PARTICLE SIZE DISTRIBUTION MEASUREMENT FROM DIFFERENT INDOOR ACTIVITIES

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ABSTRACT

Human exposure to particulate matter can have significant harmful effects on the respiratory and cardiovascular system. These effects vary with number, size, and chemical composition of particulate matter. Studying the particle size distribution under different indoor activities can help to predict the emission and settlement of particles with different sizes. In this research, an experimental study was carried out to investigate the particle size distribution under different indoor activities in main office FTeK and OSHMO. The indoor activities of office being studied were printing, photocopying and use of air freshener sprays. Data collection was done by using laser light scattering instrument to measure the number concentration of particles ranging from 0.3 μm to 10 μm. Then, the particle size distribution graph for each activity was generated using the particle number concentration measured and particle size range. Environmental parameters such as temperature, relative humidity, air velocity were measured using IAQ meter. Air change rate was measured using Concentration Decay Test Method (ASTM Standards E741-00). From the result obtained, the particle size distribution of printing, photocopy and use of freshener spray was ranged from 0.3 μm to 10 μm, with the predominant size range of 0.3 μm - 0.5 μm. The use of air freshener has the highest emission rates which are 3.73 x 10^{10} s^{-1} at FTeK and 2.97 x 10^{10} s^{-1} at OSHMO. Whereas printing has the lowest emission rates, which are 3.92 x 10^{10} s^{-1} at FTeK and 2.63 x 10^{10} s^{-1} at OSHMO. Significant elevation of indoor particle concentration was noted during the three activities. The photocopy activity can be the major source of indoor particle concentration because it emitted high number concentration of particles within a short period and the particles remain fluctuated in the indoor air with slow decay rate. In conclusion, the three activities selected produced high level of submicrometer particles (< 1 μm) and indoor particle concentration is mainly associated with the indoor activities.

ABSTRAK

Pendedahan manusia kepada zarahan boleh memberi kesan buruk yang ketara pada sistem pernafasan dan kardiovaskular. Kesan-kesan tersebut berbeza daripada segi nombor, saiz, dan komposisi kimia bahan zarahan. Pemahaman tentang taburan saiz zarah bawah aktiviti-aktiviti yang berbeza dapat membantu untuk meramalkan pelepasan zarahan dengan saiz yang berbeza. Dalam projek ini, kaijian tentang taburan saiz zarah di bawah tiga jenis aktiviti yang dijalankan di pejabat utama FTeK dan OSHMO telah dilakukan. Tiga jenis aktiviti tersebut termasuklah mencetak, fotokopi dan penggunaan semburan penyegar udara. Pengumpulan data dilakukan dengan menggunakan instrumen penyerakan cahaya laser untuk mengukur kepekatan jumlah zarah yang terdiri daripada 0.3 μm hingga 10 μm. Kemudian, pengedaran graf saiz zarah bagi setiap aktiviti telah dijana dengan menggunakan kepekatan jumlah zarah diukur dan julat saiz zarah. Parameter persekitaran seperti suhu, kelembapan relative dan halaju udara adalah diukur menggunakan IAQ meter. Kadar perubahan udara pula diukur menggunakan kaedah ujian dalam Standard ASTM E741-00. Daripada keputusan yang diperolehi, taburan saiz zarah mencetak, fotokopi dan penggunaan penyegar semburan adalah dalam lingkungan antara 0.3 μm hingga 10 μm. 0.3 μm - 0.5 μm ialah size yang dominan dalam tiga jenis aktiviti tersebut. Penggunaan penyegar udara mempunyai kadar pelepasan zarah tertinggi iaitu 3.73×10^{10} s^{-1} di FTeK dan 2.97×10^{10} s^{-1} di OSHMO. Manakala mencetak mempunyai kadar pelepasan yang paling rendah, iaitu 3.92×10^{10} s^{-1} di FTeK dan 2.63×10^{10} s^{-1} di OSHMO. Perubahan yang ketara bagi tahap jumlah zarah di dalam pejabat telah diperhatikan semasa tiga aktiviti tersebut dijalankan. Aktiviti fotokopi boleh menjadi sumber zarahan utama dalam pejabat kerana ia melepaskan jumlah zarah yang tinggi dalam masa yang singkat dengan kadar pereputan zarah yang sangat rendah. Kesimpulannya, ketiga-tiga aktiviti yang dipilih telah menghasilkan jumlah zarah submicrometer (< 1 μm) yang tinggi dan tahap jumlah zarah dalam pejabat mempunyai hubungan positif dengan aktiviti-aktiviti tersebut.

