



# Laboratory air quality and microbiological contamination in a university building

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Received: 4 August 2019 / Accepted: 12 June 2020 / Published online: 2 July 2020  
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## Abstract

The aim of this study was to measure the level of indoor air pollutants (carbon dioxide [CO<sub>2</sub>], formaldehyde [HCHO], volatile organic compound [VOC]), and bacteria and fungi in Water and Wastewater Engineering Laboratory (WWEL) (station 1) and Material Engineering Laboratory (MEL) (station 2) in a university building every 60 min. Measurements were taken over an 8-h period each day for 3 days. The results showed that the total volatile organic compounds (TVOCs) and respirable particulates exceeded the acceptable limits for indoor air quality (IAQ) set by the Department of Occupational Safety and Health (DOSH) in both locations. The concentration of formaldehyde measured at station 2 also exceeded the acceptable limit. Bacteria found in both laboratories were identified as gram-positive bacteria; the most dominant microbes were from *Bacillus* sp. A good ventilation system and a careful selection of construction materials are crucial to reduce IAQ contamination.

**Keywords** Indoor air quality · Carbon dioxide · Carbon monoxide · Fungi · Bacteria · Volatile organic compounds

## Introduction

Indoor air quality (IAQ) is a term that describes the air quality inside and around buildings and structures, particularly as it relates to the well-being of building occupants. Poor IAQ is

currently a global environmental risk to human health and to the environment (Idris et al. 2020). Indoor air refers to nonindustrial interior environments, such as classrooms, libraries, offices, and laboratories. Air can serve as a medium for the dissemination of biological and chemical pollutants; thus, an assessment of the IAQ that occupants are exposed to during their daily activities is urgent. The sources of indoor air pollutants include different chemical substances (DOSH 2010). Indoor contaminants include formaldehyde, total volatile organic compounds (TVOCs), fungi, and bacteria. The quality of indoor air is determined by chemical properties, while the thermal sensation is determined by the physical characteristics of air, such as humidity and temperature. According to Graudenz et al. (2005), factors affecting indoor environments are temperature, humidity, air movement, air exchange rate, ventilation, gaseous pollutants, particle pollutants, and bio pollutants. IAQ can also be influenced by gases: for example, carbon monoxide, carbon dioxide, volatile organic compounds (VOCs), and formaldehyde.

Some of the causes of indoor air pollution are particles originated from furniture and building materials and insufficient ventilation (Abdulaali et al. 2020; Ashraf and Hanafiah 2019). The presence of abundant synthetic chemicals and inadequate ventilation can result in high emissions of indoor particles and VOCs in the environment. Cleaning activities like sweeping and vacuuming tend to emit high concentrations of pollutants in indoor environments (Howard-Reed et al.

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Responsible Editor: Amjad Kallel

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2003). Indoor particulates were identified as resulting from vacuuming, sweeping, resuspension from clothes, human movement, sitting on cushioned furniture, and resuspension from carpets (Abt et al. 2000; Gudmundsson et al. 2007; Long et al. 2000; Ogulei et al. 2006).

The hazards of poor IAQ can occur when a person comes in contact with indoor pollutants of certain concentrations within a certain period (Ott et al. 2007; Tanha et al. 2020). Students and lab assistants that spend most of their time in laboratories are more likely to be exposed to the potential hazard. Idris et al. (2020) proved that inadequate IAQ can increase health risks among students and may increase sick school syndrome. Coughing, sneezing, and minor eye and skin irritations are among the common symptoms that are caused by poor IAQ. The Industry Code of Practices (ICOP) has set acceptable limits for indoor air contaminants and physical parameters to ensure that occupants are protected from poor IAQ, which has the potential to affect human health and working productivity. The productivity of occupants in university buildings could also be affected if the level of IAQ recorded is below the standard, as they are important places where staff and students spend about 8 h daily inside the building (Ali et al. 2016, 2018).

