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INDOOR PARTICLE SIZE DISTRIBUTION IN OFFICE

A. Norhidayah, S. H. Aui, N. Ismail, E. H. Sukadarin and M. E. A. Jalil
Faculty of Engineering Technology, University Malaysia Pahang, Gambang, Pahang, Malaysia
E-Mail: hidayahabdull@ump.edu.my

ABSTRACT

In this research, the particle size distribution (0.3µm-0.5µm, 0.5µm-0.7µm, 0.7µm-1.0µm, 1.0-2.5µm, 2.5µm-5.0µm, >5.0µm) with the variety of activities (printing, photocopying and use of air freshener spray) in administrative office were measured. The direct reading instruments were used to measure number particulate matter and environmental parameters (temperature, relative humidity and air velocity). Air Exchange Rate (AER) was determined by using a tracer gas technique. The predominance size of particulate is 0.3µm to 0.5µm with 8901 number/cm^3 and 4699 number/cm^3. The use of air freshener illustrates the highest emission rate, which is 3.73x1010s-1. Significant elevation of indoor particle concentration was noted during these three activities. The photocopy activity can be a major source of indoor particle concentration due to high number of particles emitted within short periods and the particles remain fluctuated in the indoor air with slow decay rate.

Keywords: particle size distribution, mass concentration, emission rate, air exchange rate, number of particle, indoor air quality.

1. INTRODUCTION

Nowadays, a modern society spends the vast of their time in variety types of indoor infrastructure such as residences, offices and schools. There is a broad class of sources of pollutant in indoor air such as hardware devices, widespread utilization of cleaning products, biocides, and degradation of building materials [1]. In office setting, the computers, printers, copiers and other electronic equipment are general amenities, which emit the volatile organic compounds (VOCs), ozone and particulate matter (PM). Additionally, office occupants also expose to the cleaning products such as air fresheners and cleaning agents. Thus, exposures of building occupants to these kinds of pollutants are likely to occur due to tight structure of building, poor ventilation and very close proximity to people who operate the devices. The failure to take action immediately and efficiently on the problem of poor IAQ could be have the disastrous consequences on human health [2]. In 2009, the World Organization Health (WHO) prepared a report on Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. This report proposed that indoor air pollution is responsible for 2.7% of the global burden of disease [3]. Epidemiological studies reported that the siderosilicosis and sarcoidosis-like pulmonary diseases are associated with human exposure to photocopier toner dust [4].

Printer and photocopier machines apply the concept of electrophotography technique. The final step in printing and photocopying processes that apply the electrophotography technique is the permanent fixation of the applied toner image on the paper by the fuser. In general, a fuser operation may introduce a variety of size distribution of emission particles [5]. The formation of ultrafine particles becomes predominated in every operation of printing [6] and photocopying [4]. These particles generate from the toner and paper dust. Morawksa et al., 2011 analyzed the laser printers within office workplaces. There were 25 printers, which subjected to continuous particle measurement at one metre from the printer, 18 of them recorded a significant increase in particle number concentration during printing events. In addition, four of five printers that subjected to continuous particle measurement at two metres from the printer also showed a statistically significant increase in particle number concentration during printing events. The peak particle exposure measurements ranged from 3.3 x 10^3 particles cm^{-3} to 9.9 x 10^4 particles cm^{-3} which was greater than the eight-hour time weighted average (TWA) local office background particle exposure limit. Hence, these printers could increase the exposure of office workers to particles generated by printing activity at both one and two metres, respectively. The particle size distribution monitored during photocopying indicates that the emitted particles were much smaller than the original toner powders. Additionally, the number concentration of particles that were smaller than 0.5 µm was found to increase during the first hour of photocopying and it increased as the particle size decreased [7]. The ultrafine particle (UFP, < 100 nm) dominated the number concentration and the peak concentration appeared at sizes of under 50 nm. A high number concentration of UFP was found with a peak value of 1x10^8 particles cm^{-3} during photocopying [4]. For air freshener, Afshari and co - workers (2005) measured the concentration of fine particles during the use of air-freshener sprays, fine particles were detected (< 1 µm). Emission of aerosols from sprays depends on the product usage pattern, including the quantity of product used and the frequency of application [8].

Many researches were conducted on the emission of photocopiers, printers and air fresheners in test chambers and indoor buildings [9, 10]. However, there is to date almost no quantitative information available for size resolved characterization of PM emitted by office equipment and cleaning agents. The motivation of this study is due to the association of size of individual particles influences the degree to which they can be inhaled and the health impacts that they can cause.