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%	Percentage
>	Greater than
<	Less than
±	Standard deviation
α	Air change rate
$\Delta \boldsymbol{T}$	Time difference
$\mu g\ m^{-3}$	Microgram per cubic metre
μm	Micrometre
$\mu m\ cm^{-3}$	Micometre per cubic centimetre
^{o}C	Degree Celcius
cm^{-3}	per cubic centimetre
cm^{3}	Cubic centimetre
CO_2	Carbon Dioxide
hr^{-1}	per hour
L	Litre
L/min	Litre per minute
$m\ s^{-1}$	Meter per second
m^{3}	Cubic metre
nm	Nanometre
s	second
S	Source strength or emission rate
$\boldsymbol{t}$	Time
$\boldsymbol{V}$	Volume

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
CMD	Count Median Diameter
DOSH	Department of Occupational Safety and Health
FTeK	Faculty of Technology Engineering
HVAC	Heating, Ventilating and Air Conditioning
IAQ	Indoor Air Quality
MMD	Mass Median Diameter
NAAQS	National Ambient Air Quality Standard
NMD	Number Median Diameter
NO_x	Oxides of Nitrogen
O_3	Ozone
OH	Hydroxyl radical
OSHMO	Occupational Safety and Health Management Office
PSD	Particle size distribution
PM	Particulate matter
SOA	Secondary organic aerosol
SVOC	Semi-volatile organic compounds
TACs	Toxic air contaminants
TSP	Total suspended particle
TWA	Time Weighted Average
UFP	Ultrafine particle

USEPA	United States Environmental Protection Agency
VMD	Volume Median Diameter
VOC	Volatile organic compound

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Indoor air quality has a very strong influence on human well-being and productivity. A study by Jenkins et al. (1992) showed that people spend 87% of their time indoors, with only 6% outdoors, and 7% in transit. Hence, increase of indoor pollutants is believed to increase the risks for a wide array of diseases. There is mounting evidence that exposure to poor indoor air quality leads to excess morbidity and mortality (Sundell, J., 2004).

The indoor environment can be further divided into microenvironments, such as office, shopping mall, residential houses and school. The characteristics of indoor particles can be indoor microenvironment specific (He, 2004). Many studies have revealed the significance of indoor sources to the increase of particulate concentration. These sources include many everyday activities, such as cleaning, printing, cooking, smoking, burning of candles and incense sticks and even walking (Abt et al., 2000; He et al., 2004, 2007; Hussein et al., 2006; Géhin et al, 2008; Glytsos et al., 2010). Most of the previous researches were studying on the influence of cooking activities on the indoor concentration in residential houses. There is still very limited information available on the influence of office activities.

This research will focus mainly in office since office is one of the easiest places for particles to settle and accumulate. Various electronic equipments such as printers, photocopy machines, computers and typing machine are widely used in offices and they are a potential source of indoor pollutants, producing a variety of particle emissions

(Lee et al., 2001; Kaji et al., 2007). It is also important to note that the smaller and larger particles in the air behave differently (He, 2004). In addition to the penetration of pollutants from outdoor air, most indoor built environments contain air pollution sources that release fibers, particles, organic vapours, or inorganic gases (He et al., 2007).

From the previous studies, it showed that the major sources of indoor pollutants in office are generated from photocopier, printers and air freshener spray. According to He et al. (2007), the monitoring of particle characteristics in a large open-plan office showed that particles generated by printers can significantly affect the submicrometer particle (< 1 μm) number concentration levels in the office. Besides that, fine particles were detected (< 1 μm) in the study of Afshari et al. (2005) during the use of air freshener sprays. Though specific printer-emitted VOCs and PM has been studied (Kagi et al., 2007), no information on the size distribution of the photocopier-emitted particles has been reported. Field studies on the impact of photocopiers and printers on indoor air quality are still relatively limited.