Bioaerosols are airborne particles that consist of living organisms like bacteria and fungi or nonliving organisms, such as dead microorganisms (Qian et al. 2012). Microorganisms are generally suspended in the atmosphere. The presence of bioaerosols in indoor environments like hospitals, pharmaceutical facilities, and laboratories can affect normal human activity; therefore, efficient monitoring is crucial (Venkateswaran et al. 2003; Gomy 2004; Okafor and Opuene 2007). Individual exposure to bioaerosols can be determined indirectly by taking a concentrated reading in an occupied space (Wang et al. 2012). Airborne microorganisms may originate from various sources, such as apparatuses and humans (Meadow et al. 2014). Pathogenic beads can effortlessly enter the nasopharynx of individuals during a breath and can hold fast to the nasopharyngeal epithelial cells and cause infection (Idris et al. 2020). A few studies have shown that an increase in microbial air contamination with other nonbiological factors can result in various adverse health effects, such as infection, respiratory problems, irritation, and allergic responses (Burge 2004; Gomy 2004; Tsai and Mache 2005). Since microorganisms can cause disease, this study is important to identify whether the concentration of microorganisms is hazardous to workers and students in the laboratory.

The aim of this paper is to measure the concentration level and physicochemical characteristics of biological contaminants and indoor air pollutants at different laboratory settings in a university building. This investigation will take place according to the guidelines of the ICOP 2010. Laboratories are used for learning by students every day and various types of chemicals are used as well for research activities. In most cases, increases in bacterial concentration are linked to the number of occupants inside the environment (Soto et al. 2009). It is important to

analyze indoor air pollution in laboratories, as they contain a complex mixture of microorganisms, chemicals, and contaminants. Chemical contaminants include carbon monoxide, formaldehyde, respirable particulates, and VOCs, whereas biological contaminants include bacteria and fungi.

## Materials and methods

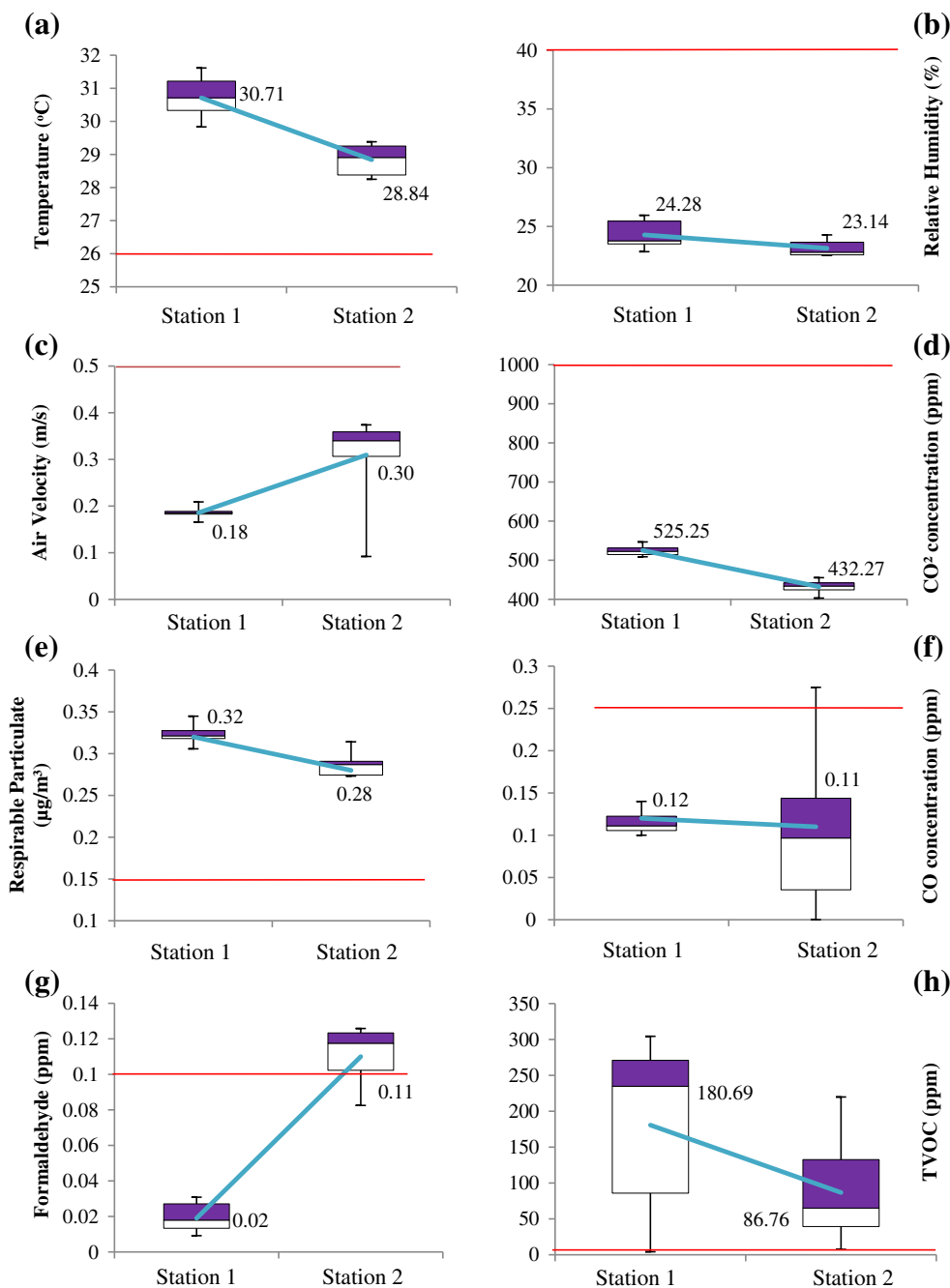
### Sampling site and collection of the samples