Therefore, this research was carried out in an administrative office by concerning the printing, photocopying and air freshener activities. The goals of this research are to 1) determine the air change per hour of an administrative office, 2) measure the mass concentration and number of particles in indoor air 3) estimate the particles size distribution in indoor air, and 4) assess the emission rate of particles from indoor activities.

2. METHODOLOGY

2.1. Study area

This study was conducted in the building of Public University of East Coast of Malaysia. This building consists of lecturer rooms, administrative offices and opens area. However, this study only carried out in the administrative offices since they have higher number of occupants spend in the office more than 8 hours. The layout design of administrative office is illustrated in Figure-1. A preliminary walkthrough observation was carried out to observe the indoor environment of offices to identify the sources, activities, ventilation systems and number of occupants as tabulated in Table-1.

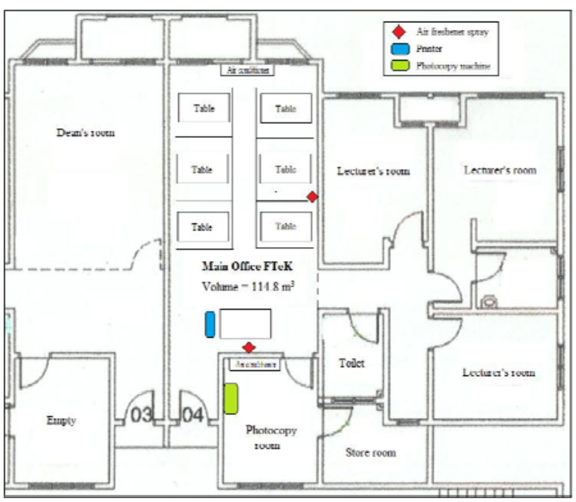

Figure-1. Layout design of administrative office

Table-1. Indoor activities and its` description.

Information	Description
Printing	Printing of 10 pages was performed using laser printer. All the printers used were LaserJet series. Measurements were taken when the printer was on and immediately after the printer started printing. Frequency of printing is every 30 minutes. Printing speed is 14 papers per minute.
Photocopying	Photocopying of 10 sheets of documents using photocopy machine.
Use of air freshener sprays	One short shot was sprayed in the middle of office room every 15 min. The maximal rate of each shot is 3s
Number of occupants	7 workers
Number of air conditioning system	1 split unit

3. INSTRUMENTATIONS AND CHEMICAL USE

The handheld calibrated fast response of instrumentations and chemical use were used as tabulated in Table-2.

Table-2. Instruments and chemical use for measuring the parameters.

Instruments and Chemical Use	Parameters
Particle Counters with Laser Detector (Model HPC600, HalTech Inc, USA)	Particle number concentration.
Dust Analyzer (DustMate Turnkey Instruments Ltd.)	Mass concentration of particles
Indoor Air Quality meter with hot wire and vane anemometer (TSI VelociCalc, Model 7565)	Environmental parameters (Temperature, air velocity and relative humidity)
Carbon Dioxide	Air Change per Hour

3.1. Determination of air change per hour (ACH)

Air change per hour was directly determined by applying a gas tracer method of carbon dioxide (CO_2). The Concentration Decay Test Method (ISO 2000, ASTM E741-00) was adopted to measure the air change rate in both office rooms [11]. Both of the main offices' windows and doors are closed during the measurement to ensure minimum infiltration of outdoor air. There was no occupant in the office during CO_2 measurements in order to reduce indoor sources of CO_2. A small volume of CO_2 gas was purged into the enclosed office rooms, with uniform concentration, until the indoor CO_2 level was more than 50% higher than background level. Then, the CO_2 was decay to the background level of CO_2 with recorded a specific period of time. The ACH α, was calculated using the Equation 1.

$$\alpha = \frac{\ln C(t_2) - \ln C(t_1)}{t_2 - t_1} \quad (1)$$

Where, t is time, $C(t_2)$ and $C(t_1)$ are the concentration of the tracer gas at times (t_2) and (t_1) .

3.2. Measurement of number and mass concentration of particle and environmental parameters

Real-time measurement number and mass concentration of particle and environmental parameters of were carried out during office hours with respect to three main indoor activities (printing, photocopying and use of air freshener sprays) were conducted. Instruments were placed near to the sources of these activities to take readings. Duration of monitoring was last around four hours per day, which started from 10:00 to 14:00. Each measurement for each activity was repeated for 3 times to obtain average value and accuracy of data.

