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Assessment of Physical Parameters of Indoor Air Quality in A Wastewater Treatment Plant Building: A Case Study

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***Abstract* — Safe building conditions, clean air, and a positive workplace environment have a significant impact on employees' well-being and productivity. A safe building condition includes a good and efficient air conditioning system in a building to provide quality indoor air for employees. This study aims to measure physical parameters, including air temperature, relative humidity, and carbon dioxide, in wastewater treatment plants and to identify potential issues contributing to poor air quality. A total of 33 stations were selected in three buildings. The inclusion criteria of the chosen locations were a centralized air conditioning system, a split air conditioning system, and places with natural ventilation. The measurements were conducted following the Industrial Code of Practice for Internal Air Quality Industry (ICOP) 2010 and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 2005. Carbon dioxide levels in three locations were below 1,000 ppm and were compliant with ICOP-Department of Occupational Safety and Health (ICOP-DOSH) and ASHRAE standards. Office rooms recorded the highest carbon dioxide level at 914 ppm. Factors contributing to the level of carbon dioxide are the activity of body metabolites, breathing, and conversations. The lobby area, office rooms, cafeteria, pantry, surau, toilets, pre-treatment facilities, clarifier process facilities, and sludge digestion recorded high relative humidity (>70%), which exceeded the standards. The cafeteria is the only station with a high temperature (26.6°C), exceeding the standard. Internal ventilation systems should be regularly maintained to ensure that air is free from contamination by foreign materials, pathogenic germs, and in compliance with air quality standards.**

Keywords— Indoor air quality, Workplace environment, Air conditioning system, Ventilation.

I. INTRODUCTION

Indoor Air Quality (IAQ) refers to the measurement of pollutant concentrations and thermal conditions that may impact the health, comfort, and [productivity of a building's occupants [1]. The majority of individuals spend 80-90% of their time indoors, whether at work or at home [2]. Hence, it is crucial to maintain a good standard of indoor air quality (IAQ), as poor IAQ can lead to allergic reactions, respiratory illnesses such as breathing difficulties, conjunctivitis, sinusitis, and bronchitis [3]. Temperature, relative humidity, and carbon dioxide (CO2) are the three primary parameters used to measure IAQ levels [4].

The productivity and thermal comfort of a building's occupants depend on the thermal environment of the building itself [5]. Maintaining a good thermal environment is not only important for comfort, but also crucial in preventing microbial growth inside the building [6]. Hence, for the comfort and safety of occupants, it is recommended to maintain the working space area at 23°C to 26°C [7]. Increasing the temperature would aid in the growth of bacteria and viruses, thereby increasing the risk of airborne disease transmission, especially in areas with poor

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ventilation [8]. Nonetheless, the recent COVID-19 pandemic was not correlated with environmental temperature, although higher temperatures might protect against COVID-19 mortality [9]. In contrast, lower temperatures and higher diurnal temperature variation may be associated with an increased incidence of influenza infection [10]. The reasons behind these differences require further study to be concluded.

A. Relative Humidity

The relative humidity is a measure of how saturated the air is with water vapour compared with the total that can be held at a given temperature [11]. In indoor space, relative humidity should be maintained at 40% to 70% for comfort and health, and to minimise the survival of viruses and bacteria [7]. Mites could not thrive in an environment below 50%, whereas fungi cannot grow when the RH is above 60% [12]. In addition, absolute humidity, i.e. the mass of water vapour per cubic meter of air, is closely linked to both temperature and relative humidity. Previous work has shown that absolute humidity is a good single parameter explaining the seasonality of influenza. However, when it comes to COVID-19, both absolute and relative humidity exhibit similar behaviour, with minimal distinction in their effects [13].

B. Carbon Dioxide (CO_2)

Carbon dioxide monitoring is another method for assessing the adequacy of ventilation in a space [4]. A poorly ventilated space facilitates the transmission of respiratory viruses, such as the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [14]. According to the Department of Occupational Safety and Health (DOSH) Malaysia, the indoor CO_2 reading should not exceed 1000 ppm, as readings above 1000 ppm indicate inadequate ventilation in an area [7]. In indoor environments, where a high volume of aerosol is produced, the CO_2 level should be kept at or lower than 800ppm. Concentrations of above 1500 ppm or higher, the space should be marked as high priority for ventilation improvement [15]. Additionally, if the indoor CO_2 concentration exceeds the benchmark value of 10% or more during periodic measurements, an investigation of the ventilation at the site should be initiated [14].

