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Investigation of Air Quality and Suspended Particulate Matter Inside and Outside of University Research Laboratories

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ABSTRACT

Counting the aerosol particles and identifying the air quality are reflectors for the efficiency of heating, ventilating and air-conditioning system (HVAC). HVAC is an important system especially in construction, agriculture, food processing and animal farming sectors. The objective of the presented research was to study the changes in local conditions and air quality in research laboratories of Universiti Teknologi PETRONAS (UTP) due to research activities and construction going on in the university suburbs. To achieve our objectives, we have measured the aerosol particles by using DUSTTRAK™ in an indoor (with and without stimulus) and outdoor environment. We even further investigated the air quality of indoor and outdoor environment, through measuring carbon dioxide concentration, ventilation rate, light intensity, relative humidity and temperature by using Telaire 7001. Data was collected from both devices, analyzed and discussed thoroughly in the discussion section.

Key words: Light intensity, dust aerosol, air pollution, CO_2 capture

INTRODUCTION

Our atmosphere air consists of many types of gaseous and fine particles. The air we breathe contains 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.039% carbon dioxide and small amount of other gaseous as well as water vapors. Apart from gases, our air also consists of many fine particles that can be dangerous to the human life form. Thus it is important for our air to be analyzed time by time in order to ensure that it is safe for human beings. Not only that, by doing the air analysis we can also increase our understanding of the physical and chemical properties of air and its effects on various aspects such as human health, air quality and global climate (Hussain *et al*., 2008a). In recent years, health and safety concerns are a growing part of air quality assessment. Airborne biological substances, gases, vapors and particles can cause adverse reactions in certain individuals, depending on their sensitivity to particular substances and concentrations. Some of these ever-present unwanted contaminants are potentially toxic, infectious, allergenic, irritating or otherwise harmful. Poor Indoor Air Quality (IAQ) is listed as a top five health concern by most major associations and agencies worldwide. Recent studies claim that over one third of the buildings in the United States have air quality problems. Now more than ever, it is increasingly important to be proactive, to identify and resolve potential problems before they get out of control (Hussain *et al.*, 2008b; Miguel and Kremer, 2004). TSI Indoor Air Quality instruments are designed to help us identify and managing these tough problems. Usually air inspections are done at construction sites, mining sites or new hospitals. Some measurements done are for example, measuring the humidity, ventilation of the building, carbon dioxide concentration and dust particle (Hussain *et al.*, 2008a; Ezzati *et al.*, 2000).

In this experiment, there will be two parts to analyze the air composition. The first part is the aerosol measurements and the second part would be carbon dioxide concentration and temperature monitoring. Thus, the objective of this experiment was to analyze the air composition and how it changes at different sites. Aerosol can be defined as anything suspended in air like water droplets, fumes, smokes, dusts and sprays. Fumes are fine particles and agglomerates generated through combustions and vapor condensation. As for smokes, it can be defined as solid and liquid particles arising from incomplete combustion. For dust, there are solid particles generated through mechanical means. Therefore, measurements were carried out to determine the personal and indoor aerosol exposures which are critical for the work place health and safety. The device used for this particular measurement was DUSTTRAK™. Through this device, we can trace the dust particle in the air and the temperature. Measurements can be in terms of mass concentration (mg m^{-3}) or No. concentration (No. m^{-3}). Mass concentration is used to quantify the aerosol measurement.

Our air has many gaseous elements in it and carbon dioxide is one of it. When we breathe, we exhale carbon dioxide therefore, increasing the concentration of carbon dioxide in the environment. The concentration however, must be monitored closely. In a building, carbon dioxide concentration may vary depending on the ventilation rate of the room. To ensure the carbon dioxide concentration is at a safe level, the ventilation must be at a higher level. If not, horrible effects like headache, nausea, shortness of breath and even death can happen. ASHRAE standard provides information regarding the recommended rate of ventilation for different types of buildings (Kunzli *et al.*, 2005; ASHRAE, 1992). Telaire 7001 was used to measure the CO_2 concentration and to calculate the outside air ventilation. Through this instrument, things that were measured are the ventilation rate, irradiance or light intensity and carbon dioxide concentration. The ventilation rate was measured in liter per person per second.

