

Portable Environmental Monitoring System Using IOT (PEMS)

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Abstract

Air pollution, which is a major health and environmental hazard, is caused by various factors such as industrial, transportation, and domestic activity. The Air Quality Index (AQI) is used as an indication of air quality and potential health dangers to increase public awareness. This work proposed a Portable Environmental Monitoring System using IoT (PEMS) to monitor the air quality parameters and mapping them to the AQI rating and CO₂ concentration. PEMS performs three major functions which are to measure the particulate matters, carbon dioxide (CO₂) concentration and flammable gases. The Blynk application is used for the monitoring of the gathered data, which is also stored in its database. The values of PM₁, PM_{2.5} and PM₁₀ in µg/m³ are measured by using PMS5003 Particulate Matter. Meanwhile, the CO₂ concentrations are obtained by using MQ-135 Air Quality sensor and flammable gases such as Butane and Propane are detected by using the MQ-6 Gas sensor. Based on the experiments, Parit Raja Industrial Estate exhibits the highest average of PM₁, PM_{2.5} and PM₁₀ values due to its industrial surroundings. TDI Residential College comes second due to tenant occupancy and smoking activities. Conversely, PTTA Library at UTHM has the lowest PM values due to its spacious area and good air circulation. In terms of CO₂ concentration, Parit Raja Industrial Estate records the highest values due to anthropogenic CO₂ influence, while TDI Residential College follows closely, influenced by tenant exhalation and poor air circulation. Meanwhile, the PTTA Library, UTHM maintains the lowest CO₂ concentration due to its spacious area and efficient air circulation. Therefore, it is shown, based on the results, that PEMS has provided vital data on air quality parameters, thereby contributing pivotal information to assess the environmental health status, particularly in terms of the AQI.

1. Introduction

Air pollution is a global threat leading to large impacts on health and urban ecosystems [1]. The air quality status may change from day to day or even hour to hour. Therefore, timely detection of low air quality is critical for an efficient early warning system and public awareness of air quality regulation and management [2]. In order to know the pollution level of an area, particulate matter (PM) needs to be measured and the readings in ppm unit shall assist to determine the level of air quality [3]. PM₁ are extremely fine particulates with a diameter of fewer than 1 micron, PM_{2.5} which are also known as fine particles, have a diameter of less than 2.5 microns and PM₁₀ have a diameter of less than 10 microns, or 100 times smaller than a millimeter [4]. The Air Quality Index (AQI) is

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used as an indication of air quality and potential health dangers and it provides an easily understandable index for public awareness. The Air Quality Index (AQI) is a measure that assesses air quality, showing the current state and trends in a specific location. It measures nitrogen dioxide (NO₂), sulfur dioxide (SO₂), carbon monoxide (CO), ozone (O₃), fine particulate matter (PM_{2.5}), and coarse particulate matter (PM₁₀) to establish the air quality index for that day [5]. The overall AQI indicates the maximum of all pollutants and it is classified into six categories, ranging from "good" to "hazardous" depending on the health impact of the air quality. In addition to this, the World Health Assembly passed a significant resolution acknowledging air pollution as a risk factor for noncommunicable diseases like heart disease and cancer [6].

Thus, a Portable Environmental Monitoring System using IoT (PEMS) is proposed to monitor air pollution parameters and detecting the possibility of gas leakage which might be harmful to the environment. This system can be used to measure the AQI in open spaces, as well as in residential and industrial settings as it is equipped with various sensors such as MQ-135 Air Quality sensor, PMS5003 Particulate Matter sensor and MQ-6 Gas sensor. The MQ-135 Air Quality sensor is used to identify, quantify, and keep track of various airborne gases, including ammonia, alcohol, benzene, smoke and carbon dioxide concentrations [7]. Apart from that, the PMS5003 Particulate Matter sensor is chosen as it has better accuracy in measuring the AQI rating [8]. In addition, it can also obtain the PM₁, PM_{2.5} and PM₁₀ readings. The NodeMCU ESP32 is a powerful microcontroller with Wi-Fi and Bluetooth built in. It is frequently used in Internet of Things applications for data collecting, monitoring, and control [9]. Internet of Thing (IoT) analytics platform - Blynk allows the project to be displayed and updated in real-time [10]. Meanwhile, MQ-6 Gas sensor is utilized to detect gas leakage such as propane and butane [11].

2. Methodology

This section discusses the methodology applied in completing this work.

2.1 Block Diagram

Fig. 1 shows the block diagram for Portable Environmental Monitoring System using IoT (PEMS). The operation of PEMS consists of input, control and output section. The input power from the wall socket or battery will turn on the sensors and will monitor the parameters of air quality index using PMS5003 Particulate Matter. The MQ-135 Air Quality sensor will detect the concentration of Carbon Dioxide (CO₂) as an added value for the PEMS project to monitor and evaluate the air quality, Meanwhile, in detecting the gas leakage, the buzzer and LED will light up if the MQ-6 Gas sensor detects the presence of gas. With the help of NodeMCU ESP32 Wi-Fi module Board, PEMS project will enable the system to access the Internet and visualize it on Blynk.

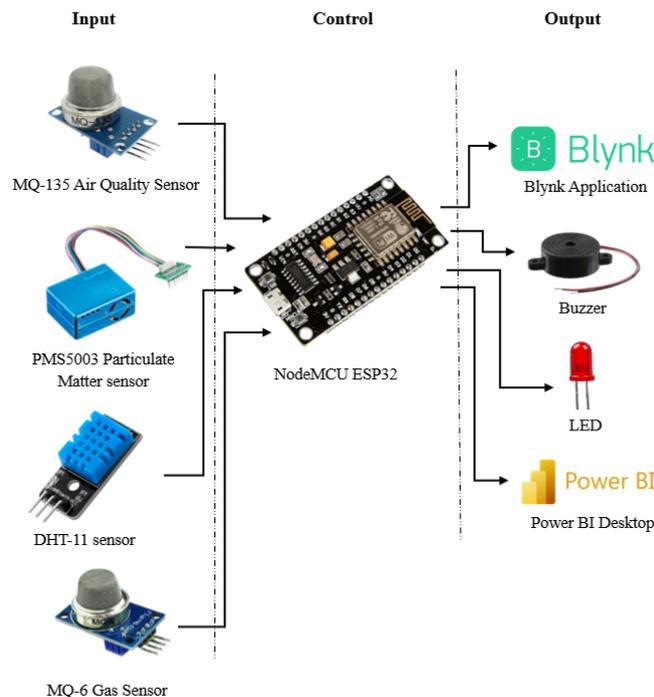


Fig. 1 Block diagram for Portable Device-Based Environmental Monitoring System using IoT (PEMS)

3. Results and Discussion

This section discusses the average results obtained about the air quality parameters such as PM₁, PM_{2.5}, PM₁₀, CO₂ concentrations, presence of flammable gases as well as the temperature of every sampling location that consists of Parit Raja Industrial Estate, PT TA Library UTHM and TDI Residential College. All the data was recorded for one hour in the morning, evening and night at an interval of 10 minutes per hour.

3.1 Particulate Matter

The values of PM₁, PM_{2.5} and PM₁₀ in µg/m³ for all sampling locations are measured by using PMS5003 Particulate Matter. The collection of data will be exported and analyzed to evaluate it with the rating of Air Quality Index (AQI) table [12]. The rating of the AQI in terms of PM_{2.5} and PM₁₀ is shown in Table 1.

