% of reading at 25°C and at RH less than 70%. For carbon dioxide monitoring, warm-up time of 15 seconds manual or automatic calibration to 400 ppm is required. Carbon dioxide sensor of the logger operates through non-dispersive infrared (NDIR) absorption. The response time for carbon dioxide sensing is 1 minute to 90% of 1 m/s airflow.


**Figure 3.4.** HOBO $CO_2$ Logger (MX1102), USA

The instrument was placed at least 0.5 meters away from any vertical surfaces and not within two meters from entrance doors to minimise interference from occupants' movement and placed at a height that could represent the breathing zone of students, which was 0.75m and less from the floor. An interval of 1 minute was taken by the researcher throughout the 10-hour period of measurement for each location.

b. TSI DustTrak II Aerosol Monitor 8532, USA

TSI DustTrak II Aerosol Monitor 8532, as shown in Figure 3.5, was used to measure the concentration of $PM_{2.5}$ in study locations. The instrument operates with sensor type of 90° light scattering within the range of 0.001 mg/$m^3$ to 150mg/$m^3$. The instrument operates with the flow rate of 3.0L/min and flow accuracy of ±5% as per factory set. Instrument is to be calibrated by running zero calibration with a zero filter being attached before starting the measurement. The instrument has the ability to detect particle size ranging from 0.1 to 10 µm.

**Figure 3.5.** TSI DustTrak II Aerosol Monitor 8532, USA

However, for the proposed research, a $PM_{2.5}$ filter was used with this instrument to specifically measure the concentration of particulate matter of 2.5 µm in size. An interval of 1 minute was taken throughout the 10-hour period of measurement for each location. The instrument was placed at a sampling point at least 0.5m away from any vertical surfaces, and not within two meters from any entrance door to ensure minimum interference, and was placed at a height no more than 0.75m from the floor to represent breathing zone of student in sitting positions.


**Figure 3.6.** Placement of TSI DustTrak II Aerosol Monitor 8532 and HOBO $CO_2$ Logger (MX1102) in lecture hall

**c.** Alnor TSI Balometer Capture Hood EBT731, USA

A balometer capture hood was used to measure the direct air flow from the air supply of the ventilation system in the lecture halls and tutorial rooms. The capture hood captures the air that exits through the diffuser in the base and directs it to the manifold, which will then average the velocity pressure before directing the air to the sensors. The air velocity and temperature of the air going through the manifold are then sensed by applying the constant temperature themoanemometer principle. Alnor TSI Balometer Capture Hood EBT731, as shown in Figure 3.7, can measure air flow velocity within the range of 25 to 5000 ft/min using the air flow probe and 25 to 15 500 ft/min using pitot probes. The accuracy if velocity measurement is ±3% of reading, ± 7 ft/min or 0.04 m/s > 50 ft/min or 0.25 m/s. The instrument also measures volume within the range of 25 to 2500 $ft^3$/min for capture hood supply and return. The measurement of volume has an accuracy of ± 3% of reading ± 7 $ft^3$/min or 12 $m^3$/s > 50 $ft^3$/min or 85 $m^3$/s.


**Figure 3.7**. Alnor TSI Balometer Capture Hood EBT731

Researcher placed the balometer hood onto the opening of a 2ft x 2ft inlet air duct of the indoor space monitored to obtain the air velocity emitted from the air duct. Measurement was taken thrice for accuracy and to obtain the average air velocity. The measurement of air velocity from air ducts is shown in Figure 3.8. To calculate the air exchange rate of the monitored indoor space, the following formula will be used:

$$N = \frac{Total\ flow\ rate, cfm}{Volume\ of\ area, ft^3} \times 60 min/hour$$

In which,

N= Air change per hour


**Figure 3.8.** The measurement of air velocity from an air inlet of tutorial room using Alnor TSI Balometer Capture Hood EBT731

### 3.5.3 Calculation of risk of indoor COVID-19 infection

d. Airborne Infection Rate Calculator (AIRC) Version 3

To calculate the risk of SARS-CoV-2 infection indoors, Airborne Infection Rate Calculator (Version 3), as shown in Figure 3.9, was used. AIRC is a novel risk modelling approach tool used to estimate individual infection and the risk of community transmission which are associated with specific indoor environments. AIRC manual states that a quantum is the required airborne droplet nuclei to infect 63% susceptible individuals. AIRC utilised SARS-CoV-2 data of quanta emission rate to find the risk of transmission in different environmental parameters, respiratory activities as well as activity levels of occupants. Version 3 of the tool was chosen as it included quanta emission rate distribution for up until 10 infectious individuals in an enclosed space by using Monte Carlo simulation which could provide better accuracy of quantification of higher cumulative emission for over-dispersed pathogens including SARS-CoV-2.

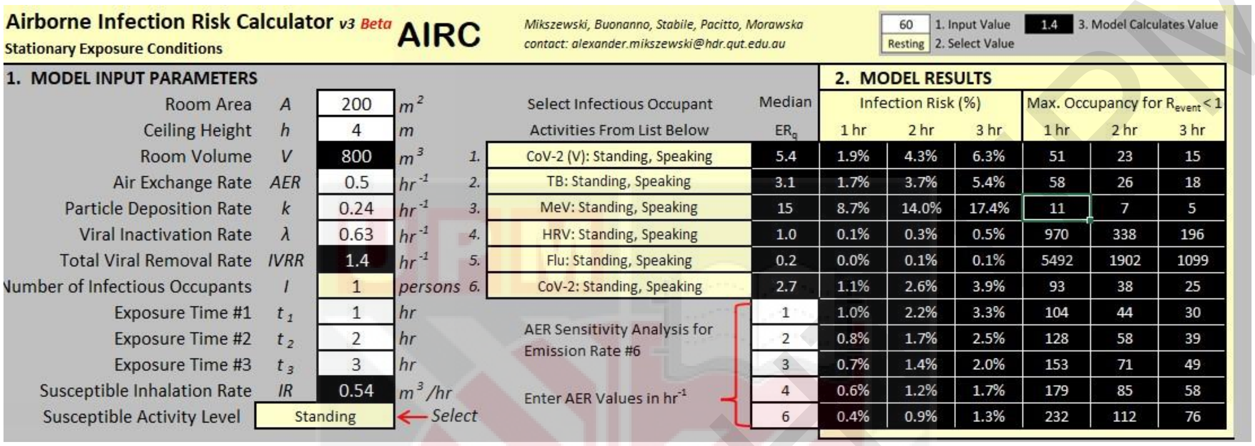



**Figure 3.9.** Airborne Infection Rate Calculator (AIRC) Version 3

The risk of COVID-19 infection was calculated using the tool by considering the following parameters:

- The volume of the indoor space. The volume was obtained by using MILESEEY Laser Distance Meter, which is a laser 2 class product to measure the length, width and space of the selected indoor spaces. The instrument was placed onto a flat surface and the bubble indicator was ensured to be within the indicated space to ensure a linear surface for accurate measurement.
- Air exchange rate. Alnor TSI Balometer Capture Hood EBT731 (USA) was used to measure the air velocity of the supply air inlet of sampling locations with centralised air conditioning system. The hood of the instrument was placed at the opening of a supply air inlet until the instrument records a reading, and the measurement was taken thrice. The air

exchange rate (AER) was calculated from the air velocity measured by using the following formula:

$$N = \frac{Total\ flow\ rate, cfm}{Volume\ of\ area, ft^3} \times 60\ \text{min/hour}$$

However, AER calculation was not included for academic buildings with split-unit air conditioning system as there was no circulation of fresh air in the academic building.

- Particle deposition rate. The recommended value of particle deposition rate for SARS-CoV-2 from Buonanno et al. (2020) is 0.24 $hr^{-1}$ as stated in the AIRC manual.
- Viral inactivation rate. The recommended value for viral inactivation rate, λ for SARSCoV-2 stated in the AIRC is 0.63 $hr^{-1}$ which is calculated using the following equation:

$$\Lambda hr^{-1} = \frac{0.693}{t1/2}$$

In which half-life of SARS-CoV-2, $t_{1/2}$ is 1.1 hour.

- Number of infectious occupants. One occupant was assumed to be infected with COVID19 in every academic building studied to estimate the minimum risk of COVID-19 infection to occupants in academic buildings.
- Exposure time. Three exposure time, $t_1$=1 hour, $t_2$=2 hours and $t_3$=3 hours to represent the usual duration of each lecture conducted in academic buildings selected in the study.
- Activity of occupants. Two types of occupants' activities were selected to represent the common activities conducted by occupants of academic buildings being studied which are standing, speaking and resting, oral breathing.

### 3.5.4 Modelling of SARS-CoV-2 transmission indoors

a. SOLIDWORKS 2021 software

The software was used to produce a 3D model of the chosen indoor space as the preliminary step or foundation towards construct a computational fluid dynamics (CFD) model. Models of a lecture hall and a tutorial room were constructed based on the measurements of height, width and length obtained, measurements of seats as well as the location of air ducts in respective academic buildings.

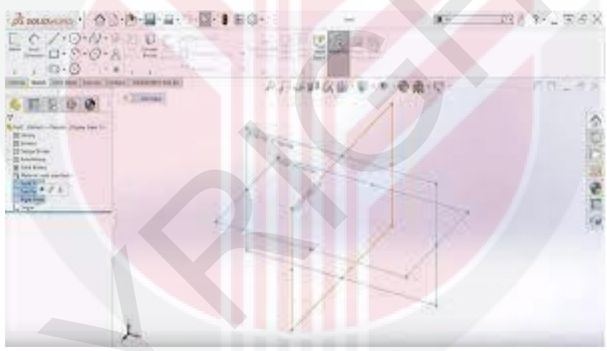


**Figure 3.10** The interface of SOLIDWORKS 2021 software

### 3.6 Data Analysis

Statistical analysis was performed based on the following objectives in Table 3.2.