This study was conducted at Water and Wastewater Engineering Laboratory (WWEL) (hereafter, station 1) and Material Engineering Laboratory (MEL) (hereafter, station 2), which are both located at the School of Informatics and Applied Mathematics (PPIMG) at Universiti Malaysia Terengganu (UMT). Its coordinates are 5° 24' 37.704" N, 103° 5' 19.021" E (Fig. 1). The building was built in 1997 and is made up of laboratories, offices, and lecture halls. Both stations 1 and 2 are located in the same building but on different levels and in different settings. Station 1 is located on the first floor and station 2 is located on the ground floor. Station 1 is half the size of station 2. Both laboratories utilize mechanical ventilation. Both laboratories are built from the same types of building materials and have been in operation for the same number of years. Station 1 is used for research activities using different types of chemicals. Station 2 is used for learning and experimental tutorials related to engineering and mechanical activities (Table 1).

Data was taken every hour, with a sampling interval of 10 min for each sampling point. The study was carried out for 8 h on each of 3 days. The number of sampling points was estimated based on the area and the perimeter of the laboratory. The physical measurements were taken 1.5 m above ground level and 0.5 m away from corners, windows, and walls (EPA Protocol 2003). The measurements taken were temperature, relative humidity, carbon dioxide (CO<sub>2</sub>), formaldehyde (HCHO), and TVOCs. These measurements were compared with the benchmark values for further studies and analysis.

The variability of the attributes was verified based on descriptive statistics of the physicochemical data recorded using a box plot and hypothesis testing. During sampling, windows and doors were closed, and the mechanical ventilation was operating as usual. The indirect approach estimated integrated exposure by combining the measurements of pollutant concentrations at fixed sites in the laboratories with the data logs and activities of people. The indirect method was used to measure the concentration data of microenvironments, information on time-activity patterns, and other relevant characteristics of the studied individuals. Collection data was obtained from the primary data through the in situ and ex situ methods. Data for the in situ method was obtained directly from the measurements, such as the physical parameters and varieties

**Fig. 1** Level and concentration of IAQ parameters at both Stations 1 and 2. **a** Temperature (°C); **b** Relative humidity (%); **c** Air velocity (m/s); **d** Carbon dioxide (ppm); **e** Respirable particulate ( $\mu\text{g}/\text{m}^3$ ); **f** Carbon monoxide (ppm); **g** Formaldehyde (ppm); and **h** TVOCs (ppm). The red line represents the maximum acceptable exposure according to DOSH; the turquoise line represents the mean value