Furthermore, this research focused more on the particle number concentration and distribution of different indoor activities. This is due to the existing database is very limited to particle mass concentration and emission rates with only a few studies reported on particle number concentration. However, since the smaller particles can be high in number but contribute very little to mass, and they have higher probability of penetration into deeper parts of human respiratory tract, they should be getting more attention from researchers. Recent studies have also suggested that the particle number concentration would be a more appropriate predictor of health impact than mass concentration.

1.2 PROBLEM STATEMENT

Human exposure to particulate matter can have significant harmful effects on the respiratory and cardiovascular system. These effects vary with number, size, and chemical composition of particulate matter, which vary significantly with space and time (Davidson et al., 2005). The PM concentration during indoor activities can reach elevated values (up to tenfold compared to the situation without the sources) for short or even for longer periods of time (Wallace, 2006). Since particle size determines the fate of particles on or in the human body which in turn affects a person's exposure risk, it is necessary to fully understand the size distribution of particles when determining secondary exposure.

Hence, in this research, several indoor activities in an office were studied in order to provide size-specific particle number distribution. This is important because particulate matter of different sizes is known to cause different levels of adverse health impacts to human. Finer particles penetrate into deeper parts of the human body and cause respiratory or cardiovascular disorders (Jimoda, 2012).

1.3 RESEARCH OBJECTIVES

The aim of the study intends to meet the objectives below:

i. To investigate the particle size distribution under different indoor activities;
ii. To evaluate the relationship between different indoor activities and indoor particle concentration level.

1.4 RESEARCH QUESTIONS

This research is further guided by the research questions below with the purpose to gain better understanding of the research based on the identified research objectives.

The two research questions are as follows:

i. How is the particle size distribution under different indoor activities?
ii. Is there any relationship between indoor activities and indoor particle concentration levels?

1.5 RESEARCH HYPOTHESIS

This study is guided by the following hypothesis:

H_{01}: There are no particles of different sizes emitted during different indoor activities in different proportion.

H_{11}: There are particles of different sizes emitted during different indoor activities in different proportion.

H_{02}: There is no relationship between indoor activities and indoor particle concentration level.

H_{12}: There is a relationship between indoor activities and indoor particle concentration level.

1.6 SCOPE OF STUDY

A continuous real time monitoring measurement was conducted in offices. Number of occupants, presence of HVAC system, models of printer, photocopier and air freshener sprays were recorded. Particle size distribution of particles ranging from 0.3μm to 10μm under different indoor activities in the office was investigated to identify number concentration of particles with different sizes. The indoor activities being studied were printing, photocopying and use of air freshener sprays. The particle size distribution of these activities will be compared to find out which activity produce the highest level of submicrometer particles (< 1 μm). Hence, we could predict the exposure risk of office workers during different indoor activities.

1.7 SIGNIFICANT OF STUDY

Indoor sources have been identified as a major contributor to the increase of particle concentration in indoor environment. Focusing on the particle size distribution of particle is very important for a number of reasons. Size has a major influence on the settling velocity of particles. Studying the particle size distribution under different indoor activities can help to predict the emission and settlement of particles with different sizes.

By understanding the particle size distribution of different indoor activities, we could compare which activities involved the submicrometer particles that have high impact on human health. This helps to identify the exposure risk so that preventive measures and action plan could be developed to reduce the risk. In addition, the information gained in this study can be used as a reference in the future studies which related to indoor air quality. This can help to further improve the safety and health system and parameters in the workplace.

1.8 OPERATIONAL DEFINITIONS

Table 1.1: Operational Definitions

Term used	Definition
Particle size distribution (PSD)	A list of values or a mathematical function that defines the relative amount, typically by number or mass, of particles present according to size (Jillavenkatesa et al., 2001). In this study, particle size range is expressed in terms of aerodynamic diameter, the diameter of a sphere of unit density (1 g cm^{-3}) having the same settling velocity. The particles measured were ranged from 0.3-10 µm.
Particulate matter	Also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets (U.S. EPA, 2013)
Coarse particles	Particles which are larger than 2.5 µm and smaller than 10 µm in diameter (U.S. EPA, 2013).
Fine particles	Particles which have an aerodynamic diameter of 2.5 µm or less. It is usually known as $PM_{2.5}$ (U.S. EPA, 2013).
Indoor activities	The indoor activities involved in this study are mainly based on the office activities conducted during office hour, which including printing, photocopy and use of air freshener spray.