MATERIALS AND METHODS

Part A: Aerosol measurement: The schematic of the aerosol monitor is given in Fig. 1. The algorithms used by the DUSTTRAK DRX Aerosol Monitor yield a mass measurement technique that is superior to either a basic photometer or Optical Particle Counter (OPC). While photometers can be used at high mass concentrations, they do not give any size information (unless used with size selective inlet conditioners) and significantly underestimate particle mass contributed by large particles. On the other hand, OPCs provide size information, however they cannot be used at high mass concentration. The DUSTTRAK DRX Aerosol Monitor is able to combine the advantages of both the measurement techniques to improve the overall accuracy of the mass measurement. Although, the DUSTTRAK DRX monitor comes with a couple of calibration impactors, they are recommended for use only during custom calibrations. The greatest advantage of using the DUSTTRAK DRX Aerosol Monitor over other photometers in the market including the DUSTTRAK II Aerosol Monitor is no requirement of size-selective inlet conditioner. PM1, PM2.5, PM4/respirable, PM10/thoracic and TPM fractions can all be measured simultaneously without the use of any size-selective inlet conditioners. To improve the accuracy of the mass measurement, the unit was calibrated with gravimetric sample(s) by conducting side-by-side comparisons with the

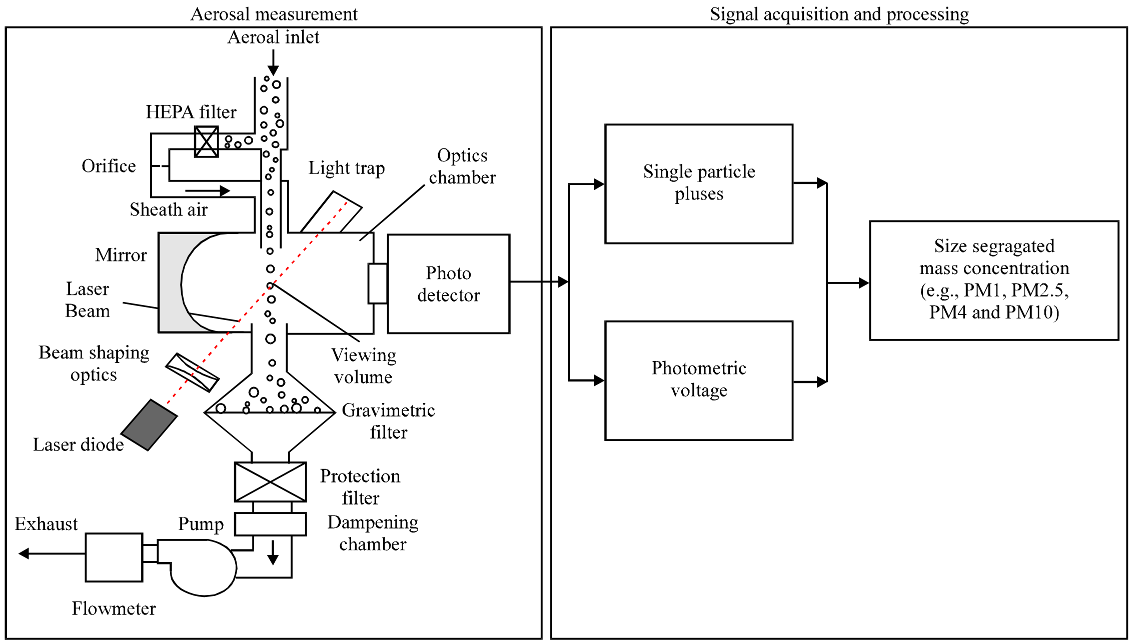

Fig. 1: Schematic of the aerosol monitor

DUSTTRAK DRX Aerosol Monitor readings to gravimetric samples. On the Desktop Model 8533, a 37 mm filter cassette sampler was inserted in-line with the aerosol stream at the outlet of the optics chamber allowing the user to perform a gravimetric analysis without the need for using an external pump and filter holder. First of all, zero calibration was done to ensure that no dust particle is detected. The zero cal function was pressed and the filter was inserted. Then, the start button was pressed to start the zeroing process. This step was taken once at the beginning of the experiment to ensure no dust or any other particulate was trapped. Once the zero cal was completed, the filter was removed and the device was ready to be used. Before the 'Start' button was clicked, the TrakPro software was initiated. Then, the mass concentration data was recorded on the machine. The experiment was done initially in the air conditioned room then carried out on to the outside environment. The apparatus was exposed to the surrounding air inside and outside the laboratory for 2 min for each run. The data presented in this paper was averaged over 3 runs. The results were then analyzed and compared.

Part B: CO_2 and temperature monitor: The Telaire 7001 hand held Carbon Dioxide sensor was used to monitor CO_2 and temperature. This sensor measures CO_2 and temperature and can calculate and display real-time ventilation rates. When combined with the HOBO U12 or ZW Series it can only record CO_2 and when connected to the H22 or U30 Series can record temperature and CO_2 as well.

Before the experiment was started, the elevation setting was corrected. To do so, the MODE button was pressed until the elevation mode is blinking. Then the Enter button was pressed and the elevation was set to 200 m. Next, the setting was saved and returned to normal mode. Before the CO_2 measurements were taken, the level of carbon dioxide must be at an acceptable level of 15-20 cfm person^{-1}. Next, measurements for temperature, humidity, ventilation rate and carbon dioxide concentration (ppm) and the light intensity were taken. Using the HOBO ware software, the instrument was attached with a computer and the data was generated. The experiment was done initially in the air conditioned room then carried out on to the outside environment. The results were then analyzed and compared.