Table 1 Air Quality Index (AQI) rating

Levels of Health Concern	PM _{2.5} Conc. (µg/m ³)	PM ₁₀ Conc. (µg/m ³)	Daily AQI Color	Air Pollution Level
Good	0–12	0–54	green	Level 1
Moderate	12.1–35.4	55–154	yellow	Level 2
Unhealthy for sensitive groups	35.5–55.4	155–254	orange	Level 3
unhealthy	55.5–150.4	255–354	Red	Level 4
Very unhealthy	150.5–250.4	355–424	Purple	Level 5
Hazardous	250.5–Higher	425–Higher	Maroon	Level 6

3.1.1 Measurements of PM₁, PM_{2.5} and PM₁₀ at TDI Residential College

Fig. 2 shows the indoor measurement results of particulate matter PM₁, PM_{2.5} and PM₁₀ recorded in the morning at TDI Residential College for one hour from 9:00 to 10:00 am with an interval of 10 minutes. From the figure, it can be observed that the values of PM₁, PM_{2.5} and PM₁₀ are very low considering the sampling locations are far from the industrial area and are surrounded by trees. The highest values of PM₁, PM_{2.5} and PM₁₀ that are recorded in the morning are 4.09, 6.12 and 4.36 µg/m³. Based on Table 1, this sampling location has a *Good* level of health concern with Level 1 of air pollution level.

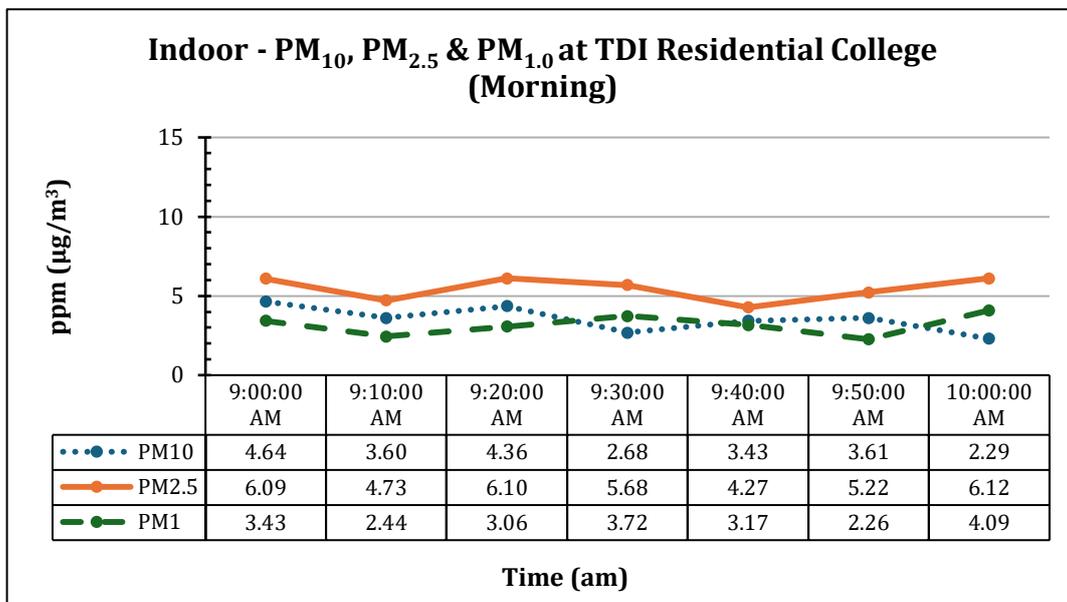


Fig. 2 Indoor measurement results of particulate matter (PM) in the morning at TDI Residential College

Meanwhile, Fig. 3. shows the indoor measurement results of particulate matter PM₁, PM_{2.5} and PM₁₀ recorded in the evening at TDI Residential College for one hour from 5:30 to 6:30 pm with an interval of 10 minutes. From the figure, the values of PM₁, PM_{2.5} and PM₁₀ are slightly increased considering the air circulation is not as good as

in the morning due to the sampling locations are occupied with the tenants during that time. The highest values of PM₁, PM_{2.5} and PM₁₀ in the evening that were recorded are 5.50, 8.14 and 7.10 µg/m³. However, all these values are still low and this sampling location has a *Good* level of health concern with Level 1 of air pollution level, based on Table 1.

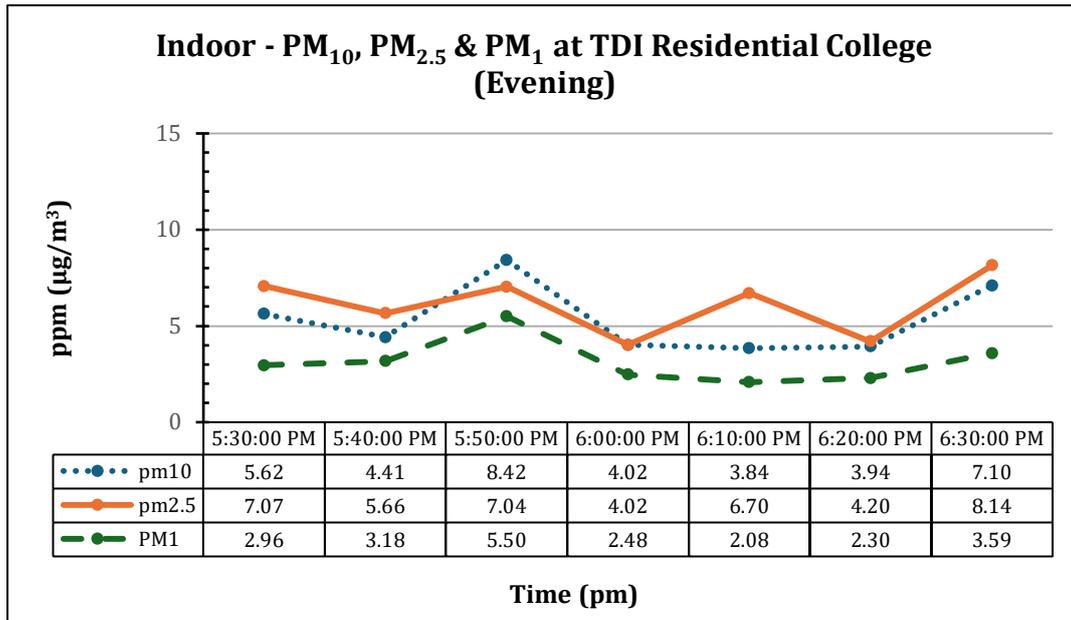


Fig. 3 Indoor measurement results of particulate matter (PM) in the evening at TDI Residential College

The indoor measurement results of PM₁, PM_{2.5} and PM₁₀ at TDI Residential College from 9:30 to 10:30 pm at night can be viewed in Fig. 4. From the figure, the values of PM₁, PM_{2.5} and PM₁₀ are quite high despite the sampling location is indoor and far from the industrial area. The highest values of PM₁, PM_{2.5} and PM₁₀ that were recorded are 6.69, 9.94 and 8.86 µg/m³. This might be due to the fact that all the tenants were staying in the room at that time and a few of them were smoking and vaping. However, based on Table 1, these values are still within a *Good* level of health concern with Level 1 of air pollution level.