**Table 1** Description of stations 1 and 2

	Station 1	Station 2
Type of laboratory	Water and Wastewater	Engineering
Type of ventilation	Mechanical	Mechanical
Floor area (m <sup>2</sup> )	40 m <sup>2</sup>	82.13 m <sup>2</sup>
Activities conducted	Research activity, chemical and apparatus storage	Lecture activity, research activity, storage of engineering materials
Building age (years)	23	23

of chemical pollutants, including the respirable particles, formaldehyde, carbon dioxide, carbon monoxide, and TVOC. The *ex situ* method was used to perform total bacterial and fungal counts and for the Gram staining method. The settling plate procedure, called sedimentation strategy, was utilized as a sample collection technique (Emojevwe et al. 2013). The measurement time for chemical contaminants was applied for airborne concentrations, according to the guidelines of ICOP 2010. This study used continuous indoor air particulate monitoring and quantitative and qualitative data on time-activity patterns to measure indoor particulates.

## Materials and apparatus

The Kanomax IAQ Monitor (model 7525, TSI Incorporated, USA) was used to measure the concentrations of carbon dioxide and carbon monoxide and the temperature. The Anemometer Climomaster (model 6501 Series, Kanomax, USA) was used to measure air flow and relative humidity. The Portable VOC Monitor MiniRae 30000 (model PGM-7320, Honeywell, USA) was used to measure TVOCs. A formaldehyde meter was used to measure the concentration of formaldehyde. An agar plate was used to identify the total count of bacteria and fungi for microbiological methods. The apparatus used for Gram staining included an inoculating loop, clean glass slides, a Bunsen burner, a microscope, bibulous paper, lens paper, and lens cleaner, including immersion oil. The reagents used for primary stain included crystal violet, Gram's iodine for mordant, ethyl alcohol for decolorizing, and safranin for the secondary stain.

## Microscopic analysis

Gram's staining method was used to distinguish the differences between types of bacteria. In a Gram staining test, after being colored with crystal violet, microscopic organisms are washed with a decolorizing solution. A counterstain, such as safranin, is added after washing. Gram-positive bacteria are colored crystal violet, while gram-negative bacteria are colored pink or red. The difference in color is caused by the structure of their bacterial cell wall. Gram-positive bacteria do not have an external cell membrane like the one found in gram-negative bacteria. Gram-positive bacteria have a thick layer of peptidoglycan in their cell wall that retains the crystal violet dye. For the bacteria test, there were six plates of nutrient agar and six plates of potato dextrose agar, which used for six sampling points. Each sampling point used two plates of different agars.

## Data analysis

The data was analyzed using Statistical Package for the Social Sciences (SPSS) and a box plot. SPSS was used to compare

the means of pollutants in both stations 1 and 2 for statistical significance. Box plots were used to identify outliers and compare the distribution and variation of the concentrations of the pollutants. From the box plot, the descriptive statistics data were used to describe the results obtained from the study. The box plot displays the distribution of data based on the six numbers summary; they are minimum, first quartile, median, mean, third quartile, and maximum. From the box plot, the distributional characteristics of the particulates and the level of pollutants were determined.

## Results and discussion

### Level and concentration of the pollutants and comfort parameters

The results of the IAQ parameters at both stations are shown in Fig. 1a–h and contrasted with the standard IAQ (from DOSH), with an 8-h weighted average as the limit. The mean temperatures for stations 1 and 2 were  $30.71 \pm 0.64$  °C and  $28.84 \pm 0.47$  °C, respectively. Station 2 had a lower temperature than station 1, but both exceeded the acceptable temperature (Fig. 1a). Idris et al. (2020) stated that the temperature of indoor environments can influence IAQ. This can be explained by the linear relationship between temperature and  $PM_{2.5}$ , where an increase in temperature occurs due to an increase in emissions and resuspension of  $PM_{2.5}$  as well as VOCs in an indoor environment.