Any irregularities in these elements may be the cause for the spread of infectious diseases at any workplace and other related illnesses that are airborne and spread through droplets [16]. It may also be the cause of a particular outbreak at work from an infectious disease which include coronavirus disease 2019 (COVID-19), severe acute respiratory syndrome (SARS), tuberculosis (TB), influenza A virus (H1N1), Aspergillosis (CDC, 2012), Legionnaires [17], building-related illnesses or sick building syndrome [18 - 20].

Hence, a good and efficient air conditioning system in a building is of paramount importance in determining healthy and quality indoor air. Optimal air movement within buildings should be given full attention to eliminate pathogenic microorganisms circulating in the air. This can prevent the spread of airborne infectious diseases from occurring at work.

Hence, this study aims to measure physical parameters, including temperature, relative humidity, and carbon dioxide, in the air. The data and information obtained will serve as a benchmark in identifying sources of airborne diseases at the workplace. Three study locations were selected for this study: Company X Headquarters Building Complex, Regional Sewage Treatment Plant A, and Regional Sewage Treatment Plant B. All the study locations are located in Kuala Lumpur, Malaysia.

The objectives of this study are to identify the capabilities of existing mechanical ventilation systems in influencing temperature, humidity, and carbon dioxide levels in the workplace, and to measure temperature, humidity, and carbon dioxide levels in the buildings and the surrounding environment. This study also aims to identify factors contributing to the temperature, relative humidity, and carbon dioxide in buildings.

II. METHODOLOGY

This study encompassed three physical measurements: temperature, relative humidity, and carbon dioxide. The three study locations selected were several sewage treatment plants in the Klang Valley area.

A total of 9 to 13 sampling stations were selected at each location. These three locations were selected based on differences in the existing air conditioning system, which were a centralised air conditioning system, a split air conditioning system, natural ventilation, and external and internal environmental factors.

The three types of air conditioning system facilities identified in these three locations were centralised air conditioning systems, split air conditioning systems, and natural ventilation. Natural ventilation was concentrated in the open building area for treating wastewater. For the Headquarters Building Complex, the ventilation system facility was a centralised air conditioning system. Meanwhile, X1 and X2 were provided with split air conditioning systems and natural ventilation, respectively. The number of air samples carried out at the sampling station was under the proposed IAQ ICOP 2010 standard.

The equipment used to measure the parameters was as follows:

(i) FLUKE 971 and Anemometer for measuring temperature, relative humidity, and airflow rate in a split air conditioning system.

(ii) Laser Distance Meter (Laica Desto) D2a for measuring floor area.

(iii) Carbon Dioxide Meter (Benetech) for measuring carbon dioxide.

All the tools used were tested before sampling. The parameters taken were temperature, relative humidity, carbon dioxide, and the breadth of space. Three sampling locations were selected in this study, namely Headquarters Building Complex, Sewage Treatment Plant A and Sewage Treatment Plant B. Sampling stations were set up at each location depending on the size of the area and the various activities conducted at each location. In all, there were 13 stations at the Headquarters, 9 stations at Sewage Treatment Plant A, and 11 stations at Sewage Treatment Plant B.

Sampling was conducted from 22 October 2021 to 29 November 2021, from 9:00 am to 5:00 pm. Samples were taken at 20-minute intervals per station. The air sampling techniques taken were per the standard guidelines of the Industrial Code of Practice for Internal Air Quality Industry (ICOP) 2010 and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2005.

III. RESULTS

Table I shows temperature readings, relative concentrations, and carbon dioxide concentrations at 13 sampling stations. There were 12 temperature readings above 25°C in compliance with ICOP-DOSH and ASHRAE standards. Only one sampling station recorded high temperatures in the cafeteria with a reading of 26.6°C, exceeding the ICOP-DOSH and ASHRAE standards.