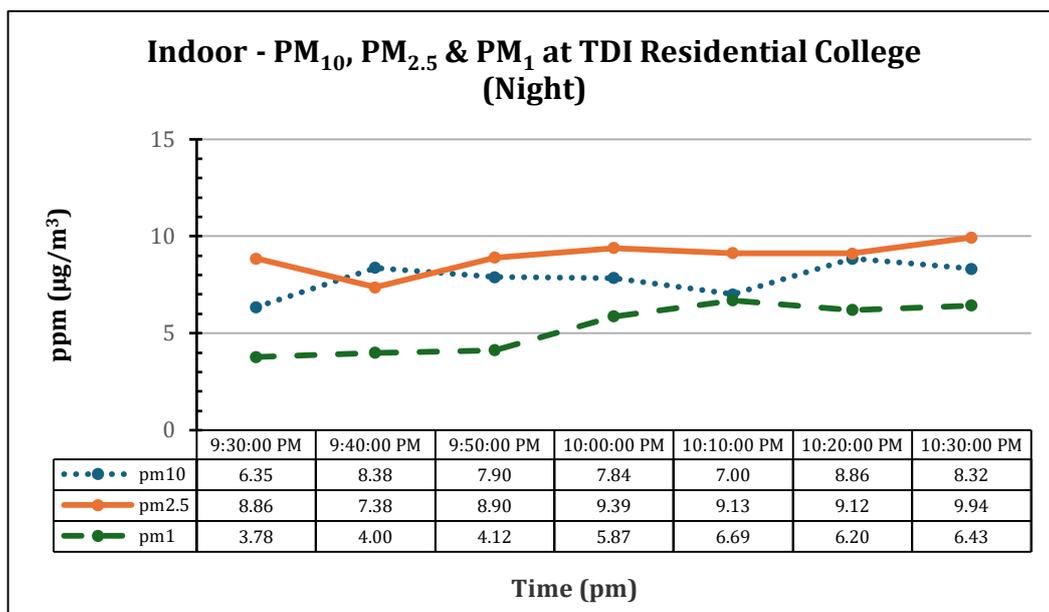


Fig. 4 Indoor measurement results of particulate matter (PM) at night at TDI Residential College

3.1.2 Measurements of PM₁, PM_{2.5} and PM₁₀ at PTTA Library, UTHM

Fig. 5 shows the indoor measurement results of PM₁, PM_{2.5} and PM₁₀ at the PTTA Library, UTHM from 9:15 to 10:15 pm. The recorded values of PM were lower as compared to the TDI Residential College, with the highest

values of PM_{10} , $PM_{2.5}$ and PM_{10} being 1.46, 2.71 and 2.09 $\mu\text{g}/\text{m}^3$, respectively. This can be attributed to the fact that the library has good air circulation, a spacious area and the smaller number of students at that particular time. Similarly, based on Table 1, it can be concluded that the air quality in the PTTA Library, UTHM was *Good* with Level 1 of air pollution level.

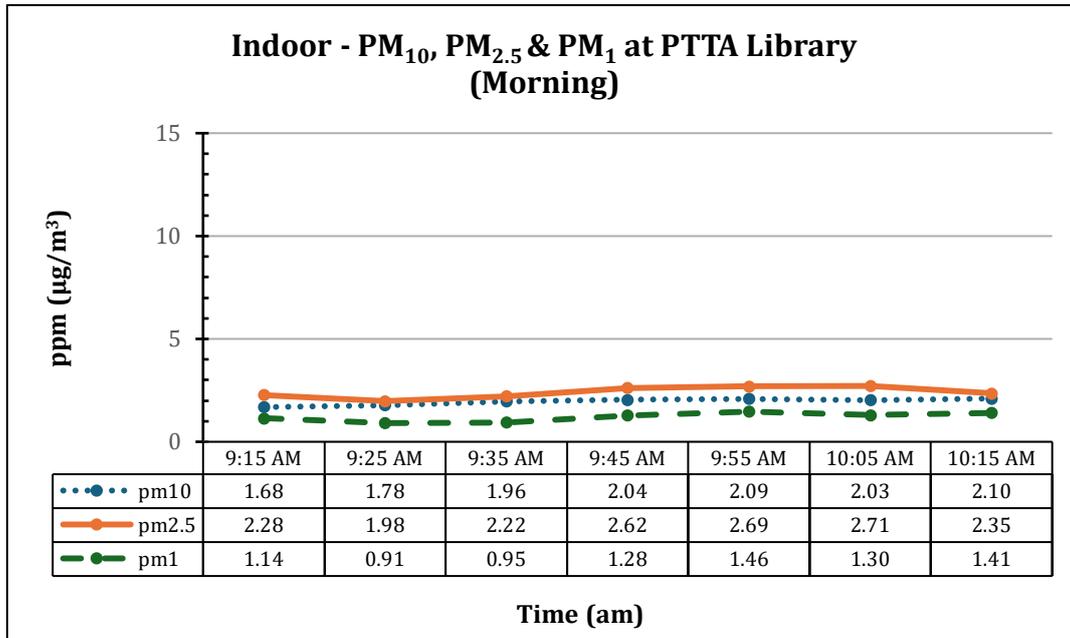


Fig. 5 Indoor measurement results of particulate matter (PM) in the morning at PTTA Library, UTHM

Meanwhile, Fig. 6 shows the indoor measurement results of every PM_1 , $PM_{2.5}$ and PM_{10} in the evening from 3:15 PM to 04:15 pm. From the figure, the values are higher than those values recorded in the morning and night, especially $PM_{2.5}$ and PM_{10} with values of 2.82 and 2.73 $\mu\text{g}/\text{m}^3$. These are due to the increasing number of students in the library and the dust that was brought from the student's shoes and clothes [13]. However, the air quality remains in a *Good* level of health concern with Level 1 of air pollution level, as can be seen in Table 1.

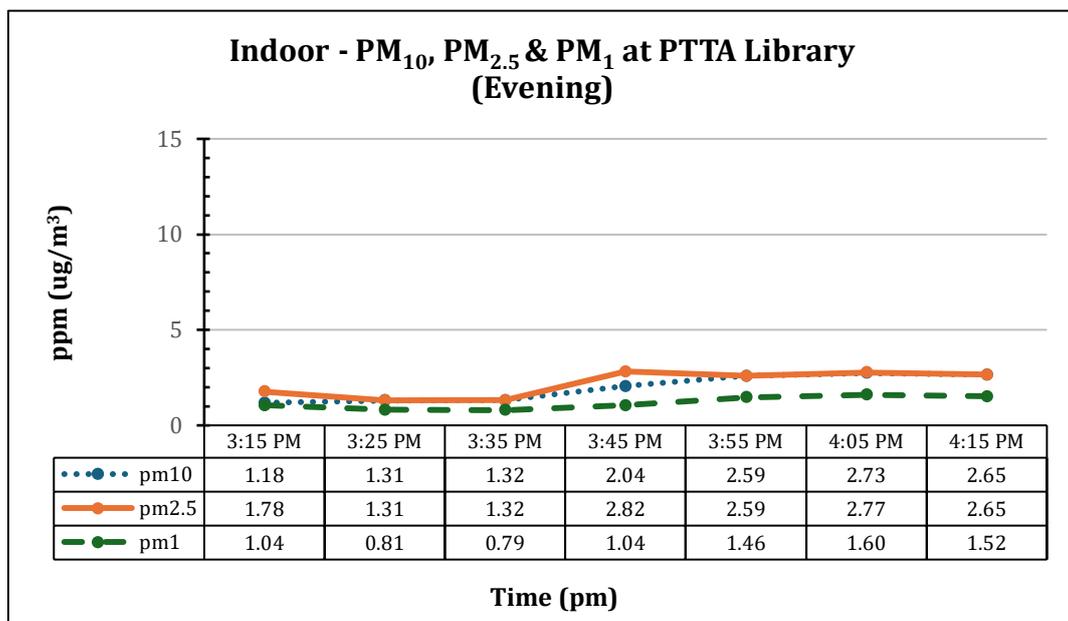


Fig. 6 Indoor measurement results of particulate matter (PM) in the evening at PTTA Library, UTHM

Fig. 7 shows the measurements PM_1 , $PM_{2.5}$ and PM_{10} that were taken at night from 8:15 to 9:15 pm at the PTTA Library, UTHM. The values of PMs are slightly decreased due to the students starting to leave the library. From the

figure, the highest values recorded for PM₁, PM_{2.5} and PM₁₀ are 1.61, 2.57 and 2.58 µg/m³, respectively. Therefore, based on Table 1, the air quality was *Good* with Level 1 of air pollution level.