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3.3. Particle emission rate

The emission rate of particles for each activity was estimated by using the method used by Wallace and Ott (2011) [12]:

$$S = \frac{C_{max} V}{t} \qquad (2)$$

Where S is emission rate or source strength (particles s^{-1}), C_{max} is the maximum concentration (cm^{-3}), V is the mixing volume (cm^3) and t is the time (s) during a source is operated. For all the activities, the mixing volume of administrative office is 114.8 m^3. The air conditioning system was on at all times during measurement to promote mixing condition of indoor air.

4. RESULT AND DISCUSSION

4.1. Air change per hour (ACH)

Figure-2 plots the decay of CO_2 at specific period of time. The ACH (a) of administrative office was determined based on the slope of the best-fitted line of graph line which approximately $0.01h^{-1}$. The ACH is considerably low since it is not complied the recommended ACH of ASHRAE for office (4 – 10 hr^{-1}) [13]. It indicates that the exchange of air to the outside as well as circulation of air within the building in office is insufficient which increased indoor particle concentration due to longer deposition rate of particles.

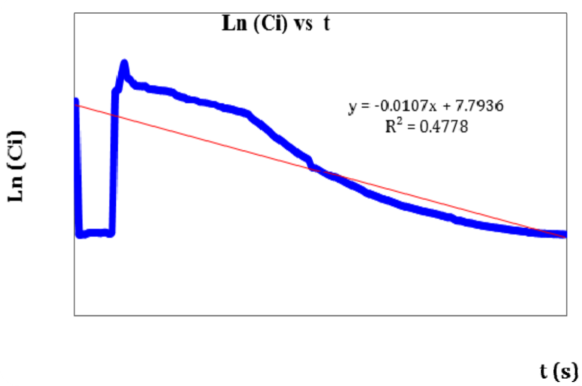


Figure-2. The graph of Ln *(Ci)* vs. time.

4.2. Environmental parameters

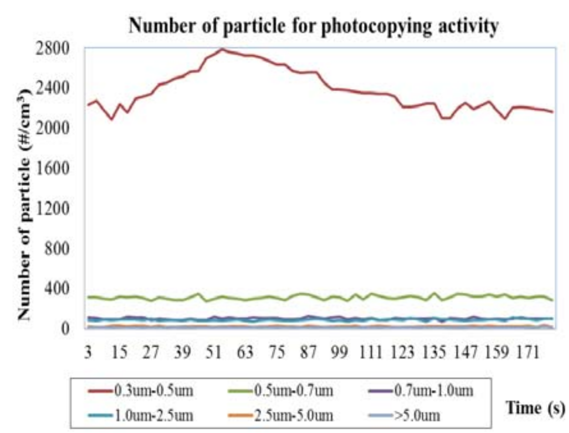
The mean environmental parameters (temperature, relative humidity and air velocity) of indoor activities were tabulated in Table 3. This finding was compared with the Industry Code of Practise on Indoor Air Quality (ICOP on IAQ) (2010), which published by DOSH Malaysia [14]. All the environmental parameters were permitted the acceptable limit value of IAQ, excluding the relative humidity of photocopy activity. It deduces that the photocopy activity generated the thermal from photocopier machines, which resulted to the increment of relative humidity.

Table-3. Mean environmental parameters with different indoor activities in administrative room.

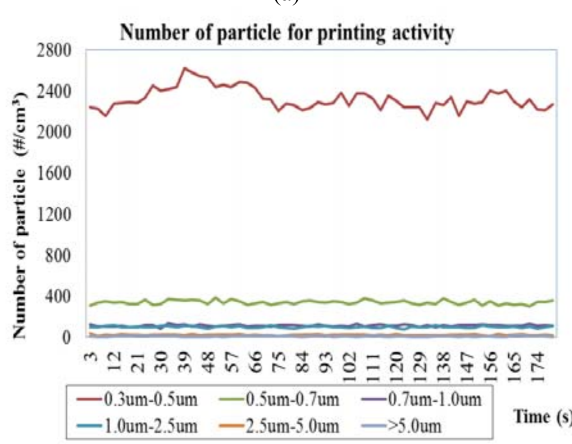
Indoor Activity	Temperature (°C)	Relative humidity (%)	Air Velocity (m s^{-1})
Printing	24.3	68.5	0.39
Photocopying	24.5	76.4	0.15
Use of air freshener spray	23.1	61.7	0.40
ICOP on IAQ (DOSH Malaysia, 2010)	23 - 26	40 - 70	00.15 – 0.50

4.3. Measurement of number and mass concentration of particles

The time dependent of particle numbers generated with different indoor activities were plotted in Figure 3. The results clearly show that the particle number concentrations generated during indoor activities are inversely proportional to the particle size. Particles with the range of 0.3–0.5µm show five and three folds higher than the other particles size of ranges for printing and photocopying, and use of air freshener, respectively. There was an observable increase in the particle number of 0.3-0.5µm diameter when activity began.