1.9 CONCEPTUAL FRAMEWORK

Figure 1.1 illustrates the variables and parameters in this study. It describes that particle size distribution of different indoor activities are dependent on a few factors.

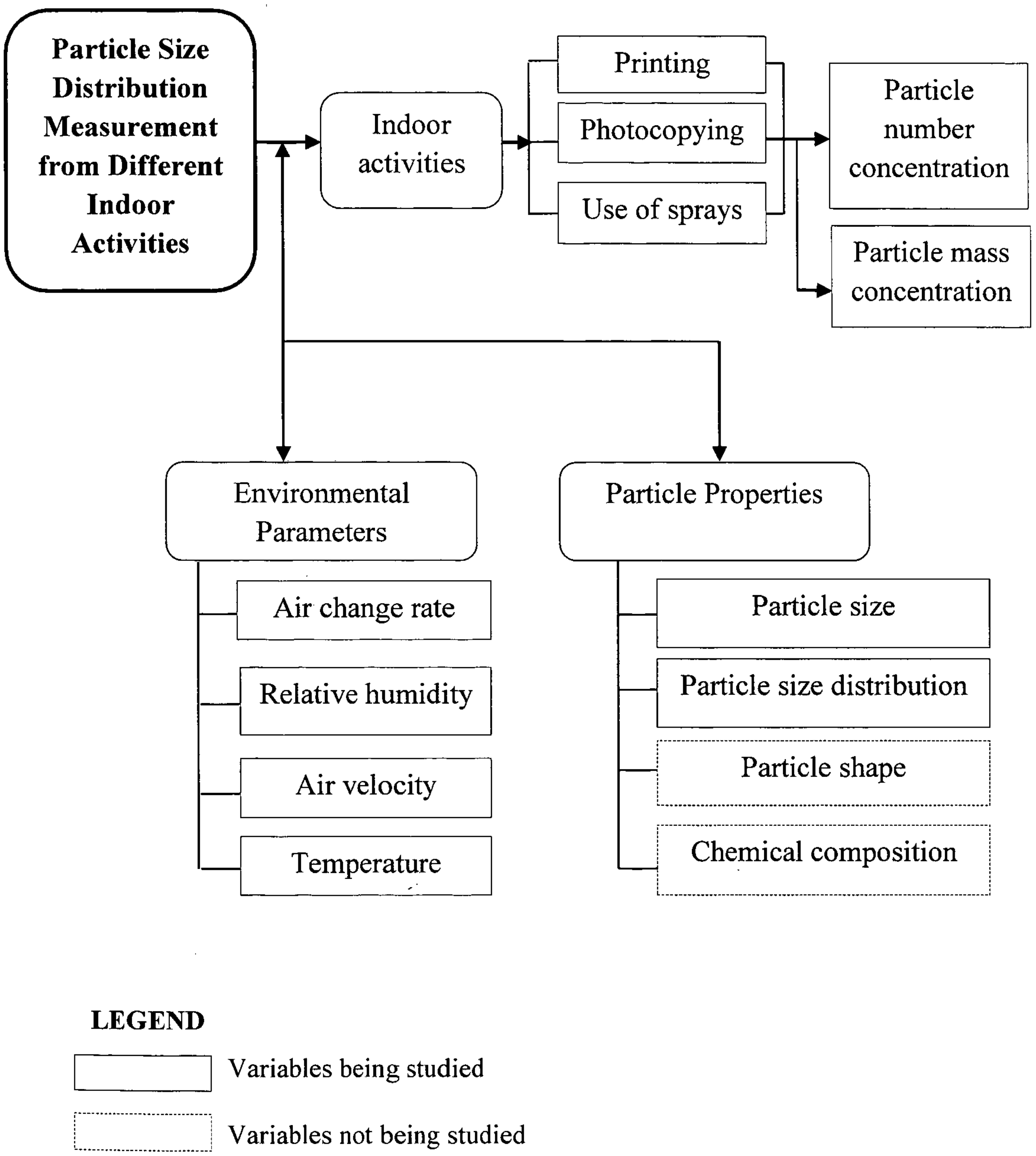

Figure 1.1: Conceptual framework of study

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the relevant literature that related to my study such as the definition of particle properties and the description of three main indoor activities in office which have been selected in this research. It also provides a solid historical background to support this study. The strengths and weakness from relevant studies will serve as a stepping stone to achieve the objectives of current research.