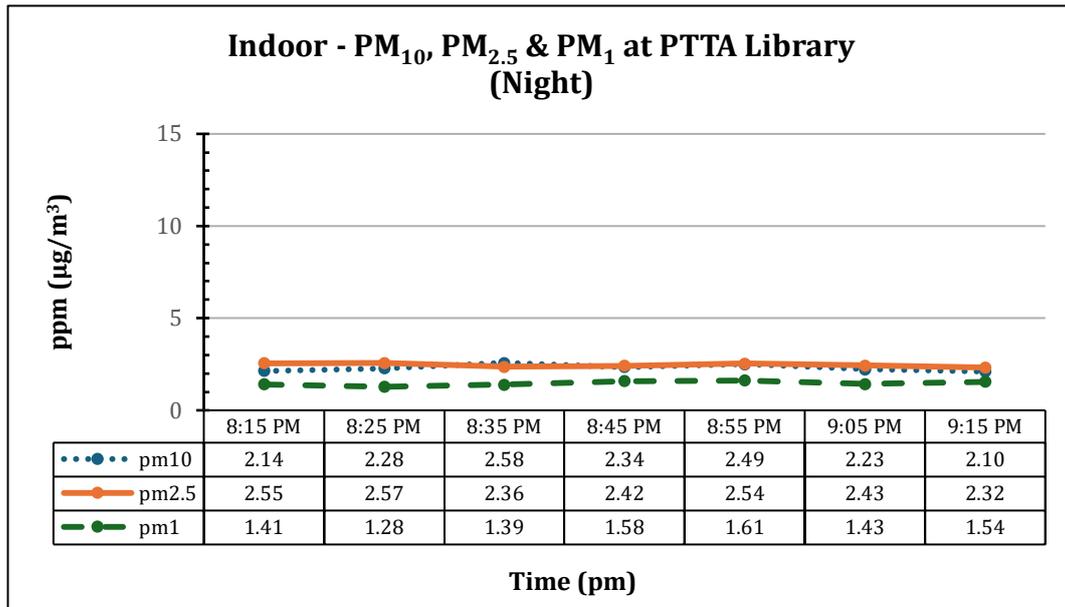


Fig. 7 Indoor measurement results of particulate matter (PM) at night at PTTA Library, UTHM

3.1.3 Measurements of PM₁, PM_{2.5} and PM₁₀ at Parit Raja Industrial Estate

Fig. 8 shows the values of PM₁, PM_{2.5} and PM₁₀ that were taken at Parit Raja Industrial Estate from 9:00 to 10:00 am. From the figure, the highest values recorded for PM₁, PM_{2.5} and PM₁₀ are 9.0, 18.18 and 17.71 µg/m³, respectively, due to the industrial activities, vehicle and industrial emissions around the area. Based on the AQI rating in Table 1 it can be observed that there are two levels of health concern at this sampling location which are *Moderate* following the PM_{2.5} concentration and *Good* following the PM₁₀ concentration, each with Level 2 and Level 1 of air pollution level. However, the level of health concern shall follow the worst PM and in this case, it is the concentration of PM_{2.5} due to its capability to penetrate deeper into the lungs [14].

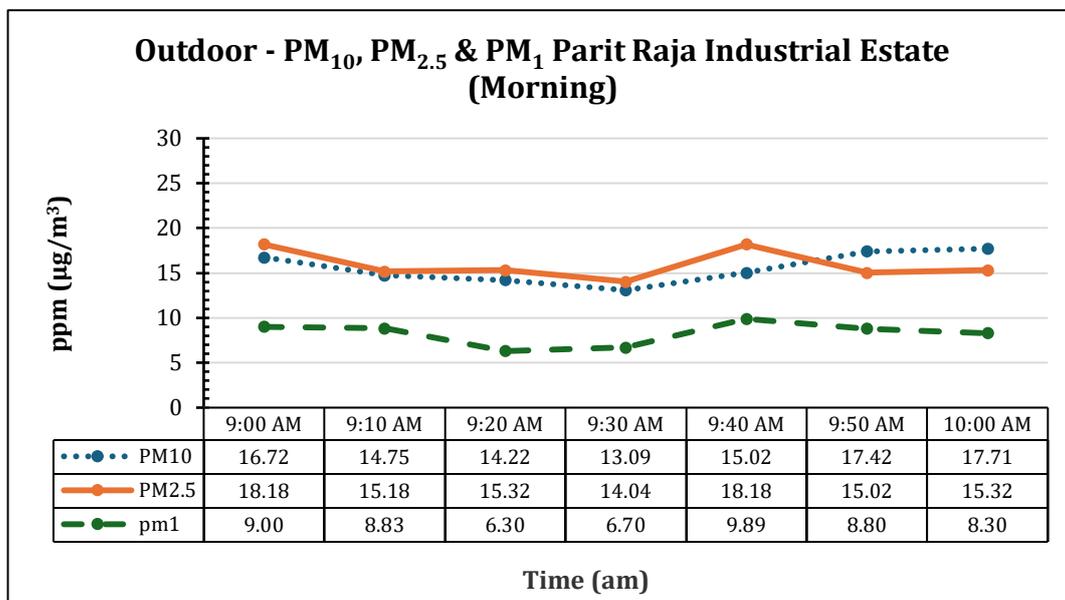


Fig. 8 Outdoor measurement results of particulate matter (PM) in the morning at Parit Raja Industrial Estate

Meanwhile, the measurements of PM₁, PM_{2.5} and PM₁₀ were also taken in the evening from 6:00 to 07:00 pm as shown in Fig. 9. From the figure, the values recorded are the highest compared to morning and night due to the

industry located around the sampling location releasing the hazardous smoke. During this period, a lot of vehicles passed in and out, thus affecting the value of PM_{2.5} and PM₁₀. Hence, the air quality during this sampling time was *Moderate* with Level 2 of air pollution level, as in Table 1.

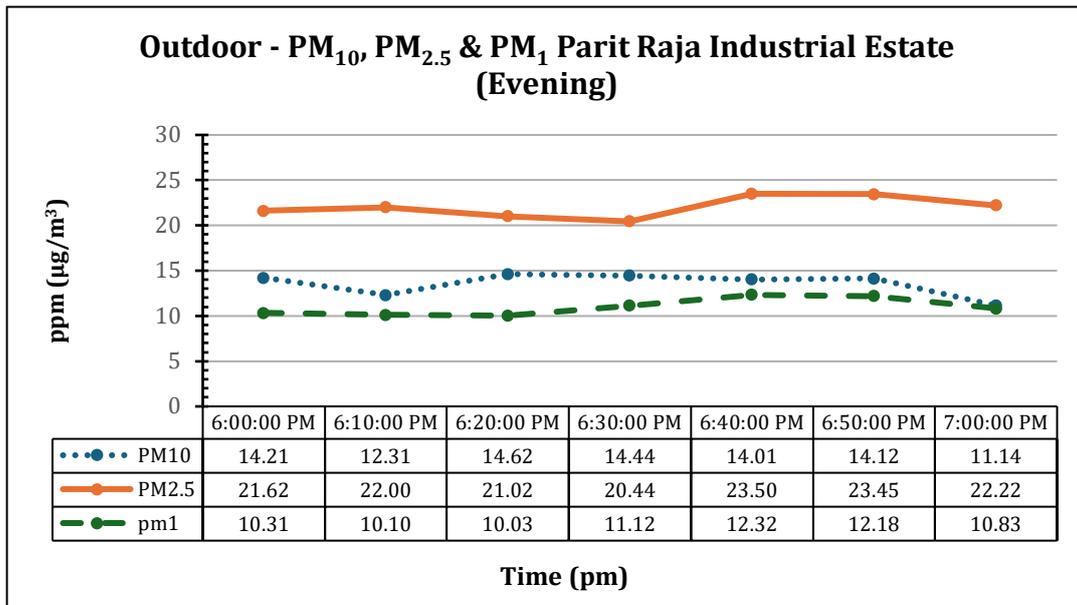


Fig. 9 Outdoor measurement results of particulate matter (PM) in the evening at Parit Raja Industrial Estate

Fig. 10 shows the values for PM₁, PM_{2.5} and PM₁₀ that were taken at night from 9:30 to 10:30 pm. From the figure, the value for each PM seems to have slightly decreased especially for the value of PM_{2.5} where the fine dust particles from the vehicle emissions and industrial activities were taken away by the wind. However, the value of PM₁₀ increased as there were burning activities coming from one of the industries. From the values recorded, the air quality at Parit Raja Industrial Estate at night was *Moderate* with Level 2 of air pollution level, based on Table 1.