**Table 3.2.**The specific objectives and the type of analysis used for the study.

| Specific Objective | Type of analysis |
|---|---|
| To determine the levels of indoor air quality factors ($CO_2$, $PM_{2.5}$, temperature and relative humidity) in lecture halls and tutorial rooms at university academic buildings | Descriptive analysis<br>• Microsoft EXCEL |
| To derive the risk of COVID-19 infection in lecture halls and tutorial rooms at university academic buildings | Descriptive analysis<br>• AIRC V3 |
| To determine the correlation between the risk of COVID-19 infection and indoor air quality parameters ($CO_2$, $PM_{2.5}$, temperature, and relative humidity) in lecture halls and tutorial rooms at university academic buildings | Statistical analysis<br>(Pearson correlation test)<br>• IBM® SPSS® Statistics 27 |

### 3.7 Quality Control

#### 3.7.1 Pilot study

A series of pilot study was held from May 2022 until June 2022 at two academic buildings in Universiti Putra Malaysia Serdang Campus to conduct real-life monitoring with the presence of occupants while lectures were being carried out. The parameters measured included $PM_{2.5}$, relative humidity, temperature and carbon dioxide. Pilot study was done to determine the feasibility of the planned approach and strategies that are intended to be implemented in the actual study. The pilot study was also done as a strategy to ensure the accuracy and validity of the methods and instruments used.

### 3.7.2 Duplicate reading

Continuous real-time measurement for 10 hours was taken twice for each sampling point. This is to ensure better accuracy and validity of measurements taken and the two replicates were able to be measured and compared.

### 3.7.3 Calibration

All monitoring instruments (TSI DustTrak II Aerosol Monitor 8532 and HOBO CO2 Logger MX1102) were calibrated by respective manufacturers. TSI DustTrak II Aerosol Monitor 8532 was calibrated by running zero calibration for 1 minute before the start of measurement. HOBO CO2 Logger MX1102 was calibrated via automatic calibration by leaving it run for 5 minutes before the start of measurement. Duplicate measurements were taken for each study location at the same time and number of occupants.

## 3.8. Permission Approval

Permission to conduct the study at selected locations of Faculty A, Faculty B and Faculty C were granted by dean of respective faculties by submitting a permission letter as attached on Appendix

B. Schedule of the use of academic buildings were obtained from the Dean's and Deputy Dean's Office of respective faculties. Information on the ventilation system and other related information of the selected academic buildings were obtained from the maintenance and engineering department of respective faculties

# CHAPTER 4

# RESULTS

## 4.1 Building characteristics

A total of six sampling locations; three lecture halls and three tutorial rooms located in three faculties of Universiti Putra Malaysia, Serdang Campus were selected to conduct the study from October until December 2022.A walkthrough inspection was done with the faculty engineers to observe and understand the current general physical condition, human exposure and indoor air condition in each sampling location. All the sampling locations use mechanical ventilation, however faculty A and B utilise centralised air conditioning system while Faculty C use split unit air conditioning system to mechanically ventilate their academic building. The age of building varies accordin to the year each faculty was built. The summary of the walkthrough results is tabulated in Table 4.1.

**Table 4.1**. Results of walkthrough inspection for LH(a), TR(a), LH(b), TR(b), LH(c) and TR(c)

| Aspect | Faculty A | | Faculty B | | Faculty C | |
|---|---|---|---|---|---|---|
| | LH(a) | TR(a) | LH(b) | TR(b) | LH(c) | TR(c) |
| **Floor located** | First floor | Second floor | Ground floor | Ground floor | Ground floor | Second floor |
| **Type of ventilation system** | Centralised | Centralised | Centralised | Centralised | Split-unit | Split-unit |
| **Building age (year)** | 26 | 26 | 12 | 12 | 18 | 18 |
| **Volume of space ($m^3$)** | 1243.0 | 203.0 | 502.10 | 197.0 | 400.40 | 80.11 |
| **Use of thermostat and indoor temperature setting** | Yes | Yes | Yes | Yes | Yes | Yes |
| **Presence of at least one supply and one extract air vent** | Yes | Yes | Yes | Yes | No | No |

### 4.2 Assessment of Indoor Temperature, Relative Humidity, Carbon Dioxide and Particulate Matter $PM_{2.5}$

The complete list of median, interquartile range, maximum and minimum value of temperature, relative humidity, $CO_2$ and $PM_{2.5}$ at each location (LH(a), LH(b), LH(c), TR(a), TR(b), and TR(c)) is shown in Table 4.2.

**Table 4.2**. The median, interquartile range, maximum and minimum value of indoor air parameters (temperature, relative humidity, $CO_2$ and $PM_{2.5}$) at LH (a), LH (b), LH(c), TR(a), TR(b), and TR(c).

| Parameter | Location | Median±IQR | Max | Min |
|---|---|---|---|---|
| **Temperature, °C** | LH(a) | 21.85±3.49 | 26.62 | 20.80 |
| | TR(a) | 24.03±0.63 | 24.77 | 23.52 |
| | LH(b) | 21.79±0.45 | 26.84 | 20.56 |
| | TR(b) | 25.16 ±1.15 | 25.36 | 25.08 |
| | LH(c) | 25.30±2.38 | 27.03 | 23.81 |
| | TR(c) | 24.01±2.76 | 28.26 | 20.72 |
| **Carbon dioxide, ppm** | LH(a) | 833.50±354.25 | 1171.50 | 473.00 |
| | TR(a) | 1142.50±394.00 | 1317.00 | 455.50 |
| | LH(b) | 865.00±294.75 | 1084.00 | 391.5.00 |
| | TR(b) | 1115.00±156.00 | 1170.50 | 374.00 |
| | LH(c) | 648.00±342.63 | 976.00 | 200.00 |
| | TR(c) | 602.67±215.45 | 1097.00 | 318.50 |
| **Relative humidity, %** | LH(a) | 77.04±4.63 | 84.18 | 70.97 |
| | TR(a) | 64.15±1.55 | 66.37 | 62.52 |
| | LH(b) | 65.64±1.11 | 72.27 | 63.33 |

| | | | | |
|---|---|---|---|---|
| | TR(b) | 68.30±1.76 | 69.81 | 66.48 |
| | LH(c) | 59.55±5.68 | 70.83 | 50.43 |
| | TR(c) | 67.33 ±12.27 | 73.22 | 55.31 |
| **$PM_{2.5}$, µg/m³** | LH(a) | 24.00±0.070 | 101.00 | 19.00 |
| | TR(a) | 2.00±0.004 | 30.00 | 1.00 |
| | LH(b) | 3.00±0.004 | 138.5 | 0.00 |
| | TR(b) | 20.00±0.001 | 26.50 | 0.00 |
| | LH(c) | 21.00±0.010 | 32.50 | 14.00 |
| | TR(c) | 32.00±0.008 | 4.60 | 17.00 |

**Acceptable limit/range**

| | |
|---|---|
| Temperature | 23-26°C |
| Relative humidity | 40-70% |
| $CO_2$ | 1000ppm* |
| $PM_{2.5}$ | 15 µg/m³** |

*ceiling limit
** limit

All the lecture halls and tutorial rooms recorded acceptable temperature within the range of 23°C to 26°C. It was found that the highest temperature was reached during the highest occupancy of the academic building throughout the day, with 56 occupants in TR(c). The lowest temperature recorded was 20.6°C at LH(b) where there was no occupant present in the academic building. The study found that only one academic building exceeded 70% of relative humidity (LH(a)), and tutorial rooms generally recorded higher relative humidity median compared to lecture halls. The highest recorded relative humidity was 84.2% at LH(a) at 10:42 a.m. while the lowest relative humidity was at LH(c) at 50.4%. at 3:26 p.m. Five out of six academic buildings exceeded the ceiling limit of $CO_2$ concentration at 1000 ppm. The highest concentration of carbon dioxide detected during monitoring was 1356.0 ppm at TR(a) while the lowest was 200 ppm recorded at LH(a). Figure 4.2 further dissects the trend of $CO_2$ concentration at both lecture halls and tutorial rooms $PM_{2.5}$ was recorded to be generally higher at lecture halls compared to tutorial rooms. LH(a) had recorded the highest $PM_{2.5}$ concentration at 101.0 µg/m³. LH(b) and TR(b) recorded the lowest concentration with 0 µg/m³ at 3:47 p.m. until 5:15 p.m. and 1:40 p.m. until 2:40 p.m. respectively. The distribution of indoor air parameters (temperature, relative humidity, $CO_2$ and $PM_{2.5}$) at LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c) is shown in Figure 4.1.