EXPERIMENTAL RESULTS

The DUSTTRAK DRX Aerosol Monitor is able to measure mass concentrations with greater accuracy because of its ability to measure single particles with size >1 μm. Since the photometric signal is less sensitive to large particles. The tests were conducted for 2 min sampling periods and not for 8 h TWA (total weight average). Moreover, 8 h TWA are used for reference since it has been used for international standards. Firstly, we conducted the tests under normal conditions. This is because we want to see the variation between IAQ compared with outdoor air quality. We analyzed the results of AIQ based on particle matters: $PM_{2.5}$, PM_1, TPM, PM_{10} and PM_4. Details are given in Table 1.

The following Fig. 2 shows the concentration level of particles indoor without stimulus. It can be noticed that there are 2 major spikes on the graph which are at early and end stage of the experiment. The level of mass/size fraction (mg m^{-3}) of two spikes are below 0.3 mg m^{-3}. On the average, the level of the airborne concentrations is below 0.1 mg m^{-3}.

Table 1: Class and range of dust particles

Particle class	Range (μm)
$PM_{2.5}$	Less than 2.5
PM_1	Less than 1
PM_{10}	Less than 10
PM_4 (Respirable)	Less than 4
TPM (Total particulate matter)	More than 10

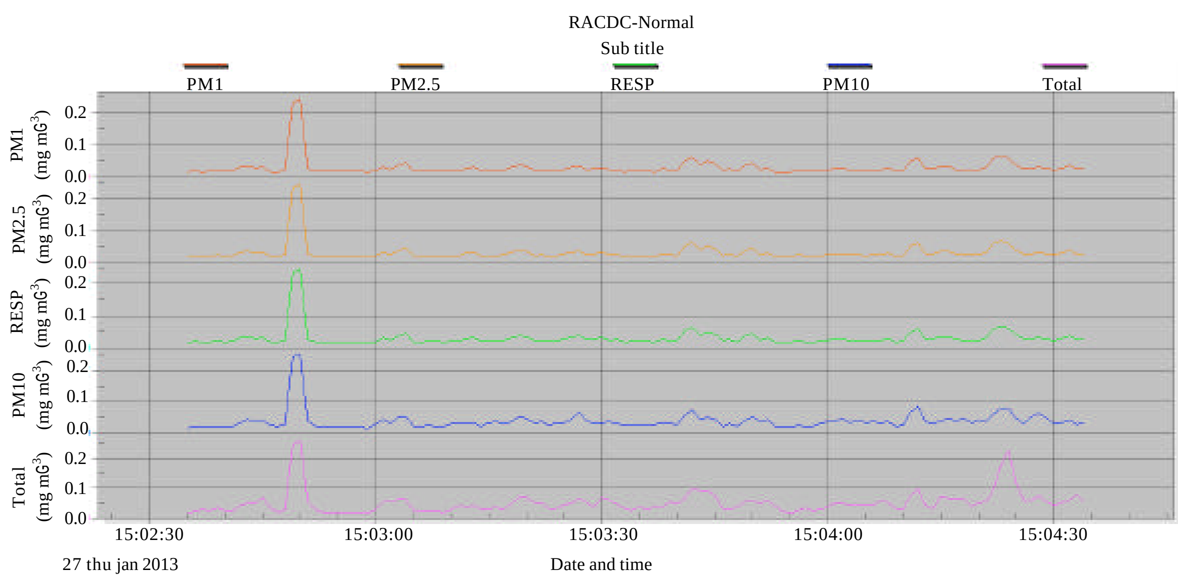

Fig. 2: Indoor conditions without aerosol stimulus

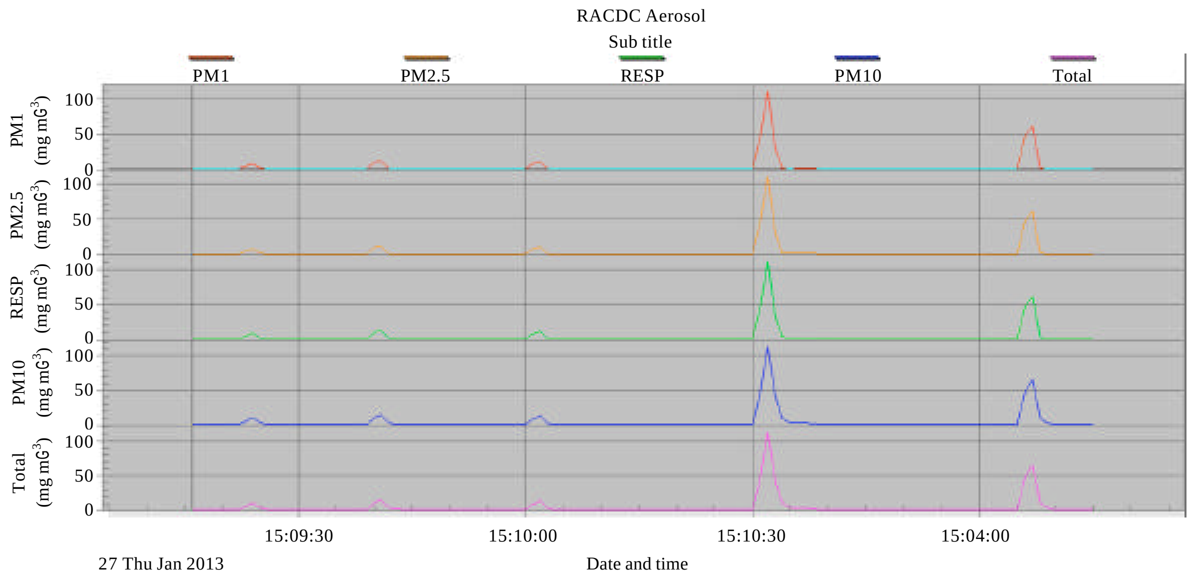

Fig. 3: Indoor condition with aerosol stimulus

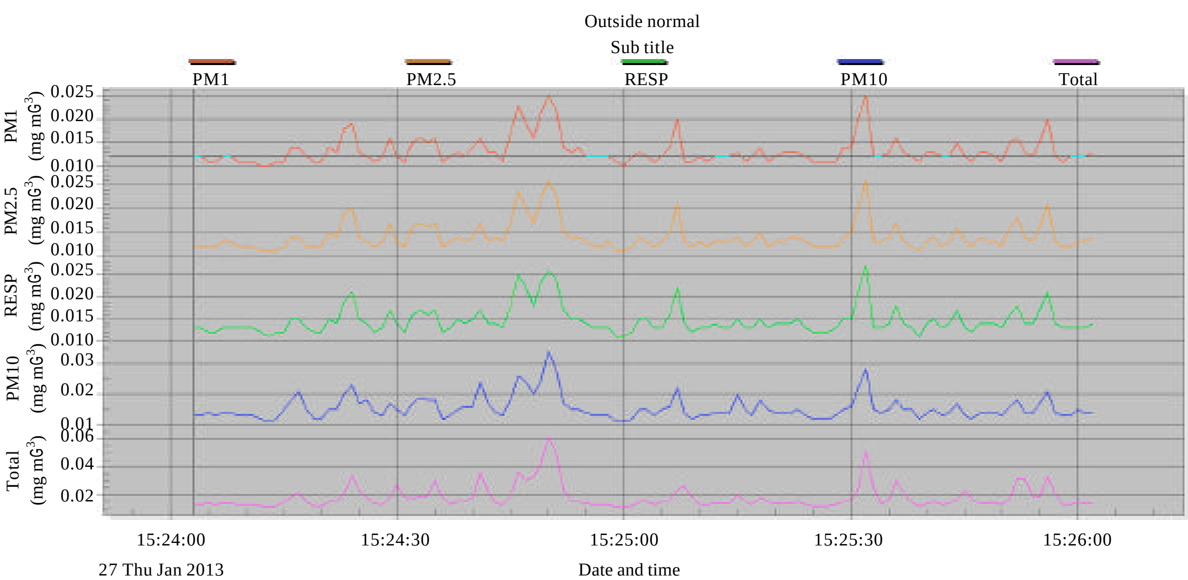

Fig. 4: Outdoor condition without aerosol stimulus

The following Fig. 3 shows the concentration level of particles indoor with stimulus. For the indoor particles under aerosol stimulus conditions, we can see that there are 2 major spikes on the graph which are nearly at the end stage of the experiment. The level of mass/size fraction of spike at 15:10:30 (which is at period of 90 sec) is over than 109 mg m^{-3} and another spike at 15:11:07 which is at period of 120 sec is 61 mg m^{-3}. There are also 3 small bumps before the 1st spike. On the average, the level of the airborne concentrations is below 1 mg m^{-3}.

The following Fig. 4 shows the concentration level of outdoor particles without aerosol stumulus. It can be seen that there are many major spikes on the graph throughout the