Figure 1b shows that the mean relative humidity for stations 1 and 2 are  $24.23 \pm 1.20\%$  and  $23.14 \pm 0.72\%$ , respectively. The results were below the acceptable limit. The recommended relative indoor humidity is 20–40%. Therefore, the conditions are good. The mean concentration of air velocity for stations 1 and 2 are shown in Fig. 1c at  $0.18 \pm 0.01$  m/s and  $0.30 \pm 0.09$  m/s, respectively. Both locations were under the acceptable limits. The condition of air velocity is generally associated with good air exchange in laboratories and is indicated by a low level of carbon dioxide, as it acts as a key parameter for evaluating IAQ and the effectiveness of ventilation. The infiltration process impacts airtightness through a stack effect that contributes to the accumulation of unhealthy dust inside the building (Ali et al. 2017).

The concentrations of carbon dioxide in both stations were below the acceptable limit, which is 1000 ppm. The mean concentration for station 1 was  $525.25 \pm 14.40$  ppm, while for station 2, it was  $432.27 \pm 17.15$  ppm (Fig. 1d). Readings above 1000 ppm are indicative of inadequate ventilation, as carbon dioxide is an indicator of adequate ventilation (DOSH 2010). Hence, the ventilation for both stations was in good condition. The low concentration of carbon dioxide might be due to the number of occupants, which, in addition to the air supply, has an effect on the level of carbon dioxide. The previous study on

IAQ stated that humans are the main source of carbon dioxide, due to respiration and human activities. The activities and movement of the students increased the concentration of carbon dioxide buildup in the indoor environment (Bjorn and Nielsen 2002). A study found that when doors and windows are open, the carbon dioxide will be lower and the rate of ventilation will be higher than 5 L/s per person (Hou et al. 2015).

The concentration of respirable particulates in both stations exceeded the acceptable limits. The mean concentration for stations 1 and 2 were  $0.32 \pm 0.01 \text{ mg/m}^3$  and  $0.28 \pm 0.01 \text{ mg/m}^3$ , respectively (Fig. 1e). The acceptable limit, according to DOSH, is  $0.15 \text{ mg/m}^3$  for every 8-h weighted average. In an indoor environment, the sources of respirable particulates can be affected by various factors, including ambient concentrations, air exchange rates, mechanisms of deposition, and indoor and outdoor penetration factors (Fromme et al. 2007). Indoor particulates can be influenced by various factors, such as building structure, the opening and closing of doors, and human activities (EPA 2005). A study by Ali et al. (2017) found that even a building equipped with mechanical ventilation could have a high percentage of pollutant sources, since outdoor particulates can infiltrate an indoor environment. In a previous study by Fromme et al. (2007), particulates in primary schools were found to be higher than in secondary schools. Aside from the differences in classroom flooring and furnishing, the intensive activity of primary students could be an explanation for this difference.

A research study in Australia by Morawska et al. (2013) found that the average concentration of submicron particles (7–808 nm) in apartments during indoor activities was higher ( $18,200 \text{ particles cm}^{-3}$ ) than when there were no indoor activities ( $12,400 \text{ particles cm}^{-3}$ ). The inhalation of respirable particulates in indoor air is likely to have harmful health effects because these particulates travel through the respiratory system and are deposited in the nasal passages, causing respiratory illnesses (Bernstein et al. 2008). Airborne particulate consists of organic and inorganic components that remain in the atmosphere for a long time and could have an impact on health and premature human mortality, as the carcinogenic pollutants can attach to or be adsorbed to the particle (Betha et al. 2014; Idris et al. 2020; Pérez-Padilla et al. 2010). These particulates can be the primary source of metal exposure; the toxic metals may be ingested or inhaled (Ali et al. 2017). To address the human health concern related to respirable particulates, the United States Environmental Protection Agency (U.S. EPA) has revised the National Ambient Air Quality Standard (NAAQS) for  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  standards to  $35 \text{ } \mu\text{g/m}^3$  for 24-h mean and  $15 \text{ } \mu\text{g/m}^3$  for annual average. However, this standard is only applicable to particles typical in rural, urban, and industrial areas (Khan et al. 2010).