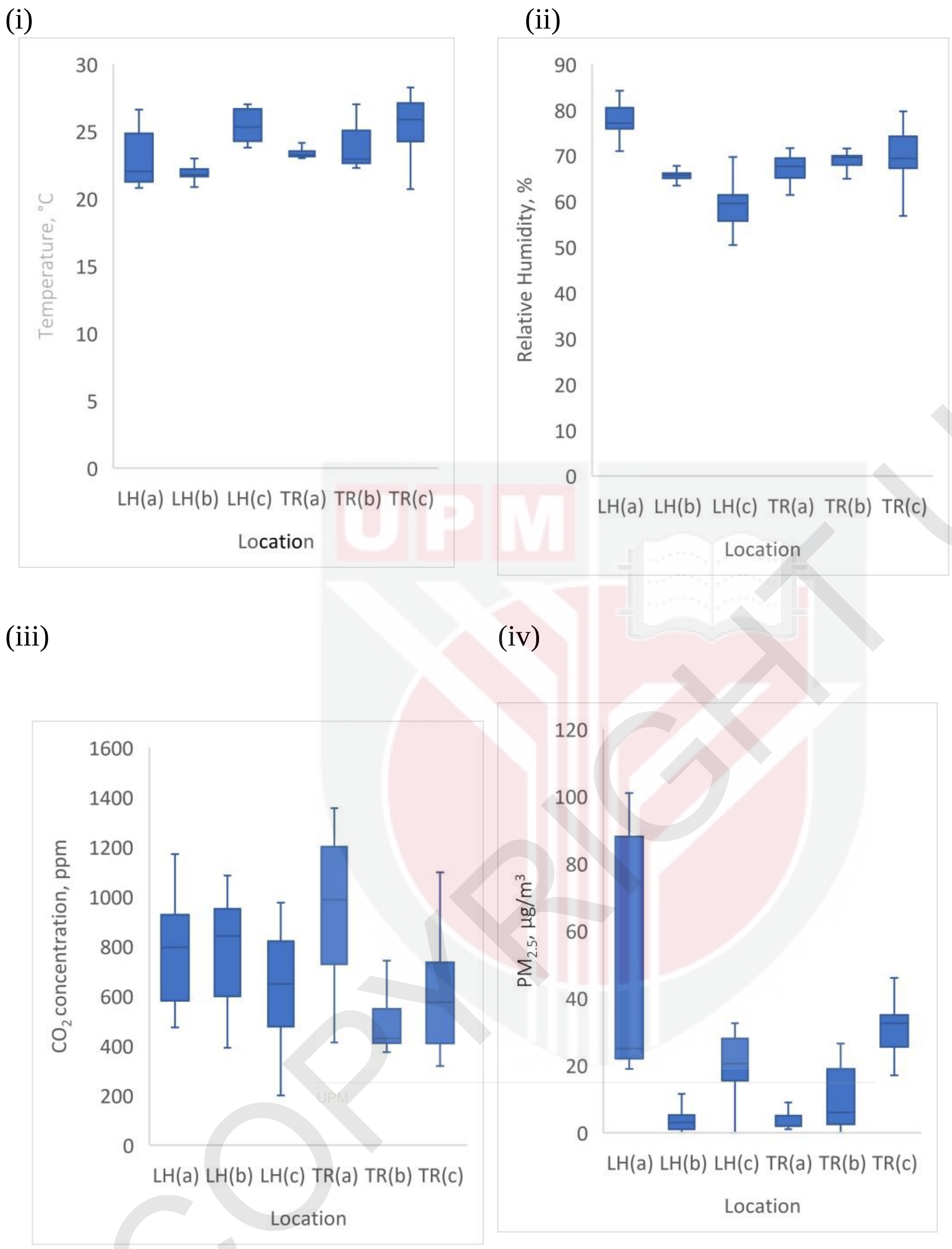



**Figure 4.1** . Distribution of indoor air temperature at LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c). (i) shows temperature, (ii) relative humidity, (iii) $CO_2$, and (iv) $PM_{2.5}$. (a), (b) and (c) represents Faculty A, B and C respectively. (LH) refers to lecture halls and (TR) refers to tutorial rooms. Horizontal line at each box shows the median value and the box span shows the 25$^{th}$ percentile (Q1) and 75$^{th}$ percentile (Q3). The upper line shows the maximum value and the lower line shows the minimum value.

### 4.3 Risk of COVID-19 Infection in lecture halls and tutorial rooms

It was assumed that one COVID-19 infected individual was present in each study location during the study to calculate the minimum risk posed to occupants at every interested activity in this study (standing, speaking and resting, breathing). The results of COVID-19 infection risk calculation is tabulated in Table 4.3.

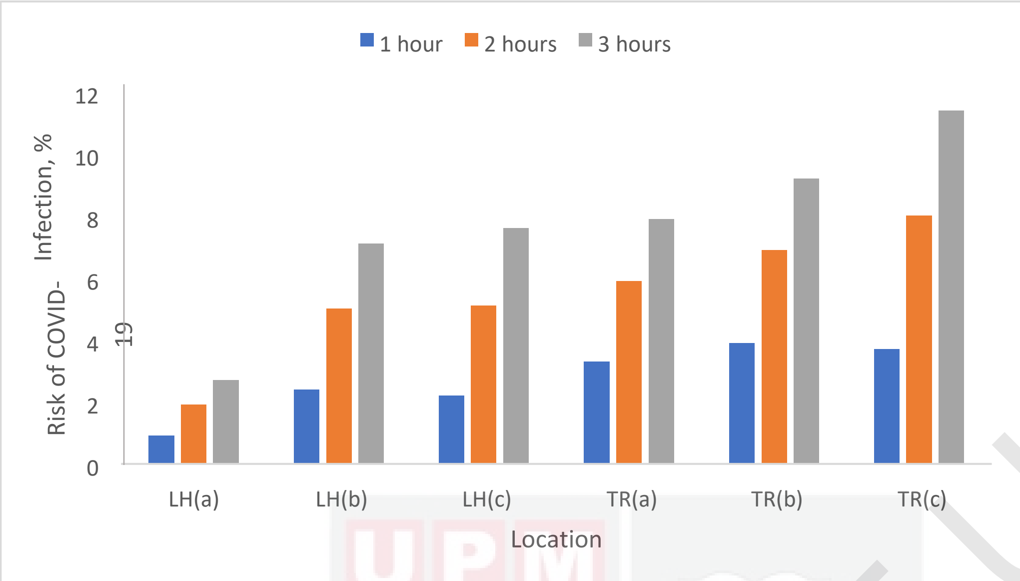
**Table 4.3.** The results of COVID-19 infection in LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c) based on the hour of exposure and the activities of occupants

| | **Location** | **Risk of COVID-19, %** | | | **Risk of COVID-19, %** | | |
|---|---|---|---|---|---|---|---|
| | Activity | Standing, speaking | | | Resting, breathing | | |
| | Hour of exposure | 1 | 2 | 3 | 1 | 2 | 3 |
| **Faculty A** | LH(a) | 0.9 | 1.9 | 2.7 | 0.2 | 0.4 | 0.7 |
| | TR(a) | 3.3 | 5.9 | 7.9 | 0.9 | 1.8 | 2.6 |
| **Faculty B** | LH(b) | 2.4 | 5.0 | 7.1 | 0.6 | 1.5 | 2.3 |
| | TR(b) | 3.9 | 6.9 | 9.2 | 1.1 | 2.2 | 3.2 |
| **Faculty C** | LH(c) | 2.2 | 5.1 | 7.6 | 0.5 | 1.5 | 2.5 |
| | TR(c) | 3.7 | 8.0 | 11.4 | 1.0 | 2.6 | 4.2 |

The highest risk of COVID-19 infection calculated when there is activity of standing and speaking for three hours was 11.4% which was at TR(c) and the lowest was 2.7% at LH(a). For the risk of COVID19 infection for occupants with activity of resting and breathing, the highest calculated risk was 4.2% at

TR(c) and the lowest was 0.7% at LH(a). Thus, the risk of COVID-19 infection was found to be higher when the activity of standing and speaking was conducted in indoor space compared to the activity of resting and breathing. For the minimum exposure duration (1 hour) with the activity of resting and breathing, only two academic buildings (TR(b) and TR(c) had COVID-19 risk infection of more than 1%, while there were five out of six academic buildings (TR(a), TR(b), LH(b) and LH(c)) that had recorded the risk of COVID-19 infection for the activity of standing and speaking. Figure 4.3 shows the level of COVID-19 risk infection for exposure time of 1, 2 and 3 hours during the activity of standing and speaking and resting and breathing.

**(a)**




**(b)**

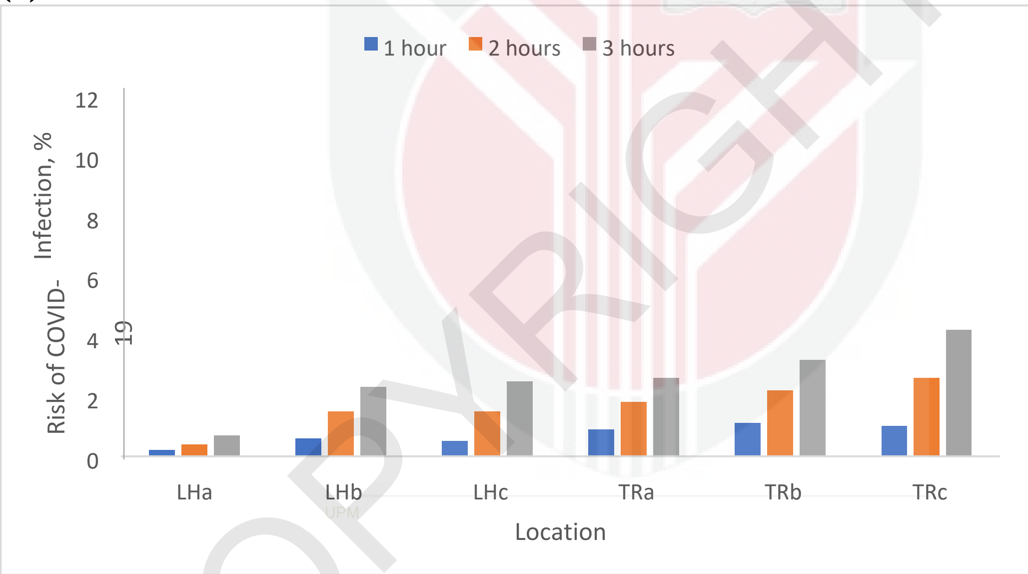



**Figure 4.2.** (a) shows the risk of COVID-19 infection at LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c) for 1, 2 and 3 hours with standing and speaking activity. Figure 4.3(b) shows the risk of COVID-19 infection at LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c) for 1, 2 and 3 hours with resting and breathing activity.