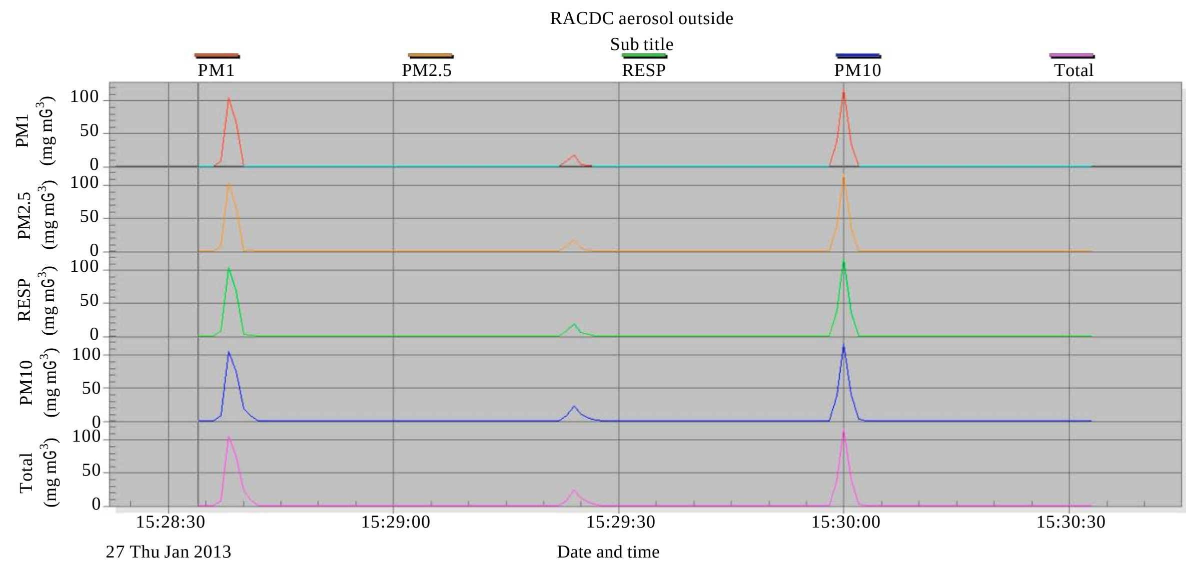

Fig. 5: Outdoor conditions with aerosol stimulus

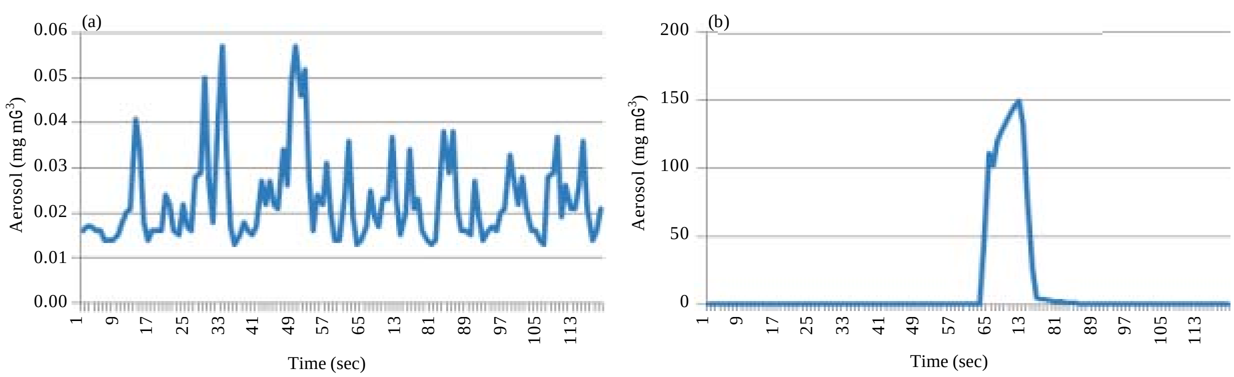

Fig. 6(a-b): Aerosol level indoor, (a) Without and (b) With aerosol stimulus

experiment. The mass/size fractions (mg m^{-3}) of these spikes are mostly below 0.025 mg m^{-3}. On the averages, the level of the airborne concentrations is below 0.01 mg m^{-3}.

The following Fig. 5 shows the concentration level of particles outdoor with aerosol stimulus. It can be seen that there are 2 major spikes on the graph and 1 small bump. The higher level of spike is at 117 mg m^{-3} which is at 15:30:00 and it is consistent for all Particle Matters (PM). Other than that, 2nd highest spike is at 15:28:38 with the level of concentration 105 mg m^{-3}. On the average, the level of the airborne concentrations is below 0.1 mg m^{-3}.

The Fig. 6 shows the concentration of aerosol particles indoor with and without aerosol stimulus. The Fig. 7 shows the concentration of aerosol particles outdoor.

The Fig. 8a and b shows the Relative Humidity (RH) and temperature indoor and outdoor. The Fig. 9a and b gives the CO_2 and light intensity level indoor and outdoor.