As shown in Fig. 1f, the concentrations of carbon monoxide for both stations were below the acceptable limit, which is 10 ppm per 8-h weighted average airborne concentration. The

mean concentration for station 1 was  $0.12 \pm 0.01 \text{ ppm}$ , and it was  $0.11 \pm 0.09 \text{ ppm}$  for station 2. Common sources of carbon monoxide are automobile exhaust, generators, and gasoline-powered equipment. The concentration of carbon monoxide was expected to be higher in the lower floor compared with that in the higher floor (Ilgen et al. 2001; Hitchins et al. 2002; Jo and Lee 2006). However, both readings were low, since the doors and windows were closed during the sampling, and outdoor vehicles were not able to have much effect on the measurement.

Figure 1g illustrates the concentration of formaldehyde:  $0.02 \pm 0.01 \text{ ppm}$  and  $0.11 \pm 0.01 \text{ ppm}$  for stations 1 and 2, respectively. Station 2 exceeded the acceptable limit and was higher than station 1. Formaldehyde is the main content of every type of plank production. The production of these artificial planks, which are made into floorboards, sticking panels, and particle board, can lead to high formaldehyde emissions (Liquan and Yanqun 2011). A study conducted in residential homes also recorded high concentrations of formaldehyde because of the sources coming from wooden and melanin furniture and from paint and varnish (Gilbert et al. 2006). The concentration present and the amount of time people spend indoors are the two main factors that affect indoor exposure to formaldehyde (Salthammer et al. 2010). Short-term exposure of formaldehyde causes irritation of the eyes, discomfort, nausea, and sneezing. Formaldehyde was listed as a probable carcinogenic, and even low levels of formaldehyde may risk sensitization for allergic people (Daisey et al. 2003). This classification is based on the cohort mortality studies of occupants who were exposed to formaldehyde and showed an elevated incidence of nasopharyngeal cancer (Mahboubi et al. 2013).

As shown in Fig. 1h, the mean concentration of VOCs for stations 1 and 2 are  $180.69 \pm 123.29 \text{ ppm}$  and  $86.76 \pm 70.37 \text{ ppm}$ , respectively. Both stations exceeded the acceptable ICOP limit (2010). The concentration of TVOCs indoors is consistently (up to ten times) higher than outdoors. The total volatile organic solvents contained in products such as paints, aerosol sprays, building materials, and wood preservatives can be released while the products are being used and, to some extent, while they are being stored (U.S. EPA 2010). Laboratories equipped with pressed wood desks and furnishings might show an increased concentration of formaldehyde and TVOCs, even though they have a naturally ventilated system (Yang et al. 2009). A high concentration of TVOCs, one that is above  $1\text{--}2 \text{ mg/m}^3$ , indicates the strong existence of TVOC sources or low ventilation. However, high concentrations of mold and TVOCs were significantly related. Significant concentrations of VOCs were found by Sahu et al. (2018) in a laboratory and were attributed to the various types of chemicals and research activities of the laboratory. This could be the cause of the high concentration of VOCs in station 1 (chemicals).



## Assessments of microbiological contaminants

Microbiological analysis was done to assess colony forming units (CFUs) of bacterial contaminants in both stations. Bacteria isolated at station 2 were larger ( $39 \pm 5.5$  cfu/m<sup>3</sup>) than those isolated at station 1 ( $23 \pm 13.4$  cfu/m<sup>3</sup>). Station 1 showed larger fungi ( $50 \pm 4.9$  cfu/m<sup>3</sup>) compared with station 2 ( $32 \pm 3.5$  cfu/m<sup>3</sup>). Microbial loads likely enhanced their growth because of the environmental conditions, which included dampness. The World Health Organization (WHO) considers dampness a risk indicator for biological contamination in indoor air. Hence, the optimum relative humidity resulted in a low number of colonies of the biological contaminant.

There were four different types of bacterial colonies at station 1. Colony 1 had a yellowish color, an irregular shape, and a convex elevation. Results from the Gram staining proved that these bacteria belonged in the genus *Bacillus* sp. Colony 2 also had an irregular shape, a raised elevation, and a white color. Colony 2 belonged to the genus *Staphylococcus* sp. Colonies 3 and 4 had a similarly flat elevation and belonged to *Bacillus* sp. genus, but they were different in form: irregular and rhizoid, respectively. Among these four colonies, only colony 2 belonged to a different genus while belonging to the same type of bacteria: gram-positive.