### 4.4 Correlation between Risk of COVID-19 Infection in Lecture Halls and Tutorial Rooms with Indoor Air Parameters

It was found that the risk of COVID-19 infection was correlated with three out of four indoor parameters in the study (indoor temperature, relative humidity and $PM_{2.5}$). The risk of COVID-19 infection was found to have a strong positive correlation with temperature (r=0.602). The risk of COVID-19 infection had a moderate negative correlation with relative humidity (r=0.487) and weak positive correlation with $PM_{2.5}$ (r=0.142). However, no correlation was found between the risk of COVID-19 infection with $CO_2$ (r=0.002). Figure 4.4 shows the correlation between indoor air parameters with the risk of COVID-19 infection in study locations.

**Table 4.4** The result of Pearson's Correlation Test between the indoor temperature, relative humidity, $CO_2$ and $PM_{2.5}$ with the calculated risk of COVID-19 infection in lecture halls and tutorial rooms.

| Parameter | r-value | Sig. two-tailed |
|---|---|---|
| Temperature | 0.602 | 0.206 |
| Relative humidity | -0.487 | 0.372 |
| $CO_2$ | 0.002 | 0.997 |
| $PM_{2.5}$ | 0.142 | 0.789 |

### 4.5 Simulation of SARS-CoV-2 transmission in academic buildings

Tutorial room of Faculty A, TR(a) and lecture hall of Faculty A, LH(a) were chosen to be modelled into 3D models to address the risk of COVID-19 infection. Figure 4.3 shows the progress of the lecture hall 3D model.

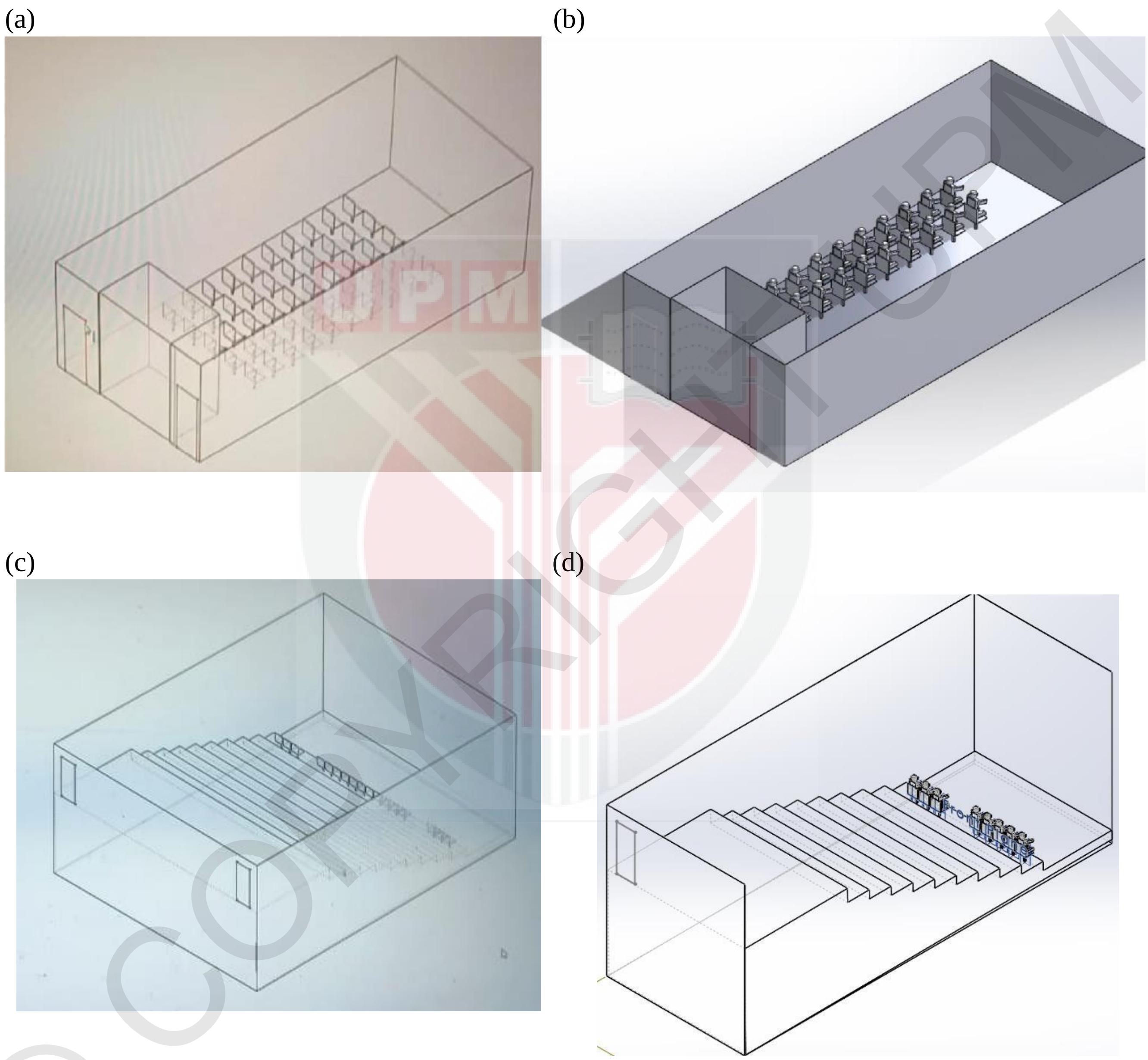



**Figure 4.3.** The construction of lecture hall 3D model. (a) shows the detailed 3D model of a tutorial room and (b) shows the cross-section of the tutorial room to view the occupants' positions in a tutorial room. (c) shows the detailed 3D model of a lecture hall and (d) shows the cross-section of the lecture hall to view the positions of occupants in the lecture hall.

# CHAPTER 5

# DISCUSSION

## 5.1 Indoor Air Quality in Lecture Halls and Tutorial Rooms

It was found that at the start of sampling (7:30 a.m.), the indoor temperature for all locations, LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c), exceeded the highest limit of acceptable range of indoor air temperature (26°C) stated by Industrial Code of Practice of Indoor Air Quality 2010 (ICOP IAQ 2010) with 26°C, 27.0°C, 26.8°C, 27.0°C, 26.1°C and 27.8°C respectively. Closed indoor space would gain heat with the absence of air circulation, openings or open windows (ARS, 2022). This was in line with the observation that all sampling locations did not have openings and windows, allowing heat accumulation when the mechanical ventilation system was switched off. The temperature at TR(c) was also recorded to elevate from 20.7°C at around 12:00 p.m., and peaked at 28.0°C at 2:00 p.m. It was observed that the air-conditioning system was switched off during the period, contributing to the rapid increase of temperature before gradually decreasing when the air-conditioning system was switched back on. In TR(c) and LH(c), it was observed that the indoor temperature also increased with the number of occupants. Temperature increased from 24.1°C to above 26.0°C during the transition of class from the occupancy of 46 occupants to 61 occupants at LHc. The activity and metabolic rate of occupants generated heat from occupants which increased the overall heat load of the enclosed space (Mokhtari & Jahangir, 2021).

Five out of six academic buildings studied, LH(b), LH(c), TR(a), TR(b) and TR(c) were found to comply with the ICOP of IAQ 2010 standards of acceptable relative humidity range between 40%

to 70%. LH(a) exceeded the maximum acceptable range only by 1.0%. It was observed that the relative humidity at TR(a), LH(b) and TR(b) were relatively consistent with IQR value of 1.6, 1.1 and 1.8 respectively. This was due to the regulation of temperature of centralised air conditioning system that helped in stabilising the level of relative humidity in the academic buildings.

Five out of six academic buildings studied, LH(a), LH(b), TR(a), TR(b) and TR(c) had recorded $CO_2$ concentration exceeding the ceiling limit of $CO_2$ by ICOP IAQ 2010, which is 1000 ppm at some several points of time throughout the measurement duration. The concentration of $CO_2$ was heavily influenced by the number of occupants and percentage of occupancy of the study location. This could be observed at all sampling locations, LH(a), LH(b), LH(c), TR(a), TR(b) and TR(c), where the concentration of $CO_2$ was at the lowest point at the start of the monitoring (7:30 a.m.) before gradually increasing with the presence of occupants inside the academic buildings when lectures were conducted. The concentration of $CO_2$ at LH(a) started with 557.5 ppm before reaching its peak at 10:40 a.m. with $CO_2$ concentration of 1171.5 ppm due to the presence of 62 occupants out of 130 maximum occupant capacity of the sampling location. The $CO_2$ concentration was then recorded to gradually drop along with the drop number of occupants after the class ended. TR(a) reached the highest recorded $CO_2$ concentration in the study at 1356.0 ppm during near maximum capacity of the academic building. Rudnick & Milton (2003) stated that higher occupancy rate in an enclosed space would increase the rate of exhaled CO2 thus increasing the $CO_2$ concentration without proper ventilation.