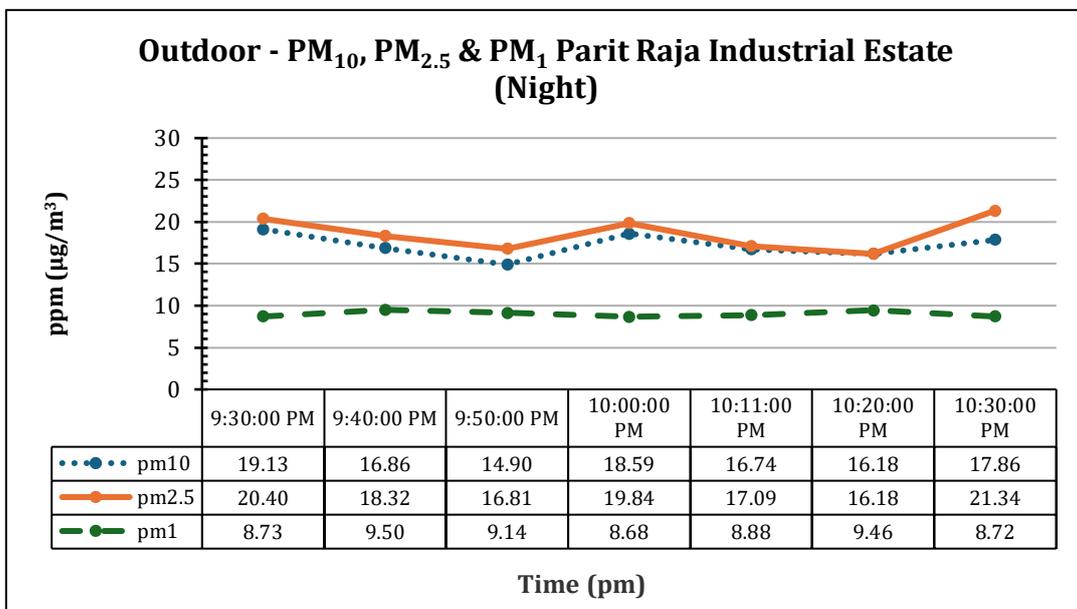


Fig. 10 Outdoor measurement results of particulate matter (PM) at night at Parit Raja Industrial Estate

3.2 Carbon Dioxide (CO₂) Concentration

The values of CO₂ concentrations in ppm for all sampling locations are measured by using MQ-135 Air Quality sensor. The collection of data shall be exported to Microsoft Excel to be analyzed and mapped to the CO₂ concentrations level chart [15]. Table 2 shows the CO₂ concentration level chart and its potential health problems.

Table 2 CO₂ concentration level chart

CO ₂ Concentration Range (in PPM)	Air Quality Descriptor	Cautionary Statements for CO ₂
250 - 350	Good	NO health impacts are expected when CO ₂ is in this range.
350 - 1000	Moderate	Typical levels found in occupied spaces with good air exchange
1000 - 2000	Unhealthy for Sensitive Groups	Levels associated with complaints of drowsiness and poor air.
2000 - 5000	Unhealthy	Levels associated with headaches, sleepiness, and stagnant, stale, stuffy air; poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
> 5000	Very Unhealthy	This indicates unusual air conditions where high levels of other gases could also be present. Toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures.
> 40000	Dangerous	This level is immediately harmful due to oxygen deprivation.

3.2.1 CO₂ Concentrations at TDI Residential College

Fig. 11 shows the indoor CO₂ concentration that was measured in the morning at TDI Residential College from 9:00 to 10:00 am. From the figure, the concentration of CO₂ during this hour is low as most of the tenants were not in the room. The highest CO₂ concentration recorded is 545 ppm and the air quality in the room was *Moderate* with a good air exchange based on the CO₂ concentration level chart in Table 2.

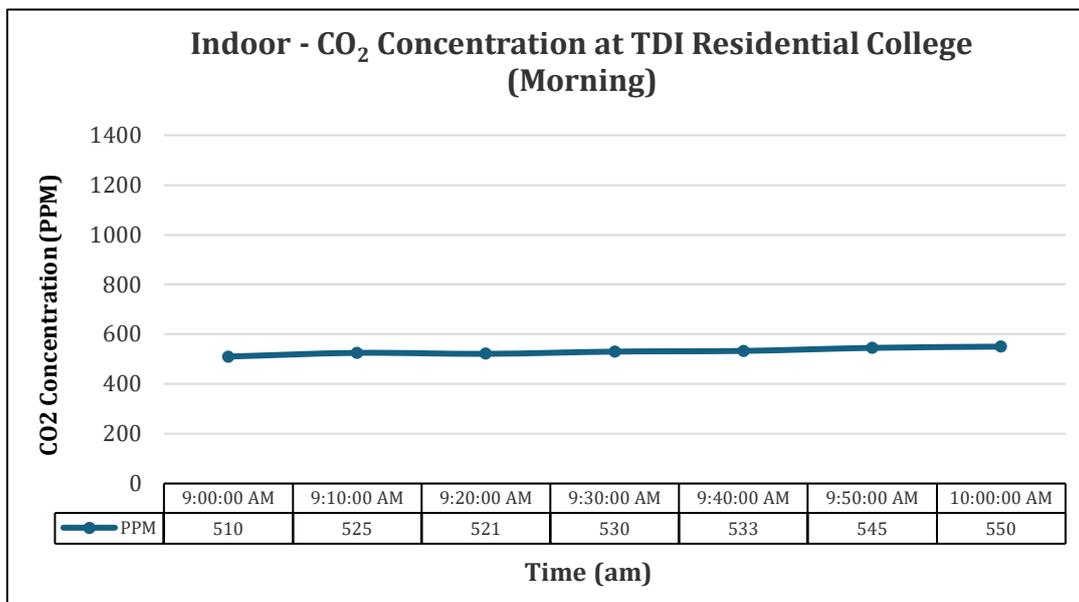


Fig. 11 CO₂ concentration in the morning at TDI Residential College

In addition, Fig. 12 shows the CO₂ concentration that was taken in the evening at TDI Residential College from 5:30 to 6:30 pm. From the figure, the highest value of CO₂ concentration during this hour is 926 ppm due to the

smoking activities from few of the tenants and the room was fully occupied. However, all the windows were open, thus contributing to a good flow of air circulation. The air quality in the sampling room was *Moderate*, based on Table 2.