In terms of morphology, the bacteria in station 2 were white, circular, and raised in elevation with the entire margin. This type of bacteria belongs in the genus *Staphylococcus* sp., and it is Gram-positive. The second colony was circular with a flat elevation and an undulate margin. It was Gram-positive bacteria from the genus *Bacillus* sp. Colony 3 had an irregular shape, was convex in elevation, had an entire margin, belonged in the genus *Bacillus* sp., and was Gram-positive. Colony 4 was very large on the plate, with an irregular shape, flat elevation, and entire margin. It belongs to the genus *Bacillus* sp. and is gram-positive. Based on a few studies of cultivation methods, both Gram-negative and Gram-positive bacteria are typical types of bacteria in the indoor air of residential settings, hospitals, and office buildings (Bouillard et al. 2005; Moschandreas et al. 2003; Gorny and Dutkiewicz 2002; Fleischer et al. 2006).

Five different colonies of fungi grew on the potato dextrose agar plate in station 1. Colony 1 was red in color and filamentous in form, and it had a raised elevation and a filiform margin. Colony 2 had an irregular form with a flat elevation and a filiform margin. Colony 3 had a knoblike bulge in the center, an umbonate elevation, a circular shape, and an entire margin. Colonies 4 and 5 had a convex elevation and an entire margin, but the fourth colony had a circular shape, and the fifth colony had an irregular shape.

Four colonies of fungi were identified in station 2. The first and second colonies had the same raised elevation with the entire margin, but they were different in shape. The first colony had a filamentous shape, and the second colony had a

circular shape. The fungi of colony 3 had the filamentous shape, a raised elevation, and a filiform margin. Colony 4 had a circular shape, umbonate elevation, and an entire margin.

When examining the fungi plates from the different stations, the colonies showed very different characteristics. The total fungi count in both stations was below the acceptable DOSH limit (DOSHS 2010). The concentration of airborne bacteria and fungi aerosol in the indoor environment of station 1 was estimated with the settle plate method to be 21–29 cfu/m<sup>3</sup>. Meanwhile, for station 2, it was 29–36 cfu/m<sup>3</sup>. The low number of colonies is due to the low number of people during sampling time (Hayleeyesus and Manaye 2014). The presence of indoor microbials not only comes from the number and hygienic standard of the people but also from mechanical movement around the room (Yassin and Almouqatea 2010). Based on the previous studies on bioaerosol exposure in Finland, fungi concentration is typically higher in a classroom than in a home, as there are more pupils inside the classroom (Toivola 2004; Toivola et al. 2004).

Nutrient agar plates are used to breed bacteria; potato dextrose agar plates are used to breed fungi. However, instead of bacteria, a few colonies of fungi were found breeding on the nutrient agar plate. The bacteria found in both laboratories were Gram-positive: *Bacillus* sp. and *Staphylococcus* sp. However, the common bacterium found was *Bacillus* sp. genus. Both stations had low total bacterial counts, which were below the acceptable DOSH limits. The colonies of microbes and fungi in the stations might be of the low percentage of relative humidity, as bacteria and molds usually favor moist and condensed areas to grow (Hospodsky et al. 2012). The favorable temperature and relative humidity range for microbial growth are 20–22 °C and 30–60%.

## Dominant microbes

The microbes isolated from the stations were found to be mostly Gram-positive bacteria in the genera *Bacillus* sp. In culture method studies, Gram-positive bacteria are the dominant bacteria present in indoor air, at up to 75% (Moschandreas et al. 2003). As in previous studies, *Staphylococcus* sp. and *Bacillus* sp. are the bacteria most often found by researchers due to their widespread nature (Bomala et al. 2016; Hayleeyesus and Manaye 2014; Hussin et al. 2011; Makut et al. 2014; Udosen et al. 2018; Umana et al. 2019). Species were identified using biochemical and morphologic criteria. Surprisingly, some of the species' cultures may develop into Gram-negative bacteria because of their age. *Bacillus* spp. are endospore-forming aerobic or facultative anaerobic bacteria. Spores are resistant to cold, heat, radiation, disinfectants, and desiccation. Due to these characteristics, they often lead to contaminations. Dispersal in the atmosphere and the microbe's survival depend on the temperature, relative humidity, and water and nutrient availability (Pegas et al. 2011). In