There were five relative humidity sampling stations that did not comply with DOSH and ASHRAE standards. The highest readings were in the cafeteria (74.1%), pantry (73.4%), manager's room (Quality Management System) (71.1%), manager's room (Operational Department) (75.1%), and head of Departments' room (72.3%).

The carbon dioxide concentrations measured at the 13 sampling stations were well below the 1,000 ppm acceptable level recommended by ICOP-DOSH and ASHRAE (Table I). The highest carbon dioxide reading was in the surau, which was at 823 ppm.

Table I. Temperature, relative humidity, and carbon dioxide readings in sampling station headquarters.

Sampling Station	Temperature (ºC)	Relative Humidity (%)	Carbon Dioxide (ppm)
Meeting room	23.2	55.3	640
Cafeteria	26.6	74.1	650
Toilet	23.4	56.2	661
Multipurpose hall	20.2	58.2	727
Surau	21.9	57.6	823
Pantry (Quality Management Section)	21.8	73.4	810
Training room	20.3	57.2	763
Gymnasium	22.1	52.1	756
Manager's room (Quality Management System)	23.4	71.1	670
Manager's room (Strategy and Billing Section)	21.1	58.2	640
Pantry (Strategy and Billing Section)	21.8	57.3	680
Manager's room (Operational Department)	23.2	75.1	610
Head of department's room	22.8	72.3	730

Table II. Temperature, relative humidity, and carbon dioxide readings at sampling station locations: Sewage Plant A.

Sampling Station	Temperature (ºC)	Relative Humidity (%)	Carbon Dioxide (ppm)
Lobby	29.1	54.3	632
Office room	23.4	51.5	630
Meeting room	27.3	53.7	605
Training room	23.1	58.5	604
Surau	23.5	57.2	593
Pantry/Cafeteria	25.2	54.2	774
Toilet	28.5	73.3	559
Digested sludge holding tank	31.2	63.2	546
Chemical lab	28.5	58.5	566

Table II presents temperature readings, relative humidity, and carbon dioxide concentrations at nine sampling stations. There were six stations with temperature readings above 25°C and 4 stations within the ICOP-DOSH and ASHRAE recommended standards. The high-temperature stations were digested sludge holding tanks (31.2°C), lobby (29.1°C), toilet (28.5°C), chemical lab (28.5°C), and meeting room (27.3°C).

For relative humidity readings, two sampling stations did not comply with ICOP-DOSH and ASHRAE standards. The highest reading of 73.3% was in the toilet, followed by the digested sludge holding tank at 63.2%. The other 7 stations fell within the levels recommended by ICOP-DOSH and ASHRAE. Meanwhile, the carbon dioxide concentration of 9 sampling stations was at the level recommended by ICOP-DOSH and ASHRAE.

Table III. Temperature, relative humidity, and carbon dioxide readings at the sampling station at Sewage Treatment Plant B.

Sampling Station	Temperature (ºC)	Relative Humidity (%)	Carbon Dioxide (ppm)
Lobby	23.4	50.1	522
Office room	29.5	82.1	914
Meeting room	23.2	22.7	605
Scada Room	23.6	52.8	593
Surau	27.7	50.8	665
Chemical lab	23.8	58.2	685
Toilet	28.3	76.1	628
Digested Sludge Holding Facility			

Ground floor	32.5	62.3	516
First floor	30.2	64.5	514
Pre-treatment facility	32.8	72.4	707
Clarifier process facility	30.2	73.5	550

Table III shows temperature readings, relative concentrations, and carbon dioxide concentrations at 11 sampling stations. There were 7 sampling stations with temperature readings above 25°C and 4 stations at the levels recommended by ICOP-DOSH and ASHRAE. High temperatures were recorded at the pre-treatment facility (32.8°C), the digested sludge holding facility on the ground floor (32.5°C) and the first floor (30.2°C), the clarifier process facility (30.2°C), the office room (29.5°C), the toilets (28.3°C) and the surau (27.7°⁰C).