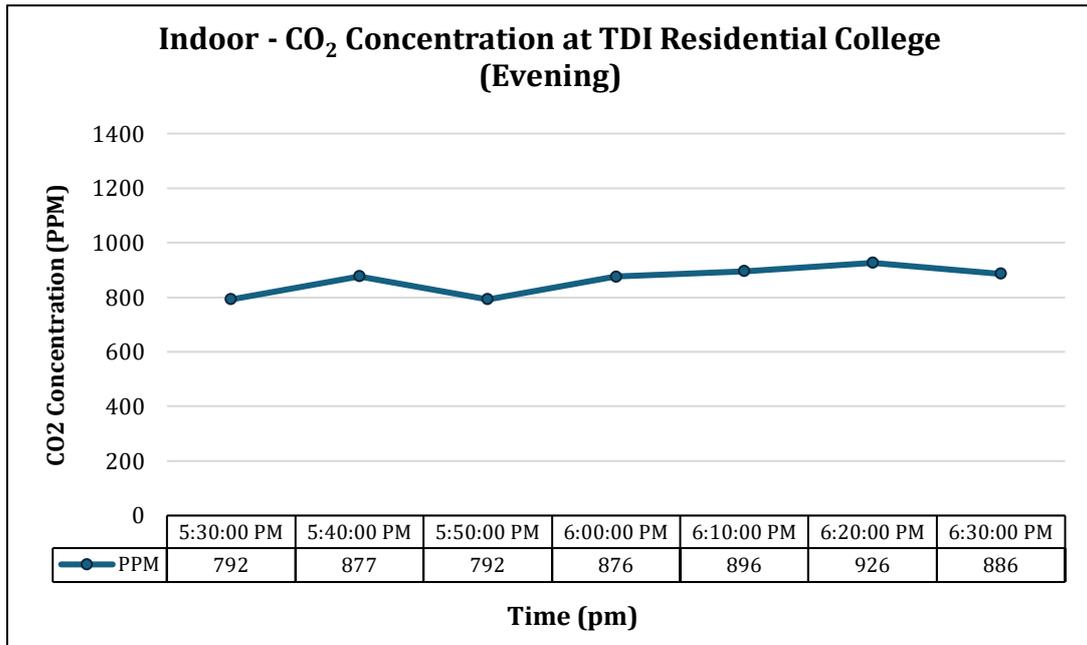


Fig. 12 CO₂ concentration in the evening at TDI Residential College

The readings of CO₂ concentration that were recorded at night from 9:30 to 10:30 pm can be shown in Fig. 13. The concentration of CO₂ during this hour is low as the room was occupied by only a few tenants as most of them went out for dinner. The highest value of CO₂ concentration is 525 ppm. Hence, the air quality in the sampling location at night was *Moderate*, as can be viewed in Table 2.

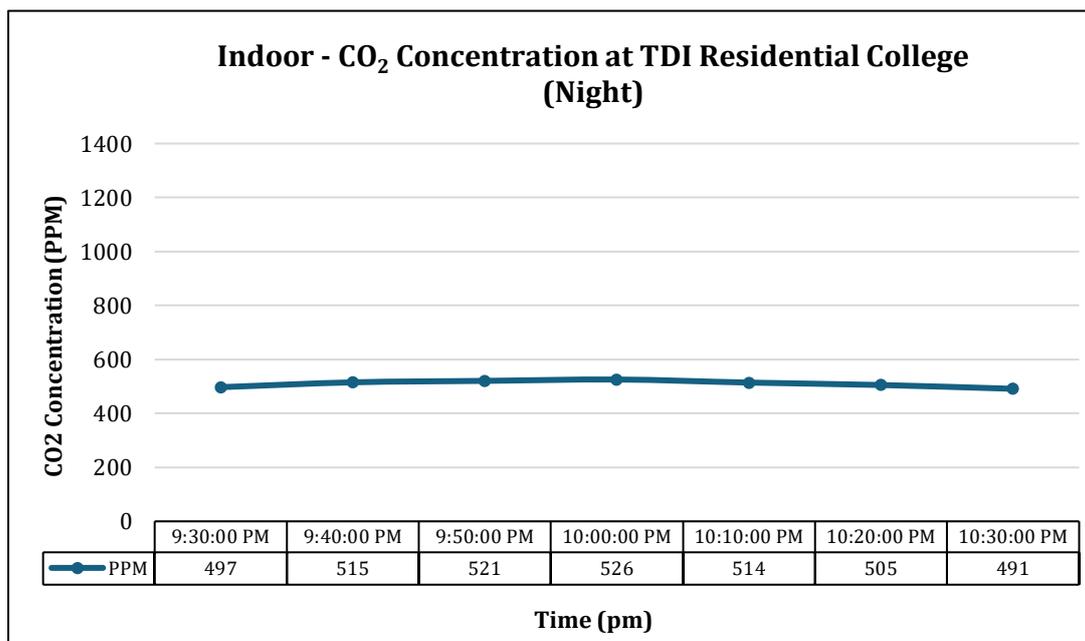


Fig. 13 CO₂ concentration at night at TDI Residential College

3.2.2 CO₂ Concentrations at PTTA Library, UTHM

Fig. 14 shows the readings of CO₂ concentration for indoor that were taken in the morning at the PTTA Library, UTHM from 9:16 to 10:15 pm. From the figure, the highest value that was recorded is 715 ppm due to the sampling

location being occupied with a lot of students at that time. The CO₂ concentration could have been higher but was prevented due to good air circulation in the library. Therefore, the air quality in the library during this hour, based on Table 2, was *Moderate*.

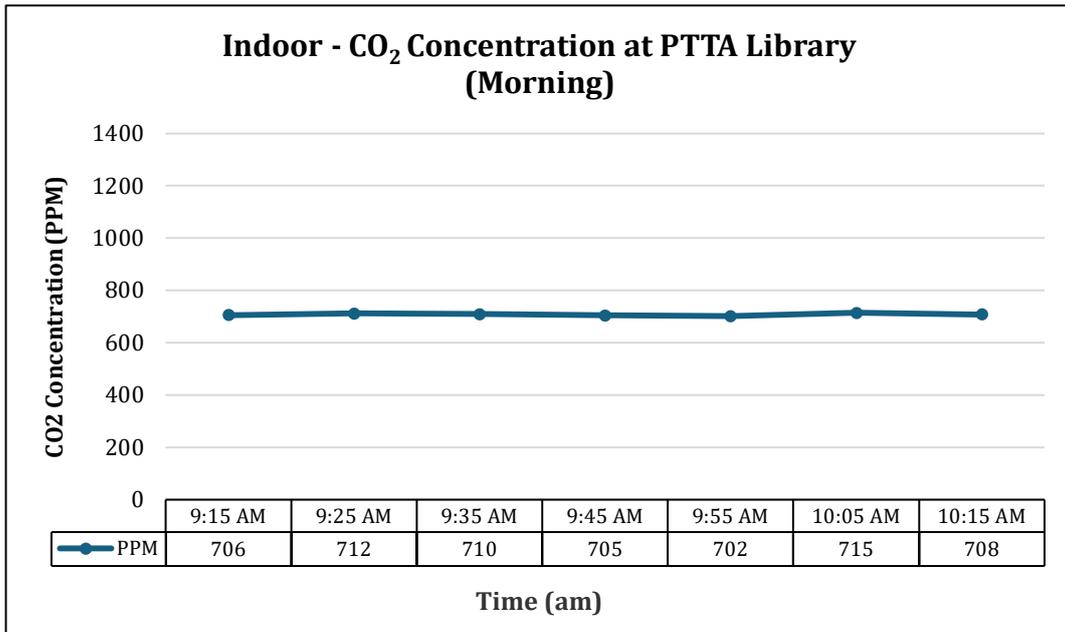


Fig. 14 CO₂ concentration in the morning at PTTA Library, UTHM

Meanwhile, CO₂ concentrations that were measured in the evening from 3:15 to 4:15 pm can be shown in Fig. 15. From the figure, the recorded values during this sampling time were quite low compared in the morning and night due to the smaller number of students at the library. The highest value of CO₂ concentration during this hour is 656 ppm and based on Table 2, the air quality was also *Moderate*.