2.2 PHYSICAL PROPERTIES OF PARTICLE

The behaviour of particulate matter is often dominated by the physical properties of particles. There are a few important physical properties of particles to measure. These include particle size, particle shape, surface properties, charge properties and microstructure. For this research, particle size distribution is the main characteristic to be studied. Hence, the focus will be placed on the most significant and easy to measure property, which is particle size.

2.2.1 Particle Size

By far the most important physical property of particulate matter is particle size. Particles are 3-dimensional objects, and they cannot be fully described by a single dimension such as a radius or diameter unless they are perfect spheres (e.g. emulsions or bubbles). Hence, it is usually convenient to define the particle size in term of equivalent spheres concept in order to simplify the measurement process.

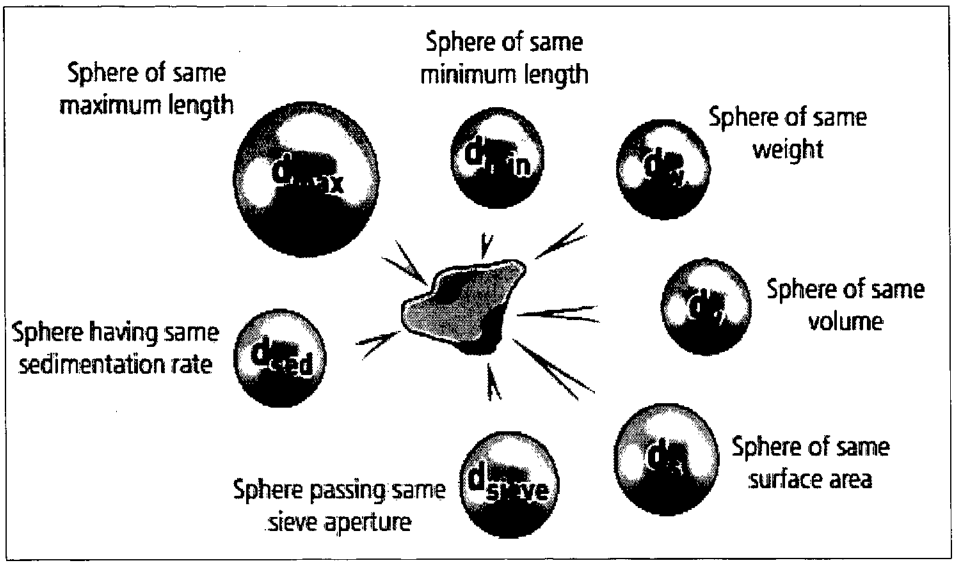

Figure 2.1: Illustration of the concept of equivalent spheres

Source: A Basic Guide to Particle Characterization (2012)