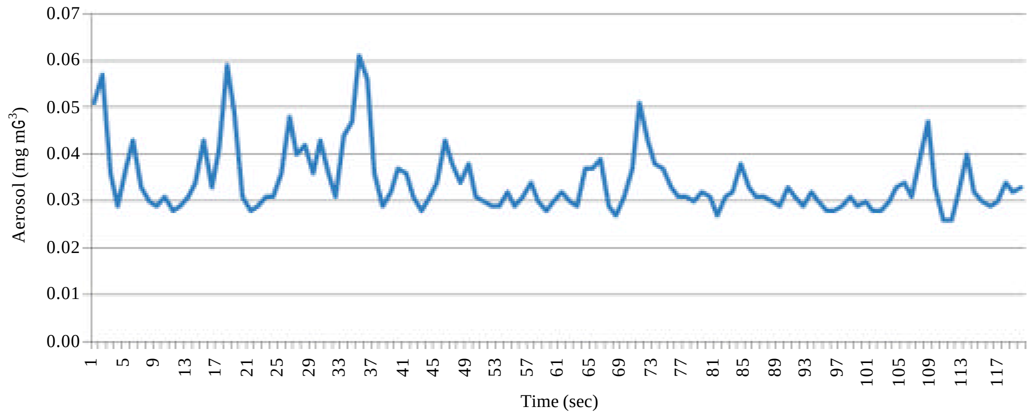

Fig. 7: Aerosol level outdoor

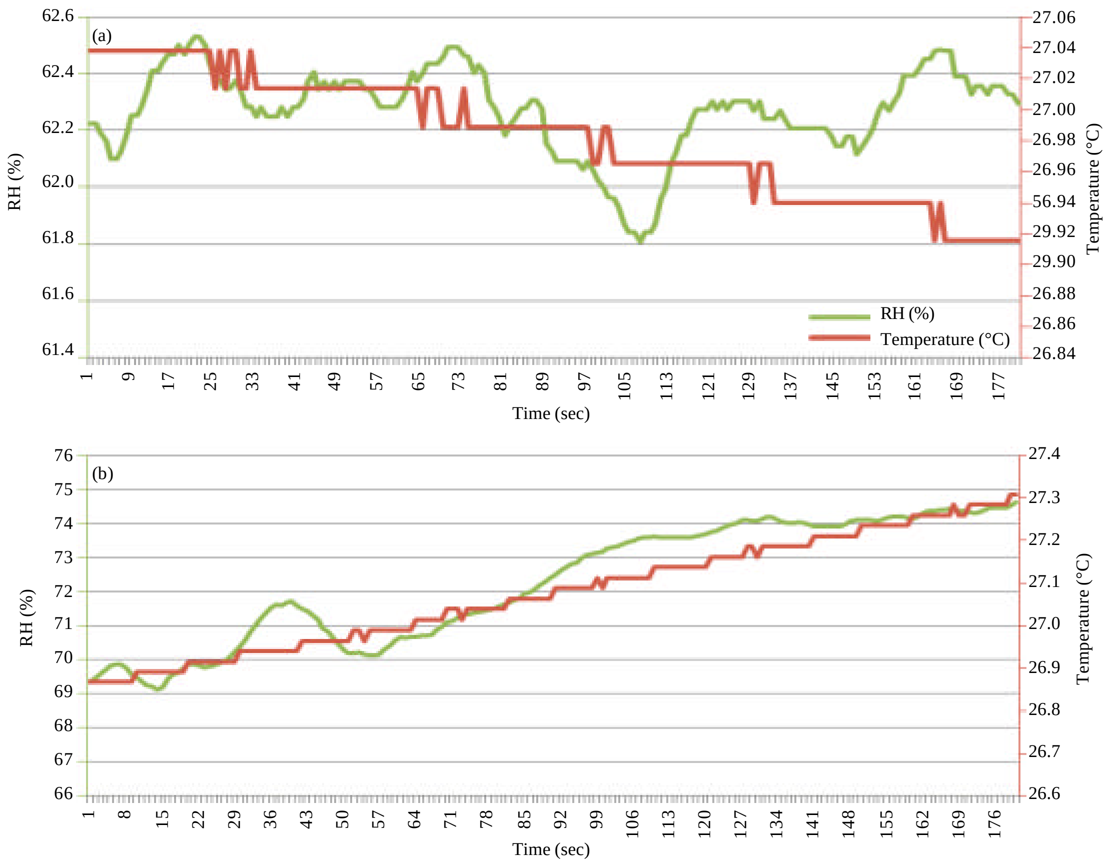

Fig. 8(a-b): (a) RH and temperature indoor and (b) RH and temperature outdoor

DISCUSSION AND CONCLUSION

Aerosol measurement: In our experiment, we have done three trials. The first trial measures the aerosol, without a stimulus, in a closed well air-conditioned ventilated room. The second trial we used stimuli, air freshener in the same room. Three channels with variable photometric sizes were