Only 5 sampling stations with relative humidity readings complied with ICOP-DOSH and ASHRAE standards: chemical lab (58.2%), Scada room (52.8%), lobby (50.1%), meeting room (22.7%) and surau (50.8%). While the other 6 stations recorded high readings and did not comply with the recommended standards. The high readings were in the office room (82.1%), the toilet (76.1%), the clarifier facility (73.5%), the pre-treatment facility (72.4%), the digested sludge holding first floor (64.5%) and the ground floor (62.3%).

The carbon dioxide concentration of the 11 sampling stations was at the recommended level of ICOP-DOSH and ASHRAE. Only one reading station approached the standard of 914 ppm, in the office room.

IV. DISCUSSION

Carbon dioxide concentration levels at all sampling stations in three locations were below 1,000 ppm. They complied with the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the Industry Code of Practice on Indoor Air Quality 2010 (ICOP-DOSH). Office rooms (see Table III) recorded carbon dioxide readings approaching the standard with a 914 ppm reading. The appearance of humans inhabiting the area was said to be the primary contributor to the recorded reading. This was supported by findings from several studies conducted in Peninsular Malaysia, where human inhabitants were identified as the primary source of carbon dioxide in indoor settings. [21 - 23].

Carbon dioxide present in the air is influenced by several factors closely related to the activity of body metabolites, breathing, conversations and others. For ventilation systems in Treatment Plants 1 and 2, the ventilation systems utilised split systems. The system works to cool the existing air in the building. Cold air will be reused repeatedly (recirculated) until it reaches the desired temperature. If many people are using the same air, increasing carbon dioxide levels can reduce the oxygen content in the air.

According to the guidelines from most external countries, carbon dioxide concentration levels have been used as an indicator of the effectiveness of in-house ventilation systems. The recommended standard was 1,000 ppm, but the Centre for Disease Control and Prevention CDC) 2021 proposed is below 800 ppm, which is the most appropriate concentration [24].

Studies have found no solid evidence to prove that carbon dioxide concentration may influence the transmission of airborne infectious diseases by pathogen [25]. The risk of transmission of communicable diseases is greatly influenced by other factors, such as close contact with a patient, droplets in the air from coughs, flu, and sneezes, not wearing a face mask, and sitting close to each other [26, 27].

A. Treatment Plant Headquarters

In the headquarters, which comprised an office building, high relative humidity was recorded in the cafeteria pantry, the Quality Management System manager's room, the operating department manager's room and the operating department head's room (as shown in Table I). These high percentages of humidity can be associated with metabolism, sweating, breathing, washing and etc. Open windows can allow hot air from the outside to enter, raising the existing temperature and humidity.

Since the ventilation system in this location was a centralised system with a diffuser that lacks cold air in the room. This occurs due to a problem with the cooling coils or the closure of dampers in the diffuser. A lack of air, poor air movement, and a large number of employees can increase humidity in the indoor environment.

The temperature readings at the 12 sampling stations complied with ICOP-IAQ, DOSH, and ASHRAE standards. Only one sampling station recorded high temperature that was in the cafeteria with a reading of 26.6°C exceeding the IAQ DOSH and ASHRAE ICOP standards.

The high temperature in the cafeteria was suspected to be affected by the heat generated during the cooking of food and heating water, etc. The resulting heat will affect the existing air, causing the air temperature to rise. The increase in temperature was also caused by the heat generated from the lights, the presence of people who came to dine, and the entry of sunlight through the glass windows that lacked protective tinting, among other factors. The position of the cafeteria in the morning also affected indoor humidity [28, 29].

The moist air and limited space contributed to the high humidity in the pantry. Signs of sluggish ceilings and leakage from sanitary pipes in the sink were also contributing to the increased humidity.

The workplace environment that faced the afternoon sunlight had caused an increase in temperature and humidity at the work location. No curtains and tinted glass facilities were installed on each window, and these were the main contributory factors. The opening of windows due to discomfort of workers in the office also encouraged the entry of hot air from outside the building into the building, although it is good for mobilisation and conversion of fresh air in the building.