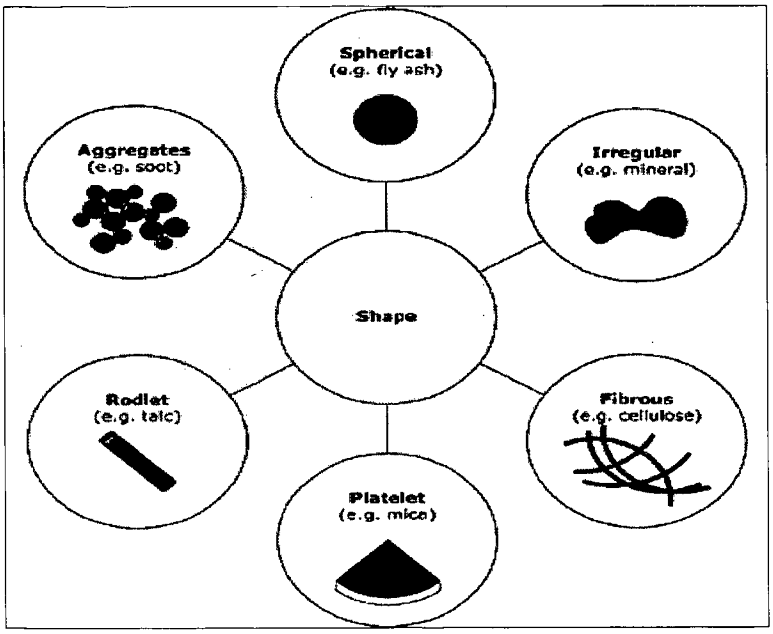

Figure 2.2: Examples of particle shapes

Souce: Valliappan (2010)

As shown in Figure 2.1, particle size is defined by the diameter of an equivalent sphere which has the same property as the actual particle such as mass or volume. The equivalent sphere concept works well for particles with regular shape. However, it may not always be appropriate to apply on particles with irregular shape due to significant difference in size dimension. In fact, the atmospheric particles could have different shapes and densities, as shown in Figure 2.2 (Valliappan, 2010).

Different terminologies have been used to define the particles in various size ranges. Total Suspended Particles (TSP) refers to all particles suspended in the air, while PM_{10} and $PM_{2.5}$ are airborne particulate matter equal to or smaller than 10 and 2.5 μm, respectively. At least one of these three type of particulates is included as part of indoor air quality guidelines in most countries around the world. These particle parameters are therefore important from a regulatory standpoint. For research purposes, airborne particles are also classified as super-coarse (> 10 μm), coarse (2.5- 10 μm), fine (< 2.5 μm), ultrafine (< 0.1 μm), and nanoparticles (< 0.05 μm). Identification of PM can also be based directly on their sizes, for example, supermicrometer and submicrometer particles denote those larger and smaller than 1 μm, respectively. Figure 2.3 summarizes the common terminologies used to describe particles of different aerodynamic diameters and their corresponding size ranges.

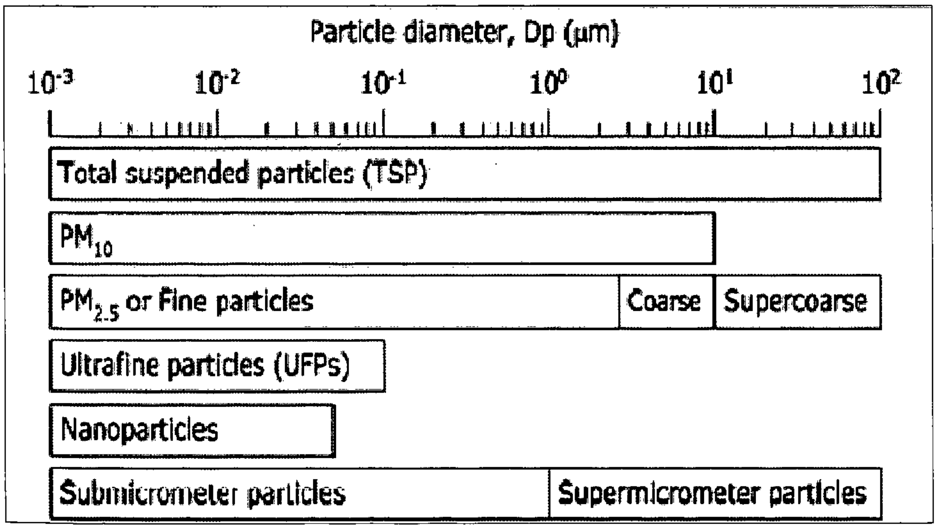

Figure 2.3: Classification of particles in different size ranges

2.2.2 Particle Size Distribution

Measurement of particle size distributions is routinely carried out across a wide range of industries and is often a critical parameter in the industrial and non-industrial buildings. Measuring particle size and understanding how it is distributed during different indoor activities is important to determine the potential health risk exposure to the occupants (Morawska and Salthammer, 2003).