(a)



(b)

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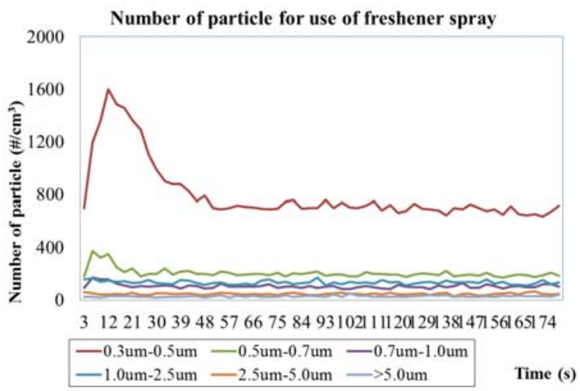

(c)

Figure-3. Time dependent results of particle numbers with different indoor activities. (a) Printing, (b) Photocopying and (c) Use of air freshener spray.

The increases in the particle concentrations during the activities were due to the time required to fill the room with a sufficiently high particle concentration. The particles with smaller size remain in high amount after the activity was end. Alterations in the distribution of particles may due to collisional growth, which is a function of the particle number, could be able to generate an imperative shift in size distribution within minutes or seconds in indoor environment.

As can be seen in Figure-4, it assumes that the estimated particle sizes for three indoor activities are smaller than 0.3-0.5μm since the actual distribution of particles are consistently dominant closed to the particles smaller than 0.3-0.5μm. This finding is in a good agreement with Massey and Taneja (2011) [15] and Afshari et al. (2005) [8]. They observed that the particle size distribution emitted from photocopying was measured from 250-1000nm, and air freshener spray was detected lower than 1μm. However, the size range of particle generated from printing activity is not included in the range of 40 to 70 nm [6].

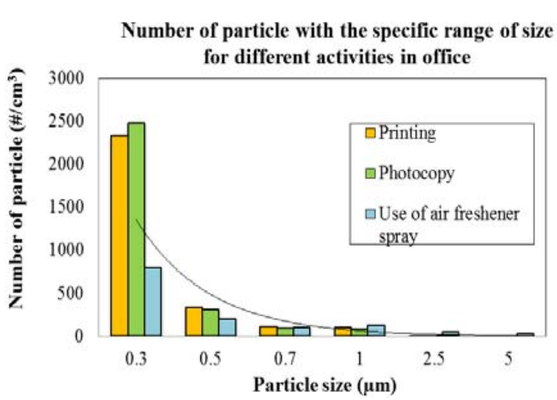

Figure-4. Particle size distribution of printing, photocopying and use of air freshener in administrative office.

Table-4 tabulates the peak mass concentration, ratio (ratio of peak mass concentration to the background mass concentration) and emission rate of particles. Photocopying is obviously showed the peak mass concentration and emission rate of particles. This condition is due to the evaporation of toner and/or fuse materials, which resulted to the nucleation and condensation to form primary particles, and these particles then coagulated to form agglomerates. Besides, the silica on the toner surface commonly detached during the two component printing processes, which induced by the mechanical stresses. The presence of detached particles obviously enhances the particle size of diameter and mass emission [16].

Table-4. Peak mass concentration, ratio and emission rate of particles for indoor activities.

Activity	Peak concentration (particles cm^{-3} x 10^3)	Ratio (number)	S (particles s^{-1} x 10^{10})
Printing	3.33	1.28	1.27
Photocopying	3.42	1.36	3.92
Use of Spray	2.60	2.49	3.73

5. CONCLUSIONS

Three customary office activities (printing, photocopying and use of air freshener) were analyzed in terms of generation of particles with the variety of size distribution. During the photocopying activities; the relative humidity was not permitted to the standard limit value, which recommended by DOSH Malaysia, the highest number of particles and emission rate were generated, respectively. Besides, the distribution of particles was dominated with the size from 0.3m to 0.5m. The recommendation for future research with concerning to indoor office activities is more focusing to the ultrafine and nanoparticles.

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