Three out of six academic buildings studied, LH(a), exceeded the daily limit of 15.0 µg/m$^3$ for $PM_{2.5}$ recommended by US EPA. It was observed that at LH(a), the concentration of $PM_{2.5}$ was in the range 80-100 µg/m at 8:00 a.m. until 10:40 a.m. before rapidly declined to lower than 15 µg/m$^3$

around 1:00 p.m.. Lecture periods and in-between transitions of lectures with 54 to 62 occupants were happening throughout the period between 8:00 a.m. until 10:40 a.m. causing frequent walking in LH(a). The same trend was observed at TR(b) where the concentration of $PM_{2.5}$ gradually declined after the end of the class and with no occupants. A study by Benabed & Boulbair (2022) found that human activities including walking significantly contributes to the increasing particle concentration in indoor spaces by causing resuspension of particulate matters.

## 5.2 Risk of COVID-19 Infection in Lecture Halls and Tutorial Rooms

The risk of COVID-19 infection was calculated for a situation with one COVID-19 infected person present in enclosed space. Similar to a study by Rodriguez et al (2022), one infected occupant was assumed to be present for each condition or activity of interest in the study (standing and speaking, and resting and breathing) to calculate the minimum risk of COVID-19 infection in enclosed space among occupants. The calculation was also done by assuming that the particle deposition rate and viral inactivation rate were constant with the value of 0.24 $hr^{-1}$ and 0.63 $hr^{-1}$ respectively. In this study, it was found that tutorial rooms generally pose higher risk of COVID-19 infection compared to lecture halls in all duration of exposure and the activities of occupants. TR(c) recorded the highest risk of COVID-19 infection compared to other study locations for the activity of standing and speaking with exposure duration of two hours (8.0%) and three hours (11.4%). TR(c) also recorded the highest COVID-19 risk for the activity of resting and breathing with exposure duration of two and three hours as well, with the risk of 2.6% and 4.2% respectively. This was due to the physical conditions and the indoor air quality of the academic building itself. TR(c) has the smallest volume space among all the study locations (80.11$m^3$) and was mechanically ventilated with split-unit air conditioning system. The building does not have any window or inlet and outlet air duct. The type of mechanical ventilation only allows recirculation of air with little to no circulation of fresh air within the building and the absence of windows and openings limits the entry of fresh air.

The risk of COVID-19 transmission was also found to increase with the increasing hour (exposure duration) of occupants spent in both lecture halls and tutorial rooms. Similar to a study by Rodriguez et al. (2022), it was also found that the relative risk of COVID-19 infection was higher for occupants with longer event duration in every simulated situation in the study (with or without the wearing of surgical masks among students and teachers) as it was understood in the study that longer duration of contact and event increases the exposure of occupants to respiratory aerosols indoors. Result of the study also found that the risk of COVID-19 infection in academic buildings were higher when activities of standing and speaking is performed compared to when resting while performing oral breathing. Talking emits particles and saliva droplets the size of ≤1 μm in diameter through 'fluid-film burst' mechanism that could be contaminated with SARS-CoV-2 and be transmitted to other occupants (Borak, 2020). In line with the findings, another study to estimate the risk of COVID-19 infection found that teachers had high probability of infection outbreak compared to students due to vocalization activity among teachers were higher than students (Rodriguez et al., 2022). This suggests that activities of standing and speaking such as delivering a presentation or lecture pose higher risk of COVID-19 infection among occupants in academic buildings.

**5.3 Correlation between the Risk of COVID-19 Infection and Indoor Air Parameters**

The results obtained found that the risk of COVID-19 infection to have no significant correlation with the indoor air quality parameters in this study; temperature, relative humidity and $PM_{2.5}$.

Results of the study suggested that the risk of COVID-19 infection had a pattern of negative correlation with relative humidity (r=-0.487), with no significant association (p=0.372). The pattern of the result was found to be in line with a study by Park et al. (2022) which found that the increase of relative humidity is associated with the reduction of COVID-19 transmission indoors which is in line with our findings. The study also stated that higher relative humidity lowers the transmission of SARS-CoV-2 by reducing the spread of particle droplets such as cough droplets indoors, thus decreasing the risk of COVID-19 infection indoors. A pattern of positive correlation with no significant association was detected between the risk of COVID-19 infection with the indoor temperature of academic buildings in this study (r=0.602, p=0.206). The result obtained disagrees with previous studies that found negative correlation between indoor air temperature and COVID-19 infection risk. Mao et al. (2022) and Raines et al. (2021) found that higher temperature contributes to the reduction of viral infectivity among enveloped viruses including SARS-CoV-2 due to destabilisation of virus in droplet matrix, virus droplet evaporation and settling, and the reduction of viral titre. The studies were conducted at locations that experience median temperature above 30°C and median relative humidity below 78%. The contradicting result obtained in this study might suggest further studies on the role and impact of temperature in tropical climate with the risk of COVID-19 infection in indoor spaces.

$PM_{2.5}$ concentration was found to have a positive correlation pattern with no significant association with the risk of COVID-19 infection (r=0.142, p=0.789). Similarly, in Iran, a study by Khaniabadi et al (2022) found that $PM_{2.5}$ has similar pattern of correlation with the incidence of COVID-19 cases. The same study found that an increase of long-term PM2.5 exposure by 1 $\mu g/m^3$ rises the risk of death caused by COVID-19 by 15% (Khaniabadi et al., 2022). Respiratory viruses are found to be able to remain in the air for a long duration of time after being attached to particulate matters, allowing virus to be transmitted further via airborne route (Lindsley et al., 2010). To add, particulate matters have also been suggested to play an important role in the transmission of SARSCoV-2 as it is found in the study that the size of airborne particles were adequately small to remain in the air for an extended period of time thus increasing the spread of virus, and are able to be inhaled into the respiratory tract.

Person-to-person transmission of virus via recirculated air in modern buildings has been found to be a potential significant source of morbidity (Rudnick & Milton, 2003). It is also stated that airborne infectious agents could remain suspended in longer duration of time in the air with improper ventilation. These were the parameters of concern that were brought up in this study which involved the type of ventilation system. $CO_2$ is measured as an indicator of ventilation effectiveness and renewal capacity of the indoor space, thus indicating the suitability of $CO_2$ as a ventilation effectiveness indicator (Domínguez-Amarillo et al., 2020). This supports the result that found TR(c) to have the highest risk of COVID-19 infection compared to other academic buildings due to high concentration of $CO_2$ (1356.0 ppm) and split-unit air conditioning system being used as its mechanical ventilation system that only circulates air with no air change of fresh air.
However, this study found no correlation and significant association between $CO_2$ concentration and the risk of COVID-19 infection ($r=0.002, p=0.997$) after running Pearson correlation test. Thus, the result of the correlation test contradicts to suggestions in which higher $CO_2$ concentration (which reflects to inefficient ventilation) would increase higher risk of COVID-19 infection in enclosed spaces. This might be due to oversimplification of the study on $CO_2$ without considering other possible contributing factors such as individual breathing rate (Rudnick & Milton, 2003), occupancy rate and air flow pattern in the calculation of COVID-19 infection risk.

### 5.4 Modelling of Lecture Halls and Tutorial Rooms of Academic Buildings

To further address the complexity of the risk of COVID-19 infection among occupants in lecture halls and tutorial rooms, a lecture hall and tutorial room studied were translated into 3D models. As the calculated risk of COVID-19 infection were simplified by assuming even distribution of aerosol at the studies indoor spaces, further studies need to be conducted to understand the dispersion pattern of SARS-CoV-2 in lecture halls and tutorial rooms. As shown in Figure 4.3, the location of students and lecturer vary with the placement of air inlet and outlet which could lead to various situations and circumstances of occupancy. According to Sze To et al (2009), the risk of the infection via expiratory aerosol is influenced by the ventilation and airflow rate, aerosol exposure, the position of occupants from the source of viral dispersion and the position of source of virus or aerosol in the indoor space. It was mentioned in the study that higher ventilation or air supply would increase the dispersion of aerosol. However, the pattern of dispersion would still be dependent on the size of aerosol, position of occupants from the source of dispersion and the position of the source of aerosol or virus. Another study by Wan et al (2007) also found that the air vent locations could influence the dispersion pattern of expiratory droplets, thus impacting the risk of infection among occupants based on their position from the air vents.

As the understanding of COVID-19 risk infection among occupants of academic buildings was limited in the study, it is justifiable that computational fluid dynamics (CFD) would be a suitable tool to aid in visualising the effect of different ventilation and indoor air quality towards the airborne dispersion and transmission of SARS-CoV-2 in different situations and buildings. CFD has also been used to study the pattern of viral particulate dispersion in aircraft cabin and other indoor spaces during the break of influenza (Mohamadi & Fazeli, 2022). The 3D models in Figure

4.3 could be used to run the analysis of computational fluid dynamics for further studies.