addition, the ventilation system is one of the factors that contribute to particle spread indoors (Jamriska 2000; Howard-Reed et al. 2003; Wallace et al. 2004). Many species of this genus can exhibit a broad range of physiological abilities that allow them to live in every kind of natural environment. Since *Bacillus* spp. are commonly found in organisms, their existence in small numbers is usually considered insignificant. Many *Bacillus* spp. are quite crucial in pharmaceutical, medical, and industrial uses because of their ability to produce antibiotics and the potential to synthesize a wide range of metabolites with antimicrobial activity (Waites et al. 2009). Some *Bacillus* spp. have been used in the natural or artificial degradation of waste products, and some have been important in the manufacture of active ingredients for insecticides.

*Bacillus* sp. is a rod-shaped bacterium that includes both free-living (nonparasitic) species and parasitic pathogenic species, which can cause food poisoning and anthrax. Anthrax occurs in four forms: on skin, inhalation, intestinal, and injection. Exposure to skin can cause a painless ulcer with a black center and difficulty breathing, which leads to chest pain and shortness of breath. The injection variety can cause fever, and the intestinal variety presents with vomiting, diarrhea, and nausea. *Staphylococcus* sp. is also Gram-positive bacteria, but these bacteria were not as common in the samples. The existence of the *Staphylococcus* species might be influenced by the number of occupants inside the enclosed space, as these species are likely to shed from the clothing, skin, and hair of humans; they might also be affected by poor ventilation and by the increased susceptibility of the organism to environmental stress (Borrielo et al. 2005). It includes 40 species, most of which are harmless to humans and other organisms. Although it is a benign bacterium, it can also cause skin lesions, systemic infections, and toxemic syndromes (Jarraud et al. 2002).

## Conclusions

The present study found that the measured air velocity and CO<sub>2</sub> concentrations in both stations were below the DOSH guidelines, which indicates adequate ventilation. There were no statistically significant relationships (at the 95% confidence level) between asthma and environmental factors such as carbon dioxide, air exchange rate, and humidity. However, the concentration of respirable particulates from both stations exceeded the acceptable limit by two times (the acceptable limit of IAQ standard by DOSH is 0.15 mg/m<sup>3</sup>). The formaldehyde concentration in station 2 exceeded the acceptable limit by 0.01 ppm. This might be due to the wooden product that is found in this laboratory. The concentrations of TVOCs in both stations exceeded the acceptable DOSH six limits (2010). Formaldehyde and TVOCs are commonly measured pollutants because they appear in building materials, such as furniture and paint. The emission of airborne particulate

matter should be minimized by prevention and control measures because it may pose a significant risk. Certain levels of respirable particulate will be harmful to human health and nature. The installation of heat recovery ventilators (HRVs) may help decrease the concentration of indoor pollutants. Several measures, such as improving operations, maintenance, and housekeeping, can be implemented to decrease the emission of pollutants in the microenvironment. Bioaerosol levels in indoor environments are influenced by a variety of biological and physical factors, such as the building materials and the occupants' life styles (Mandal and Brandl 2011; Mirhoseini et al. 2016). Hence, the study of indoor airborne microorganisms is necessary to address the impact on human health.

One limitation of this study is that both laboratories are located in the same building. The two stations, however, are different types of settings; one is a chemical lab and the other is an engineering lab. The physical characteristics of the lab as well as chemical pollutants and biological contaminants were identified in both stations. Sources of contamination could originate from outdoor sources as well, but the present study did not investigate this possibility, as this study focuses on the nature of indoor pollutants alone. In this study, individual exposure is taken to be synonymous with the indoor environment. It is suggested that future study to include this aspect because people spent different amounts of time inside each day.

**Acknowledgments** We would like to thank the University Malaysia Terengganu for providing facilities to conduct this study.

**Funding information** Marlia M. Hanafiah was funded by the Ministry of Education Malaysia (FRGS/1/2018/WAB05/UKM/02/2) and UKM research grants (KRA-2018-054 and DIP-2019-001).

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