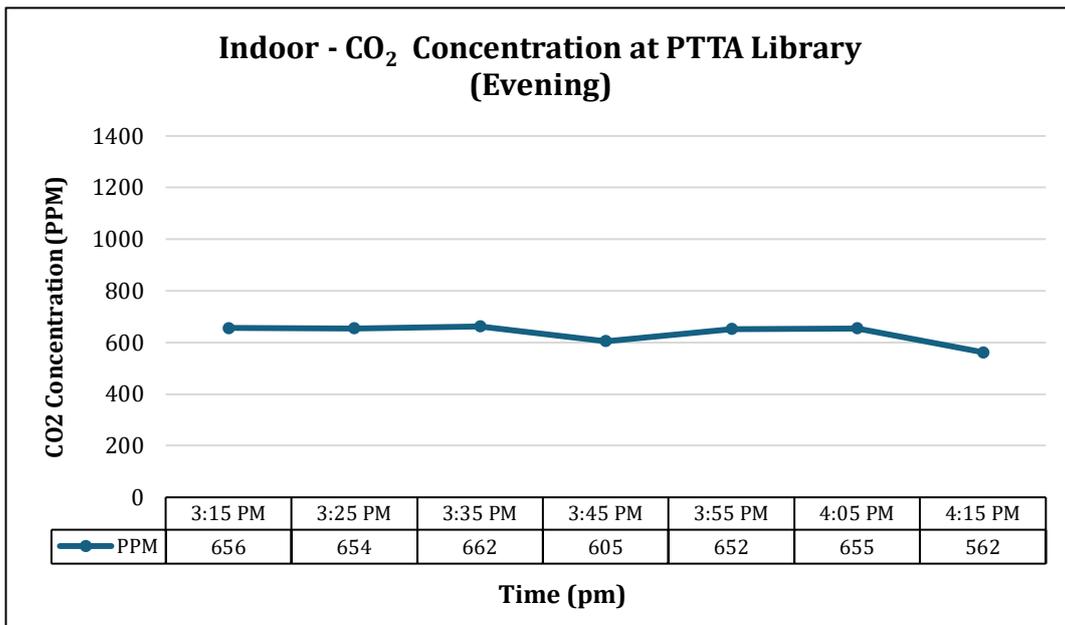


Fig. 15 CO₂ concentration in the evening at PTTA Library, UTHM

Fig. 16 shows the readings of CO₂ concentration that were measured at night from 8:15 to 9:15 pm. The concentration of CO₂ during this hour has slightly increased compared to the evening as the number of students coming to the library has increased. From the figure, the highest CO₂ concentration was recorded at 718 ppm and the air quality at night was *Moderate*, based on Table 2.

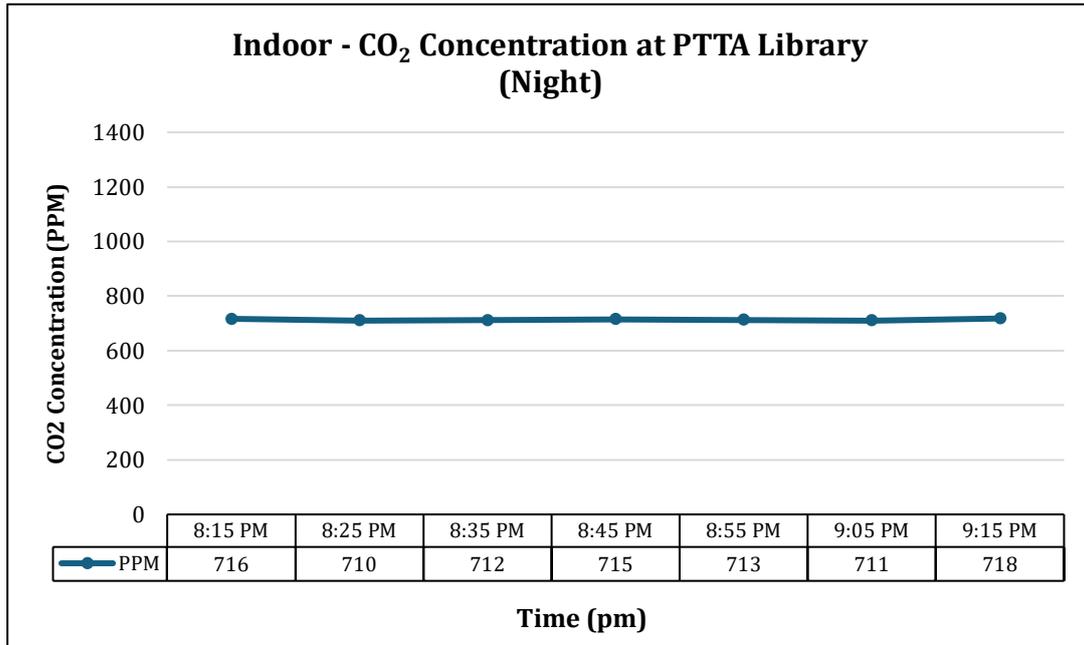


Fig. 16 CO₂ concentration at night at PTTA Library, UTHM

3.2.3 CO₂ Concentrations at Parit Raja Industrial Estate

Fig. 17 shows the outdoor CO₂ outdoor concentrations that were collected in the morning at Parit Raja Industrial Estate along Jalan Padi Ria from 9:00 to 10:00 am. The concentration of CO₂ during this hour is high due to the anthropogenic CO₂ sources such as fossil fuel combustion, deforestation, and industrial processes [16]. From the figure, the highest recorded value is 993 ppm and it is safe to conclude that the air quality at this sampling location was Moderate, as can be seen in Table 2.

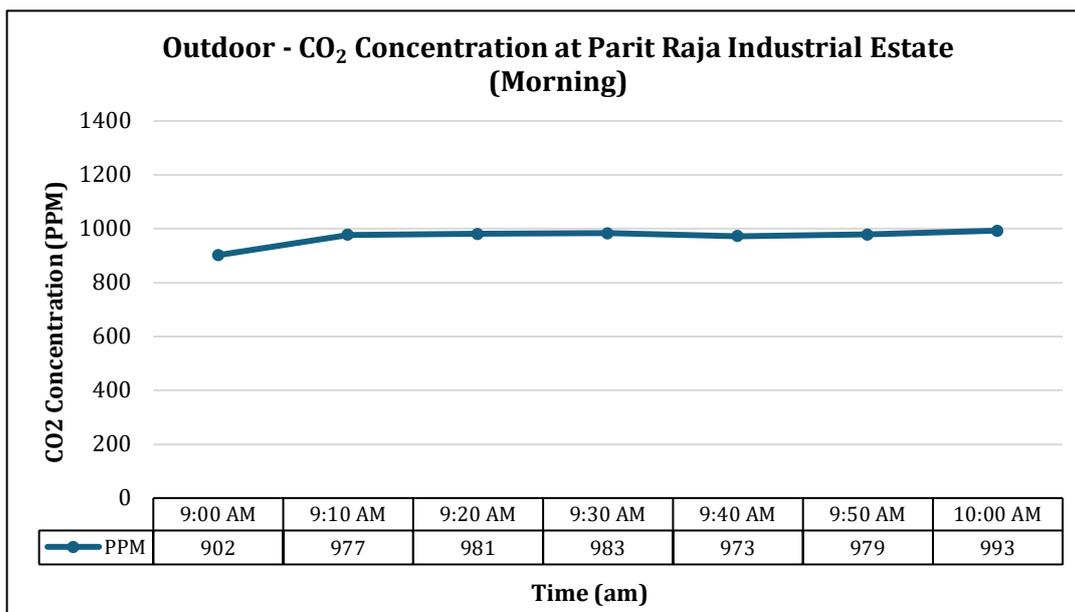


Fig. 17 CO₂ concentration in the morning at Parit Raja Industrial Estate

Meanwhile, the readings of CO₂ concentrations that were collected in the evening from 6:00 to 7:00 pm can be viewed in Fig. 18. From the figure, the concentration of CO₂ is the highest among all the sampling locations as the industrial activities were still active during that time and thus, increasing the source of anthropogenic CO₂. The highest concentration of CO₂ recorded is 1033 ppm and based on Table 2, the air quality during this hour was *Unhealthy for Sensitive Groups*.