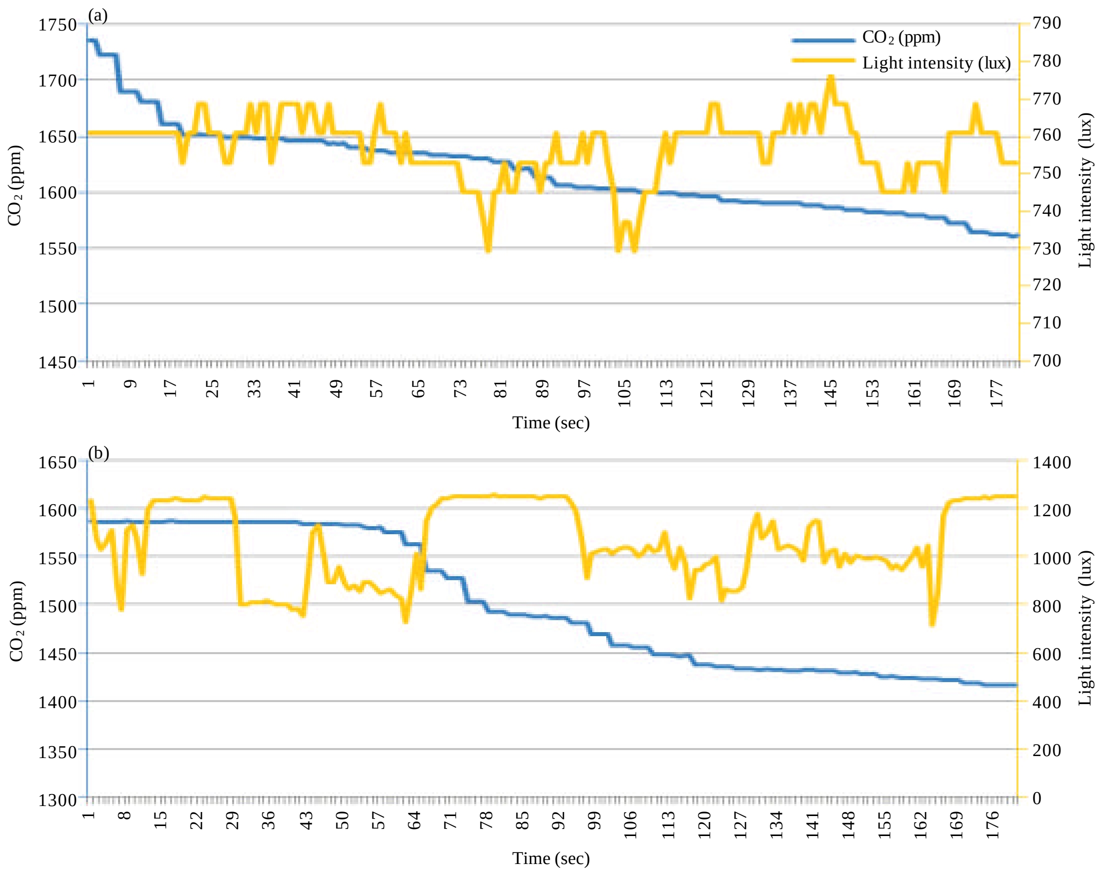

Fig. 9(a-b): (a) CO_2 and light intensity level indoor and (b) CO_2 and light intensity level outdoor

used; nevertheless, our analysis shall be basing on the total of the three sizes (PM_1, $PM_{2.5}$ and PM_{10}) (Bind *et al.*, 2012). Our concern was to count the aerosol particles regardless of their size. The last trial was in an outdoor area. From the result obtained, it was noticed that the outdoor dust level was generally higher than indoor dust level in terms of average, maximum or minimum. This shows that the indoor air was generally cleaner than the outdoor air. This may be due to several reasons. Firstly, the air which enters the room may have been properly filtered when it passes through the Air Handling Unit (AHU), thus the dust particles are filtered before entering the room. On the other hand, as there was no boundary for the outdoor air, the air was exposed to different types of pollutants like emissions from various sources, dust, dirt etc. which cause the aerosol content to be higher (Jerrett *et al.*, 2005). For the case where the aerosol was sprayed to the device for 60 sec, it was found that the aerosol content had drastically increased to its maximum level which is 150 mg m^{-3} and it was decreased again when the spraying was stopped. It can be concluded that the spraying of aerosol can greatly affect the reading during the measurement and thus it should be avoided during any measurement process.

I was concluded that for the first trial; number of aerosol suspended in the air was the lowest compared to the other three trials. The room was well ventilated hereby; the number of aerosol particles suspended in the air should be much less compared to the other two trials. Graph in Fig. 2 shows a total maximum of 0.057 mg m^{-3}. In Fig. 3, after the 1st minute, air freshener was used. The air freshener acted as a stimuli input, increasing tremendously the number of aerosol particles suspended in the air (around 2631 times from the 1st trial). Thus, as we can see from the graph, that the size and the number of aerosol particles recorded at 150 mg m^{-3} clustering around 60 to 70 sec. We can observe that the size of the particles before the 1st min, was very small to the extent that the graph was a straight line passing through the zero coordinate, the aerosol count rate was almost negligible when compared during the period of 60 to 70 sec (Chay and Greenstone, 2005).