B. Sewage Treatment Plant A

For the location of Plant A as in Table II, a high percentage of relative humidity was found in the toilets and digested sludge tanks. The humidity in the toilet was affected by the natural warm and humid winds and environment. Tropical humid hot climate is a contributing factor to humidity. There are 3 small-sized exhaust fans provided but there were not enough to remove air out of the toilet. Indirectly, internal ventilation affects the temperature and humidity of the air in a building.

For moisture in digested sludge tanks, the percentage of recorded temperature humidity was 63.2%, which was below the 70% recommended by ICOP IAQ DOSH, while under ASHRAE, it exceeded 60%. Moisture levels were affected by the evaporation of treated wastewater and sludge processes, hot and humid air from natural blowing winds, heat from the machinery, and the location of the plant in an open area.

There were 5 sampling stations above 25°C and 4 stations complied with ICOP IAQ DOSH and ASHRAE. The sampling stations were at the lobby (29.1°C), toilet (28.5°C), chemical lab (28.5°C), meeting room (27.3°C) and digested sludge holding tank (31.2°C).

High temperatures in the lobby were affected by the morning sunlight coming through doors and glass walls. There were no blinds installed to prevent sunlight and heat from entering. The heat present caused the air to heat up and the temperature to rise. A separate air conditioning system (split system) was insufficient to cool the hot air and was less effective.

High temperatures in the toilet were affected by the hot air from outside that entered into the toilet. The lack of internal air movement caused the toilet to become hot, resulting in a temperature increase. Only windows and exhaust fans were provided to remove air from the toilet.

High temperature in the chemical lab was affected by a lack of an exhaust fan to remove the hot air resulting from the use of equipment and laboratory work. The incoming morning sunlight through the windows and the absorption of heat in the walls had caused the lab to heat up. The existing split air conditioner was not able to cool the indoor air and this caused the temperature to rise. High temperatures in the sludge holding tanks were affected by the heat generated by large machinery that treats sludge and sewage, hot air from outside and the location of open plant exposed to the hot sun.

C. Sewage Treatment Plant B

A high percentage of relative humidity was found in office rooms, toilets, sludge treatment facilities, pre-treatment facilities, clarifier process facilities, and digested sludge holding facilities, with values ranging from above 64.5% to below 62.3% in the Sewage Treatment Plant 2. Humidity in the office rooms, with a reading of 82.1%, was caused by window openings that allowed natural air to enter the office. Hot and humid air, when mixed with existing cold air, could result in increased humidity in the building.

Humidity in the toilet was affected by less air movement and humid environmental conditions. Natural ventilation only enters through the door and openings on the wall. Only one exhaust fan was provided to remove indoor air from the building. High humidity recorded at the clarifier (73.5%), pre-treatment facility (72.4%) and digested sludge in the first floor (64.5%) and ground floor (62.3%) were affected by open environments, exposed to hot and humid natural wind, evaporation of sewage and sludge into the air and heat from the machinery.

Moisture is the amount of water contained in the air that can cause condensation. If high relative humidity persists continuously in buildings, this moisture can allow pathogenic germs to thrive and reproduce. Humidity exceeding 70% can promote the growth of pathogens, such as bacteria, viruses, and fungi, and can indirectly lead to the spread of airborne infections and droplets [30]. Low relative humidity in internal ventilation can also cause discomfort, headaches, throat itching, dry eyes, and dry skin [31]. Low humidity can also reduce immunity to diseases and increase the risk of becoming infected with viruses and other microorganisms [32]. The movement of air in buildings is crucial for reducing humidity, thereby achieving freshness and comfort. The recommended airflow is in the range of 0.10 to 0.15 – 0.55 m/s [7].

For temperature readings, there were 7 sampling stations above 25°C and 4 stations complied with the IAQ DOSH and ASHRAE ICOP standards. The recorded high temperatures were 32.8°C at the pre-treatment facility, 32.5°C at the digested sludge holding facility on the ground floor, 30.2°C at the clarifier process facility, 29.5°C at the office room, 28.3°C at the toilets, and 27.7°C at the surau.