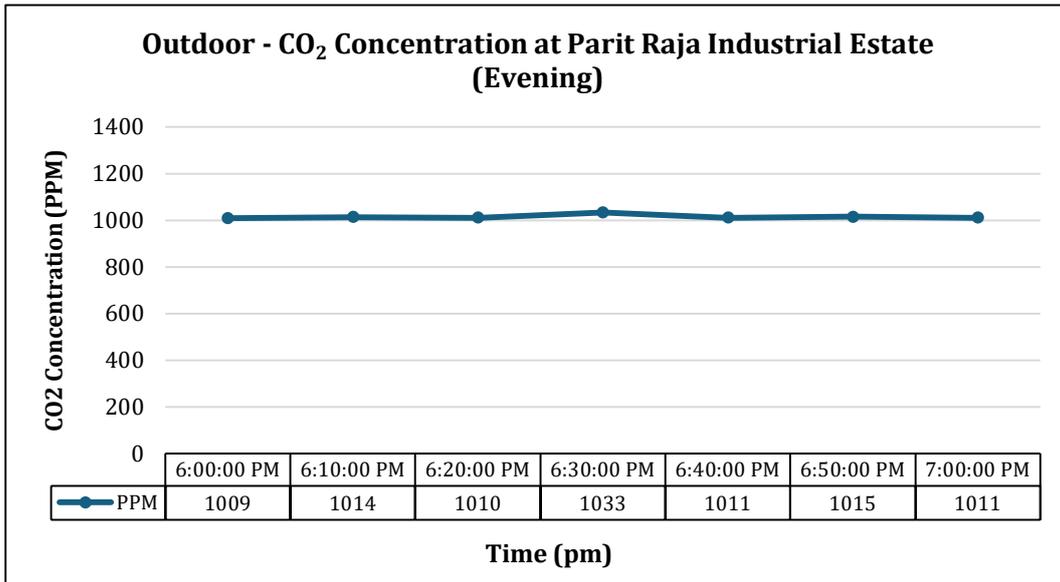


Fig. 18 CO₂ concentration in the evening at Parit Raja Industrial Estate

Fig. 19 shows the readings of CO₂ concentrations that were measured at night from 9:30 to 10:30 pm. From the figure, the recorded values are slightly decreased, with the highest value being 628 ppm, as the sources of anthropogenic CO₂ were washed away by the rain. Therefore, it can be concluded that the air quality during this hour was *Moderate*, based on Table 2.

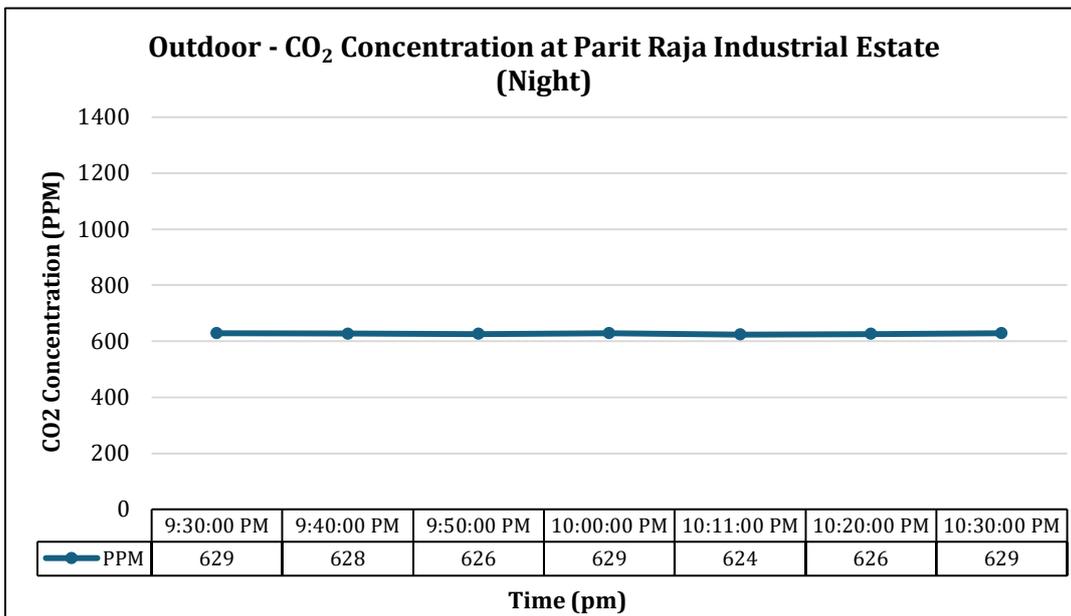


Fig. 19 CO₂ concentration at night at Parit Raja Industrial Estate

4. Conclusion

In this work, a Portable Environmental Monitoring System using IoT (PEMS) has demonstrated its effectiveness in collecting the particulate matter of PM₁, PM_{2.5}, PM₁₀ and CO₂ concentrations. The PEMS is equipped with the MQ-135 Air Quality sensor, PMS5003 Particulate Matter sensor, MQ-6 Gas sensor and DHT-11 sensor. These sensors collect the data of particulate matter in µg/m³ and CO₂ concentrations in ppm. The collected data can be monitored on the Blynk application and stored in its database. The pool of the data is then exported from the Blynk application to Microsoft Excel to be analyzed and establish the rating of air quality index (AQI) and CO₂ concentrations based on the pollution level. The experiments have been conducted at three sampling locations which are TDI Residential College, PTTA Library, UTHM and Parit Raja Industrial Estate along Jalan Padi Ria for one hour, with intervals of 10 minutes. From the average data, the TDI Residential College

revealed variations throughout the day, with morning measurements indicating low values and maintaining a *Good* air quality level, while the evening saw a slight increase and the level keep increasing at night due to smoking activities, but still remained within a *Good* range. However, the PTTA Library, UTHM consistently exhibited lower PM values due to its spaciousness and effective air circulation. There has been a slight increase in the evening due to the dust particles that were brought from the student's shoes but yet, still maintaining a *Good* air quality level. In addition, Parit Raja Industrial Estate has consistently led higher PM values, reaching *Moderate* levels due to the industrial activities. In terms of CO₂ concentrations, the concentration at TDI Residential College varied, with morning values indicating a *Moderate* air quality level and a slight increase of CO₂ concentration in the evening due to increased occupancy and smoking activities. The PTTA Library, UTHM displayed moderate CO₂ concentration despite students' occupancy, while Parit Raja Industrial Estate recorded higher CO₂ levels, particularly in the evening, reaching *Unhealthy for Sensitive Groups* levels. Notably, no traces of flammable gases were detected at any locations, emphasizing the safety of the sampling locations. Overall, this comprehensive analysis provides valuable insights of air quality parameters, contributing crucial information for environmental health status in terms of air quality index.

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Conflict of Interest

The author declares that there are no conflicts of interest associated with this paper's publication. There are no any personal, business or professional ties that might influence this work. The research's neutrality and integrity are guaranteed by this transparency. The author promises to immediately disclose any future possible conflicts of interest that might surface.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Zul Helmy Izzani Rokhmad; **data collection:** Zul Helmy Izzani Rokhmad; **analysis and interpretation of results:** Zul Helmy Izzani Rokhmad; **draft manuscript preparation:** Zul Helmy Izzani Rokhmad, Shaharil Mohd Shah. All authors reviewed the results and approved the final version of the manuscript.

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