CHAPTER 6

# CONCLUSION

## 6.1 Conclusion

Academic buildings in the study generally have acceptable level of temperature and relative humidity. However, there was a concern on the $PM_{2.5}$ concentration and high $CO_2$ level in the academic buildings as five out of six academic buildings studied exceeded the ceiling limit of 1000 ppm by ICOP of IAQ 2010 and four out of six academic buildings exceeded the limit for daily indoor $PM_{2.5}$ concentration of 15 µg/m³ recommended by WHO . Study found that the risk of COVID-19 were present in both lecture halls and tutorial rooms, in which the risk was influenced by the occupants' duration of exposure and the activities conducted — the longer the time spent by the occupants, the higher the risk of COVID-19 infection, and activities that involve more vocalisation and physical movements also increase the risk of occupants being infected by COVID-19. The study also found that indoor temperature and $PM_{2.5}$ had a trend of positive correlation with no significant association with the risk of COVID-19 infection indoors. Relative humidity had a negative correlation with no significant association with the risk of COVID-19. Thus, the study could not conclude that indoor air parameters have significant correlation with the risk of COVID-19 indoors as there was no significant association found between each indoor air parameter with the risk of COVID-19 infection indoors. Thus, the study suggests more extensive study needed to further understand the influence of IAQ towards the risk of COVID-19 infection in academic buildings.

## 6.2 Study recommendations and limitations

The study found AIRC Version 3 to be a powerful and convenient tool for the university administrations especially the Occupational Health and Safety Department to evaluate and estimate the risk of COVID-19 and other viral airborne infection among staffs and students in academic buildings. This is to allow related authorities to construct necessary mitigating measures to control COVID-19 and other airborne communicable disease infection in university campus. It is also suggested for the university and faculty administrations to take necessary steps in improving the air quality in respective academic buildings by re-evaluating the maintenance and cleaning frequency of the ventilation system and the academic buildings.

For future studies, it is recommended for researchers to run computational fluid dyamics analysis of the 3D modelling of lecture halls and tutorial rooms to study the pattern and behaviour of SARSCoV-2 dispersion in academic buildings under different situations and levels of indoor air parameters. This is to address the limitation of the study in which the aerosol distribution, air distribution, breathing rate were assumed constant, and no engineering control (no mask wearing, no filtration of AHU system) was considered to simplify the calculation of the COVID-19 risk infection. It is also suggested for future studies to involve questionnaires to further understand the perception of occupants towards the IAQ level and its health impacts. This is to improve the current study where occupants' perception on IAQ, current health and the health impact of IAQ among occupants were not considered. The study could also be improved by involving more academic buildings and not limited to tutorial rooms and lecture halls to include more extensive building parameters in the study.

# REFERENCES

Ahlawat, A., Wiedensohler, A., & Mishra, S. K. (2020). An Overview on the Role of Relative Humidity in Airborne Transmission of SARS-CoV-2 in Indoor Environments. *Aerosol and Air Quality Research*, *20*(9), 1856-1861. https://doi.org/10.4209/aaqr.2020.06.0302

Ahmad, N., & Hassim, M. (2015). Assessment of indoor air quality level and sick building syndrome according to the ages of building in Universiti Teknologi Malaysia. *Jurnal Teknologi*, *76*. https://doi.org/10.11113/jt.v76.3995

Aliakbari, F., Torabi, S., & Lombardi, P. (2022). Indoor Air and Light Quality Assessment in a University Campus Classroom. *30*, 163-182. https://doi.org/10.5755/j01.sace.30.1.30328

ARS. (2014). HVAC. https://www.ars.com/blog/why-is-my-room-so-hot

Artzrouni, M. (2020). CovidRiskCalc: An online app to calculate the risk of COVID infection in a gathering. *medRxiv*, 2020.2012.2001.20241646. https://doi.org/10.1101/2020.12.01.20241646

Azlan, N., Hazwani, D., & Mohd Uzid, M. (2022). Assessment of Indoor Air Quality at Different Sites of Higher Educational Buildings of a University, Shah Alam. *Malaysian Journal of Medicine and Health Sciences*, *18*, 1-7. https://doi.org/10.47836/mjmhs.18.s9.1

Benabed, A., Boulbair, A. PM10, PM2.5, PM1, and PM0.1 resuspension due to human walking. *Air Qual Atmos Health* 15, 1547–1556 (2022). https://doi.org/10.1007/s11869-02201201-3

Bhagat, R. K., Davies Wykes, M. S., Dalziel, S. B., & Linden, P. F. (2020). Effects of ventilation on the indoor spread of COVID-19. *Journal of Fluid Mechanics*, *903*, F1, Article F1. https://doi.org/10.1017/jfm.2020.720

Bhatia, D., & De Santis, A. (2020). A preliminary numerical investigation of airborne droplet dispersion in aircraft cabins. *Open Journal of Fluid Dynamics*, *10*(3), 198-207.

Birnir, B. (2020). The Build-Up of Aerosols Carrying the SARS-CoV-2 Coronavirus, in Poorly Ventilated, Confined Spaces. *medRxiv*, 2020.2008.2011.20173195. https://doi.org/10.1101/2020.08.11.20173195

Borak, J. (2020). Airborne Transmission of COVID-19. *Occupational Medicine*, *70*(5), 297-299. https://doi.org/10.1093/occmed/kqaa080

Busco, G., Yang, S. R., Seo, J., & Hassan, Y. A. (2020). Sneezing and asymptomatic virus transmission. *Physics of Fluids*, *32*(7), 073309.

Chan, K. H., Peiris, J. S., Lam, S. Y., Poon, L. L., Yuen, K. Y., & Seto, W. H. (2011). The Effects of Temperature and Relative Humidity on the Viability of the SARS Coronavirus. *Adv Virol*, *2011*, 734690. https://doi.org/10.1155/2011/734690

Choo, C. P., & Jalaludin, J. (2015). An overview of indoor air quality and its impact on respiratory health among Malaysian school-aged children. *Reviews on Environmental Health*, *30*(1), 9-18. https://doi.org/doi:10.1515/reveh-2014-0065

Coccia, Mario. (2020). Diffusion of COVID-19 Outbreaks: The Interaction between Air Pollutionto-Human and Human-to-Human Transmission Dynamics in Hinterland Regions with Cold Weather and Low Average Wind Speed. Working Paper CocciaLab n. 48/2020, CNR - National Research Council of Italy, Available at SSRN: https://ssrn.com/abstract=3567841 or http://dx.doi.org/10.2139/ssrn.3567841

Domínguez-Amarillo, S., Fernández-Agüera, J., Cesteros-García, S., & González-Lezcano, R. A. (2020). Bad Air Can Also Kill: Residential Indoor Air Quality and Pollutant Exposure Risk during the COVID-19 Crisis. *International Journal of Environmental Research and Public Health*, *17*(19), 7183. https://www.mdpi.com/1660-4601/17/19/7183

Dugdale, C. M., Rubins, D. M., Lee, H., McCluskey, S. M., Ryan, E. T., Kotton, C. N., Hurtado, R. M., Ciaranello, A. L., Barshak, M. B., McEvoy, D. S., Nelson, S. B., Basgoz, N., Lazarus, J. E., Ivers, L. C., Reedy, J. L., Hysell, K. M., Lemieux, J. E., Heller, H. M., Dutta, S., . . . Shenoy, E. S. (2021). Coronavirus Disease 2019 (COVID-19) Diagnostic Clinical Decision Support: A Pre-Post Implementation Study of CORAL (COvid Risk cALculator). *Clinical Infectious Diseases*, *73*(12), 2248-2256. https://doi.org/10.1093/cid/ciab111

Environmental Protection Agency. (2021). Introduction to indoor air quality. https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality

Fadaei, A. (2021). Ventilation Systems and COVID-19 Spread: Evidence from a Systematic Review Study. *European Journal of Sustainable Development Research*, *5*(2), em0158. https://doi.org/10.21601/ejosdr/10845

Feng, Y., Marchal, T., Sperry, T., & Yi, H. (2020). Influence of wind and relative humidity on the social distancing effectiveness to prevent COVID-19 airborne transmission: A numerical study. *Journal of Aerosol Science*, *147*, 105585. https://doi.org/https://doi.org/10.1016/j.jaerosci.2020.105585

Graphical Weather. (2022). Definition of relative humidity. https://graphical.weather.gov/definitions/defineRH.html (Accessed 19 April 2022).

Gupta, J. K., Lin, C.-H., & Chen, Q. (2012). Risk assessment of airborne infectious diseases in aircraft cabins. *Indoor Air*, *22*(5), 388-395. https://doi.org/https://doi.org/10.1111/j.16000668.2012.00773.x

Habeebullah, T. M., Abd El-Rahim, I. H. A., & Morsy, E. A. (2021). Impact of outdoor and indoor meteorological conditions on the COVID-19 transmission in the western region of Saudi Arabia. *J Environ Manage*, *288*, 112392. https://doi.org/10.1016/j.jenvman.2021.112392

Ho, C. K. (2021). Modeling airborne pathogen transport and transmission risks of SARS-CoV-2. *Applied mathematical modelling*, *95*, 297-319.

Howard, H. (2012). *Fluid Mechanics (5th ed.)*. Academic Press. https://doi.org/10.1016/C2009-0-63410-3

Ismail, A., Ibrahim, M., Ismail, S., Aziz, A., Yusoff, H., Mokhtar, M., & Juahir, H. (2022). Development of COVID-19 Health-Risk Assessment and Self-Evaluation (CHaSe): a health screening system for university students and staff during the movement control order (MCO). *Network Modeling Analysis in Health Informatics and Bioinformatics*, *11*. https://doi.org/10.1007/s13721-022-00357-3

Ismail, I. F., Nasir, N., & Hariri, A. (2020). Indoor Air Quality (IAQ) in Educational Institutions: A Review on Risks of Poor IAQ, Sampling Strategies, and Building-Related Health Symptoms. 1-9.