The relative ratio between the 1st and the 2nd trial was governed by the equation as:

$$\frac{150}{0.057} \approx 2631$$

The Fig. 4 reflects the outdoor environment. The reason behind it is the number of peaks and valleys per second is much higher compared to the graphs' of the 1st and 2nd trial. This is because that the flow rate of the air in the outdoor environment is inconsistent with respect to time. Moreover, the outdoor environment is considered to behave infinite boundaries compared to the finite boundary of the room. More over the number of aerosol particles outdoor was also higher than the 1st trial, a maximum of 0.061 mg m^{-3} (Thevamanoharan *et al*., 2001; Hussain *et al*., 2008b).

CO_2 and temperature monitor: In this part of the experiment, we have done two trials. The first trial was to measure air quality in an indoor air-conditioned room and the other in an outdoor environment. Values of temperature, relative humidity, Ventilation rate, CO_2 concentration and Light intensity measurement were considered. Based on the obtained graphs, it was found that the carbon dioxide concentration in a building was higher than the carbon dioxide concentration outside the building. This should always be true because the air within a building always come from the outside (Thevamanoharan *et al*., 2001; Hussain *et al*., 2008a). Due to the limited ventilation and the occupants in the building exhale carbon dioxide, the carbon dioxide concentration within the building can only be less than or at best equal to the carbon dioxide concentration outside the building. The rate of ventilation measured from the device was inconsistent and it was kept on increasing from 48.4 to 70.7 cfm person^{-1} when the measurements were carried out at the indoor. This was far greater than the value recommended by ASHRAE standard which is typically range from 15 to 25 cfm person^{-1}. This implies that the measuring device is either faulty or there are plenty of room for energy saving by reducing the ventilation rate.

The indoor temperature was decreased gradually while the outdoor temperature was increased gradually. This can be interpreted as the temperature of the device and the surrounding temperature was not at equilibrium when the reading was taken. Thus, this reading might not be reliable. Meanwhile, the outdoor relative humidity was higher than the indoor relative humidity. This may due to the dehumidification process which is carried out at the AHU. Besides, the outdoor light intensity was higher than the indoor light intensity. This was because the experiments were carried out in day light, where there plenty of sunlight was available at the outdoor. The results showed that the light intensity due to the lighting inside the building was less than the light intensity from the natural sunlight at that time (Langdon and Atkinson, 2005; Sial *et al*., 1991; Prill, 2000).

By comparing the Fig. 9a and b, it was noticed that the carbon dioxide concentration in the indoor environment was at higher level than the outdoor environment. A recorded concentration of 1735.5 ppm in the indoor room compared to a concentration of 1587.2 ppm in the outdoor environment. Human beings exhale carbon dioxide during the respiration process. The average adult's breath contains about 35,000 to 50,000 ppm of CO_2 (100 times higher than outdoor air) (Prill, 2000; Luyssaert *et al*., 2008). Without adequate ventilation (fresh air) to dilute and remove CO_2, it will accumulate in the room and can cause health issues. As cited by Prill (2000), the concentrations of CO_2 found in most of the domestic building such as homes, universities buildings and offices are well below the 5,000 ppm occupational safety standard (time weighted average for an 8 h workday within a 40 h work week) for an industrial workplace. One of the examples illustrated above was the workplace at Universiti Teknologi PETRONAS. The concentration was below the 5,000 ppm thus the level was very adequate not to pose any serious health threat. But in regions such as congestion of traffic or industries that produce CO_2 as a waste product, the concentration count might be higher than the 5000 ppm and individuals exposed to such cases tend to be diagnosed with drowsiness, lethargy and a general sense that the air is stale. Moreover, the outside carbon dioxide concentration was lower as expected; as Universiti Teknologi PETRONAS is surrounded by forests and since trees use carbon dioxide gas as part of their photosynthesis chemical reaction during daylight, thus the concentration should be lower.

Ventilation rates for schools/universities buildings and office spaces are defined by certain codes and standards. The most widely accepted standard is the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 62. According to ASHRAE Standard 62, lecture halls should be provided with 15 cubic feet per minute (cfm) outside air per person and offices with 20 cfm outside air per person. Ventilation rates for other indoor spaces are also specified. Using CO_2 as an indicator of ventilation, ASHRAE has recommended indoor CO_2 concentrations be maintained at or below 1,000 ppm in schools and 800 ppm in offices (Luyssaert *et al*., 2008). Clearly the outdoor CO_2 concentration directly impacts the indoor concentration. Therefore, it is critical to measure outdoor CO_2 levels when assessing indoor concentrations. As cited Prill, ASHRAE recommends indoor CO_2 levels not exceed the outdoor concentration by more than about 600 ppm (ASHRAE, 1992; Luyssaert *et al*., 2008).

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