High temperatures in the office were affected by hot air coming through the windows. Rooms exposed to the evening sunlight also contributed to the rise in temperature. High temperatures at pre-treatment plants, digested sludge holding plants, and clarifier process facilities were caused by hot air entering the treatment plant, heat from wastewater treatment machinery, and the plant's location being exposed to the hot sun. As for the high temperature in the toilet, it was influenced by hot air coming through the windows and doors. The lack of internal air movement caused the toilet to overheat. The windows and exhaust fan were less effective at removing air from the toilet. High temperatures in the surau were affected by the lack of cold air. Only one separate air conditioner and one wall fan were provided. The large number of workers praying at one time will cause the temperature and humidity to rise.

V. CONCLUSION AND RECOMMENDATIONS

The occurrence of airborne and droplet infectious diseases often occurs in buildings and workplace environments. Many factors influence it and are usually associated with poorly ventilated ventilation systems. Relative humidity exceeding 70% and temperatures of 5°C to 63°C continuously indoors can promote the growth of bacteria, viruses, fungi, and other pathogen-causing diseases.

This study revealed that carbon dioxide levels in three locations were below 1,000 ppm, complying with ICOP-DOSH and ASHRAE standards. Meanwhile, the high temperatures and humidity have violated the standards set by ICOP-DOSH and ASHRAE in the lobby areas, office rooms, cafeteria, pantry, surau, toilets, pre-treatment facilities, clarifier process facilities, and sludge digestion facilities.

These places were identified as high-risk areas for infectious disease transmission. Hence, the organisation should be extra caution and provide adequate preventive measures to prevent the spread of infectious diseases among the workers. In addition, optimal airflow movements within the building should be given attention to ensure that clean and fresh air exchange is obtained. Internal ventilation systems should also be maintained to ensure that air is free from contamination of foreign materials, pathogenic germs and in compliance with the air quality standards.

Based on the above analysis, the management of the building in the waste treatment facilities should focus on centralizing air conditioning system with clean air supply (MVAC). The system should be adequately maintained to ensure that the cooling tower, chiller, AHU unit, and associated components, such as intake water, dampers, cooling coils, filters, ductwork, diffusers, grilles, and dehumidifier, run smoothly and do not cause any disturbances in the building. Additionally, regular filter inspections should be conducted to ensure a clean and safe air supply. For building environment and water-handling unit components such as fans and dampers, inspection should be done at every six months to ensure they are in good condition and functioning properly.

For air-conditioned spaces without a fresh air supply, it is recommended to increase the room ventilation rate by frequently opening windows and doors, allowing for cross-natural ventilation into the space. An exhaust fan should also be installed in the toilets and the kitchen, operating at maximum capacity. The installation of a mechanical ventilation system is also recommended to supply fresh air. Surfaces should be cleaned regularly to maintain a clean environment, with regular inspections of sanitary pipe water seals to prevent water leakage into the space.

Safe Operation Procedures or SOPs for infectious diseases must be adhered to prevent and control infectious diseases. The personal protective equipment's need to be worn correctly and there should be hand sanitisers, and ensure the maintenance of social distancing of one meter, install barriers at work stations, minimise the large number of workers in the workspace and the frequency of conducting disinfectants in spaces that could potentially spread pathogenic microorganism [33, 34].

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AUTHOR CONTRIBUTIONS

Mohd Izwan Masngut: Writing–Original Draft Preparation & Investigation, Siti Munira Yasin; Conceptualization & Methodology , Kamarulzaman Muzaini; Writing-Review & Editing, Nurhuda Ismail; Data Curation & Formal Analysis, Ayu Suriawaty Bahkia; Investigation & Supervision; Nik Nairan Abdullah; Methodology & Validation, Noramira Nozmi;Writing- Review & Editing, Ahmad Faiz Azhari Noor; Supervision & Visualization, Ahmad Fitri Abdullah Hair; Supervsion & Visualization.

CONFLICT OF INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

ETHICS STATEMENTS

This study was approved by the The Research Ethics Committee, Faculty of Medicine, Universiti Teknologi MARA. No human subjects or vertebrate animals were used in this research. Fieldwork was conducted in accordance with Malaysia Occupational and Safety regulations, and necessary permits were obtained from the sewage treatment plant operator prior to data collection regime.

DATA AVAILABILITY STATEMENT

No available.

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