Karia, R., Gupta, I., Khandait, H., Yadav, A., & Yadav, A. (2020). COVID-19 and its Modes of Transmission. *SN Comprehensive Clinical Medicine*, *2*(10), 1798-1801. https://doi.org/10.1007/s42399-020-00498-4

Kasioumi, M., & Stengos, T. (2022). The Effect of Pollution on the Spread of COVID-19 in Europe. *Economics of Disasters and Climate Change*, *6*(1), 129-140. https://doi.org/10.1007/s41885-021-00099-y

Khaniabadi, Y. O., Sicard, P., Dehghan, B., Mousavi, H., Saeidimehr, S., Farsani, M. H., Monfared, S. M., Maleki, H., Moghadam, H., & Birgani, P. M. (2022). COVID-19 Outbreak Related to PM10, PM2.5, Air Temperature and Relative Humidity in Ahvaz, Iran. *Dr. Sulaiman Al Habib Medical Journal*, *4*(4), 182-195. https://doi.org/10.1007/s44229-022-00020-z

Leclerc, Q. J., Fuller, N. M., Knight, L. E., Funk, S., & Knight, G. M. (2020). What settings have been linked to SARS-CoV-2 transmission clusters? *Wellcome Open Res*, *5*, 83. https://doi.org/10.12688/wellcomeopenres.15889.2

Lindsley, W. G., Blachere, F. M., Davis, K. A., Pearce, T. A., Fisher, M. A., Khakoo, R., Davis, S. M., Rogers, M. E., Thewlis, R. E., Posada, J. A., Redrow, J. B., Celik, I. B., Chen, B. T., & Beezhold, D. H. (2010). Distribution of Airborne Influenza Virus and Respiratory Syncytial Virus in an Urgent Care Medical Clinic. *Clinical Infectious Diseases*, *50*(5), 693698. https://doi.org/10.1086/650457

Mohamadi, F., & Fazeli, A. (2022). A Review on Applications of CFD Modeling in COVID-19 Pandemic. *Archives of Computational Methods in Engineering*, *29*(6), 3567-3586. https://doi.org/10.1007/s11831-021-09706-3

Mokhtari, R., & Jahangir, M. H. (2021). The effect of occupant distribution on energy consumption and COVID-19 infection in buildings: A case study of university building. *Build Environ*, *190*, 107561. https://doi.org/10.1016/j.buildenv.2020.107561

Mikszewski, A., Buonanno, G., Stabile, L., and Pacitto, A. (2021). Airborne Infection Risk Calculator, DRAFT PRELIMINARY, User's Manual for Version 3.0 Beta. https://research.qut.edu.au/ilaqh/wp-content/uploads/sites/174/2021/04/AIRC-v3.0-BetaDraft-Manual.pdf

Milicevic, O., Salom, I., Rodic, A., Markovic, S., Tumbas, M., Zigic, D., Djordjevic, M., & Djordjevic, M. (2021). PM2.5 as a major predictor of COVID-19 basic reproduction number in the USA. *Environmental Research*, *201*, 111526. https://doi.org/https://doi.org/10.1016/j.envres.2021.111526

Morawska, L., & Cao, J. (2020). Airborne transmission of SARS-CoV-2: The world should face the reality. *Environment International*, *139*, 105730. https://doi.org/https://doi.org/10.1016/j.envint.2020.105730

Nair, A. N., Anand, P., George, A., & Mondal, N. (2022). A review of strategies and their effectiveness in reducing indoor airborne transmission and improving indoor air quality. *Environmental Research*, *213*, 113579. https://doi.org/https://doi.org/10.1016/j.envres.2022.113579

Nor, N. S. M., Yip, C. W., Ibrahim, N., Jaafar, M. H., Rashid, Z. Z., Mustafa, N., Hamid, H. H. A., Chandru, K., Latif, M. T., Saw, P. E., Lin, C. Y., Alhasa, K. M., Hashim, J. H., & Nadzir, M. S. M. (2021). Particulate matter (PM2.5) as a potential SARS-CoV-2 carrier. *Scientific Reports*, *11*(1), 2508. https://doi.org/10.1038/s41598-021-81935-9

Park, H. J., Lee, S.-G., Oh, J. S., Nam, M., Barrett, S., Lee, S., & Hwang, W. (2022). The effects of indoor temperature and humidity on local transmission of COVID-19 and how it relates to global trends. *PLOS ONE*, *17*(8), e0271760. https://doi.org/10.1371/journal.pone.0271760

Pray, I. W., Kocharian, A., Mason, J., Westergaard, R., & Meiman, J. (2021). Trends in OutbreakAssociated Cases of COVID-19 - Wisconsin, March-November 2020. *MMWR Morb Mortal Wkly Rep*, *70*(4), 114-117. https://doi.org/10.15585/mmwr.mm7004a2

Qu, G., Li, X., Hu, L., & Jiang, G. (2020). An Imperative Need for Research on the Role of Environmental Factors in Transmission of Novel Coronavirus (COVID-19). *Environmental Science & Technology*, *54*(7), 3730-3732. https://doi.org/10.1021/acs.est.0c01102

Raines, K. S., Doniach, S., & Bhanot, G. (2021). The transmission of SARS-CoV-2 is likely comodulated by temperature and by relative humidity. *PLOS ONE*, *16*(7), e0255212. https://doi.org/10.1371/journal.pone.0255212

Rodríguez, D., Urbieta, I. R., Velasco, Á., Campano-Laborda, M. Á., & Jiménez, E. (2022). Assessment of indoor air quality and risk of COVID-19 infection in Spanish secondary school and university classrooms. *Building and Environment*, *226*, 109717. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.109717

Rowe, B. R., Canosa, A., Drouffe, J. M., & Mitchell, J. B. A. (2021). Simple quantitative assessment of the outdoor versus indoor airborne transmission of viruses and COVID-19. *Environmental Research*, *198*, 111189. https://doi.org/https://doi.org/10.1016/j.envres.2021.111189

Rudnick, S.N. and Milton, D.K. (2003), Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. Indoor Air, 13: 237-245. https://doi.org/10.1034/j.16000668.2003.00189.x

Sarhan, A. R., Naser, P., & Naser, J. (2021). COVID-19 aerodynamic evaluation of social distancing in indoor environments, a numerical study. *Journal of Environmental Health Science and Engineering*, *19*(2), 1969-1978. https://doi.org/10.1007/s40201-021-00748-0

Setti, L., Passarini, F., De Gennaro, G., Barbieri, P., Perrone, M. G., Piazzalunga, A., Borelli, M., Palmisani, J., Di Gilio, A., Piscitelli, P., & Miani, A. (2020). The Potential role of Particulate Matter in the Spreading of COVID-19 in Northern Italy: First Evidence-based Research Hypotheses. *medRxiv*, 2020.2004.2011.20061713. https://doi.org/10.1101/2020.04.11.20061713

Shereen, M. A., Khan, S., Kazmi, A., Bashir, N., & Siddique, R. (2020). COVID-19 infection: Emergence, transmission, and characteristics of human coronaviruses. *Journal of Advanced Research*, *24*, 91-98. https://doi.org/https://doi.org/10.1016/j.jare.2020.03.005

Sze To, G. N., Wan, M. P., Chao, C. Y. H., Fang, L., & Melikov, A. (2009). Experimental Study of Dispersion and Deposition of Expiratory Aerosols in Aircraft Cabins and Impact on Infectious Disease Transmission. *Aerosol Science and Technology*, *43*(5), 466-485. https://doi.org/10.1080/02786820902736658

Wang, J., Tang, K., Feng, K., Lin, X., Lv, W., Chen, K., & Wang, F. (2021). Impact of temperature and relative humidity on the transmission of COVID-19: a modelling study in China and the United States. *BMJ Open*, *11*(2), e043863. https://doi.org/10.1136/bmjopen-2020043863

Wan, M. P., Chao, C. Y. H., Ng, Y. D., Sze To, G. N., & Yu, W. C. (2007). Dispersion of Expiratory Droplets in a General Hospital Ward with Ceiling Mixing Type Mechanical Ventilation System. *Aerosol Science and Technology*, *41*(3), 244-258. https://doi.org/10.1080/02786820601146985

Wan Yusoff, W. Z., & Azwan Sulaiman, M. (2014). Sustainable Campus: Indoor Environmental Quality (IEQ) Performance Measurement for Malaysian Public Universities. *European Journal of Sustainable Development*, *3*(4), 323. https://doi.org/10.14207/ejsd.2014.v3n4p323

WHO. (2022). WHO Coronavirus (COVID-19) Dashboard. https://covid19.who.int/

WHO. (2014). Infection prevention and control of epidemic-and pandemic-prone acute respiratory infections in health care. https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infectionprevention-precautions. (Accessed 19 April 2022).