Particles suspended in the air are ranged in size from about 1 nm to about 100 μm. The former is molecular size and the latter is the size above which particles sediment rapidly due to gravitational forces. Almost all sources generate particles with some distribution of the sizes (polydisperse aerosol) rather than particles of a single size (monodisperse aerosol). The spread of the particle size distribution is characterized by an arithmetic or geometric (logarithmic) standard deviation. The most common ways of characterizing a particle distribution are in terms of its mean size, which is the average of all sizes, its median size, which means that there are an equal number of particles above and below this size, or its mode size, which is the size with the maximum number of particles. The terms used include: count median diameter (CMD), number median diameter (NMD) or mass median diameter (MMD) respectively (Morawska and Salthammer, 2003).

The particle size distribution is always presented in either a frequency distribution curve, or a cumulative (undersize) distribution curve. Particles generated by most sources have a log-normal size distribution, which means that the particle concentration versus particle size curve is "normal" (bell-shaped) when the particles are plotted on a logarithmic scale. Geometric standard deviation characterizes the width of the peak in the distribution. When a single pollution source is investigated and when it operates under steady conditions (for example, steady parameters for a combustion process), the size distribution obtained is likely to have one distinctive peak and sometimes additional, usually much smaller peaks. These peaks are called modes of the distribution. Different emission sources are characterized by different size distributions and while these distributions are not unique to these particle sources alone, the information from the size distribution can help to identify their contribution to particle concentrations in ambient air, and also serve as a source signature (Morawska and Salthammer, 2003).

Particle distributions can be presented either in terms of number or mass distributions. In terms of number, the vast majority of airborne particles are in the ultra-fine range. Different sources contribute to the generation of particles in the submicrometer range, which is predominant in particle number, and different sources to larger particles, which predominate in mass. For example, measurements of particle concentrations as a function of time conducted in a large office building with mechanical ventilation, air-conditioning, and sealed windows, demonstrated that for the three smaller particle size bins of 0.3–0.5 μm, 0.5–0.7 μm, and 0.7–1.0 μm, the particle number concentrations decrease under most conditions by roughly an order of magnitude as the particle size bin increases one step (Fisk et al., 2000). Figure 2.4 presents an example of number distributions of particles generated during printing and idle mode.

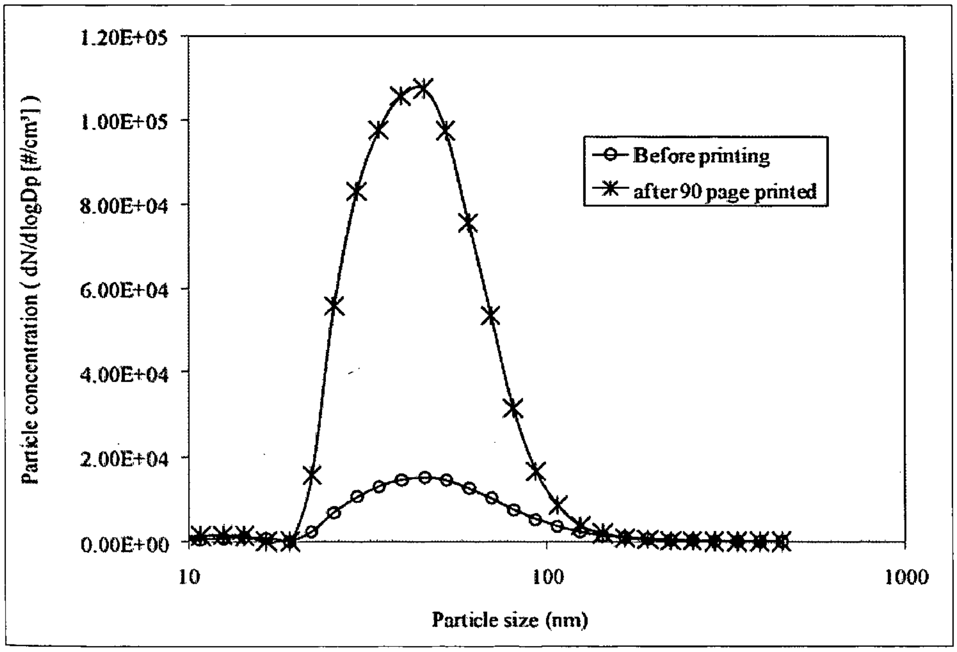

Figure 2.4: Particle number distributions of particles generated during printing and idle mode

Souce: Valliappan (2010)