WHO. (2020). Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID19). https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-oncovid-19-final-report.pdf

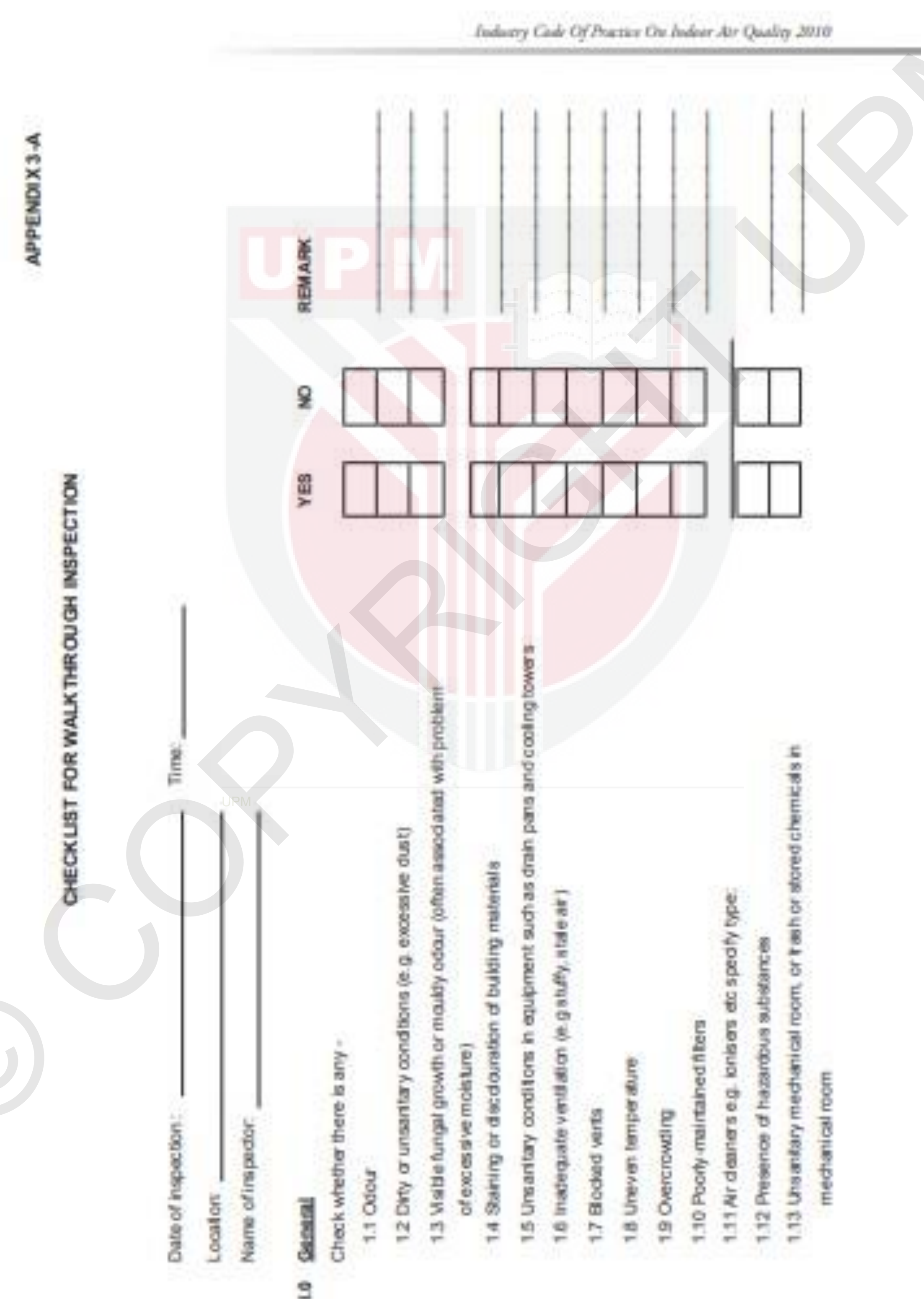
WHO. (2020). Transmission of SARS-CoV-2: implications for infection prevention precautions, scientific brief. https://www.who.int/news-room/commentaries/detail/transmission-ofsars-cov-2-implications-for-infection-prevention-precautions

Zhao, X., Liu, S., Yin, Y., Zhang, T. T., & Chen, Q. (2022). Airborne transmission of COVID-19 virus in enclosed spaces: An overview of research methods. *Indoor Air*, *32*(6), e13056. https://doi.org/10.1111/ina.13056

Zhang, Y., Feng, G., Kang, Z., Bi, Y., & Cai, Y. (2017). Numerical Simulation of Coughed Droplets in Conference Room. *Procedia Engineering*, *205*, 302-308. https://doi.org/https://doi.org/10.1016/j.proeng.2017.09.981

Zuhari, Z. (2019). *Indoor thermal comfort in university classroom: a case of Universiti Teknologi Malaysia*. Centre for Real Estate Studies Pub. http://eprints.utm.my/id/eprint/88430/1/LowSheau-Ting2019_IndoorThermalComfortinUniversityClassroom.pdf http://eprints.utm.my/id/eprint/88430/ https://www.utm.my/intrest/files/2020/01/INDOOR-THERMAL-COMFORT-IN-UNIVERSITY CLASSROOM-A-CASE-OF-UNIVERSITI-TEKNOLOGIMALAYSIA.pdf

## APPENDIX A: WALKTHROUGH INSPECTION CHECKLIST



*Industry Code Of Practice On Indoor Air Quality 2010*

APPENDIX 3-A

**CHECKLIST FOR WALKTHROUGH INSPECTION**

Date of inspection : ____________ Time: ________

Location: ____________

Name of inspector: ____________

| 1.0 **General** | YES | NO | REMARK |
|---|---|---|---|
| Check whether there is any - | | | |
| 1.1 Odour | ☐ | ☐ | ________ |
| 1.2 Dirty or unsanitary conditions (e.g. excessive dust) | ☐ | ☐ | ________ |
| 1.3 Visible fungal growth or mouldy odour (often associated with problem of excessive moisture) | ☐ | ☐ | ________ |
| 1.4 Staining or discolouration of building materials | ☐ | ☐ | ________ |
| 1.5 Unsanitary conditions in equipment such as drain pans and cooling towers | ☐ | ☐ | ________ |
| 1.6 Inadequate ventilation (e.g stuffy, stale air) | ☐ | ☐ | ________ |
| 1.7 Blocked vents | ☐ | ☐ | ________ |
| 1.8 Uneven temperature | ☐ | ☐ | ________ |
| 1.9 Overcrowding | ☐ | ☐ | ________ |
| 1.10 Poorly-maintained filters | ☐ | ☐ | ________ |
| 1.11 Air cleaners e.g. ionisers etc specify type: | | | |
| 1.12 Presence of hazardous substances | ☐ | ☐ | ________ |
| 1.13 Unsanitary mechanical room, or trash or stored chemicals in mechanical room | ☐ | ☐ | ________ |

| | | YES | NO | REMARK |
|---|---|---|---|---|
| 3.0 | **Potential sources of contaminants** | | | |
| 3.1 | Are there any occupants smoking?<br>If Yes, indicate where and If No, indicate the designated areas for smoking? | ☐ | ☐ | ________ |
| 3.2 | Are there furniture, furnishings, carpets, etc. that emit noticeable odours? | ☐ | ☐ | ________ |
| 3.3 | Have detergents, pesticides or other chemicals been used in the building? | ☐ | ☐ | ________ |
| 3.4 | Has there been any recent renovation or maintenance in any part of the building- | | | |
| | 3.4.1 Done during working hours | ☐ | ☐ | ________ |
| | 3.4.2 That can be a source of contaminants, such as painting, carpet installation, air conditioning repairs, use of acid drain cleaners, carpet cleaning, disinfecting of HVAC system, pesticide application | ☐ | ☐ | ________ |
| | 3.4.3 That can alter air flow patterns such as installation of partitions or relocation of air intake or exhaust? | ☐ | ☐ | ________ |
| 3.5 | Is there a kitchen or pantry where cooking is done? | ☐ | ☐ | ________ |
| | If Yes, is exhaust ventilation provided there? | ☐ | ☐ | ________ |
| 3.6 | Is the building adequately cleaned? | ☐ | ☐ | ________ |
| 3.7 | Is regular dusting of office furniture, ledges, shelves, etc. carried out to help keep dust to a minimum? | ☐ | ☐ | ________ |

| Item | Question | YES | NO | REMARK |
|---|---|---|---|---|
| 3.8 | Are the carpets vacuum-cleaned regularly? | ☐ | ☐ | ______ |
| 3.9 | Are there any office equipment giving off gases or fumes such as copying machines, blueprint machines and other office machines? | ☐ | ☐ | ______ |

**4.0 Ventilation and air-conditioning**

| Item | Question | YES | NO | REMARK |
|---|---|---|---|---|
| 4.1 | Is there at least one supply air and extract air vents in every room or area? | ☐ | ☐ | ______ |
| | If Yes, how many supply air and extract air vents are there in each room or area? ______ | | | |
| 4.2 | Are supply air or extract air vents blocked in any way by partitions, files or other structures that obstruct air flow? | ☐ | ☐ | ______ |
| 4.3 | Has dust collected around the air vents? | ☐ | ☐ | ______ |
| 4.4 | Is the air-conditioning system turned off- | | | |
| | 4.4.1 Any time during the day? | ☐ | ☐ | ______ |
| | 4.4.2 After office hours? | ☐ | ☐ | ______ |
| | 4.4.3 Are there still occupants in the building after office hours? | ☐ | ☐ | ______ |
| 4.5 | Where is the outdoor air intake duct located? | | | |
| | 4.5.1 Near the cooling tower in this building | ☐ | ☐ | ______ |
| | 4.5.2 Near adjacent buildings? | ☐ | ☐ | ______ |
| | 4.5.3 At street level | ☐ | ☐ | ______ |

4.5.4 Near a car park ☐ ☐ ____

4.5.5 Is it obstructed? ☐ ☐ ____

4.5.6 Others, please specify: ____

4.6 Are heavy industries located nearby? ☐ ☐ ____

4.7 Are there any construction work going on nearby? ☐ ☐ ____

4.8 Is outdoor air actually getting into the building? ☐ ☐ ____

4.9 Is there a regular schedule for cleaning and maintenance of the air-conditioning system in the building? ☐ ☐ ____

4.10 Are all the components of the air-conditioning system regularly inspected for leaks, breaches etc.? ☐ ☐ ____